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Agriculture and Future Climate Dynamics in Africa: Impacts and Adaptation Options

by

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Submitted in partial fulfilment of the requirements for the degree of

PhD Environmental Economics

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Dedication

To my wife Charity and son Blessings

Declaration

I declare that this thesis I hereby submit for the degree of PhD in Environmental Economics at the University of Pretoria is entirely my own work and has not been submitted anywhere else for the award of a degree or otherwise.

Parts of the thesis have been published and submitted for publication in journals.

Any errors in thinking and omissions are entirely my own responsibility.

Signed: ………………………

Name: Charles Nhemachena

January 2009

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Degree:	PhD Environmental Economics
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Abstract

This study had two main objectives. One objective was to measure the aggregate impact of climate change on income from all agricultural production systems (crop, livestock and mixed) in Africa and to predict future impacts under various climate scenarios. In addition to measuring economic impacts, the study analysed determinants of farmers' choices between alternative adaptation measures available to African farmers. The study is based on a cross-section survey of over 8000 farming households from 11 countries in east, west, north and southern Africa.

To achieve the first objective, the cross-section (Ricardian) approach was used to measure the impact of climate change attributes (rainfall and temperature levels) on income from all agricultural production systems (crop, livestock and mixed) in Africa, controlling for other production factors. Based on empirical estimates from the Ricardian model, the study predicts future impacts under various climate scenarios. In addition to estimating impacts on mixed crop–livestock farms, the study also measures and compares impacts on specialised crop and livestock farms. Responses of different production systems are analysed under irrigation and dryland conditions. The response of net revenue from crop and livestock agriculture across various farm types and systems in

Africa, to changes in climate variables (i.e. mean rainfall and temperature) is analysed. The analysis controlled for effects of key socio-economic, technology, soil and hydrological factors influencing agricultural production. In addition to measuring impacts on aggregate revenue, the study examined variations in the response of three distinct production systems characterising African agriculture: specialised crop; specialised livestock and mixed crop and livestock systems. Differential impacts of climate change on the studied systems were measured under irrigation and dryland conditions.

Results show that net farm revenues are in general negatively affected by warmer and dryer climates. The mixed crop and livestock system predominant in Africa is the most tolerant, whereas specialised crop production is the most vulnerable to warming and lower rainfall. These results have important policy implications, especially in terms of the suitability of the increasing tendency toward mono-cropping strategies for agricultural development in Africa and other parts of the developing world, in the light of expected climate changes. Mixed crop and livestock farming and irrigation offered better adaptation options for farmers against further warming and drying predicted under various future climate scenarios.

For the second objective, the study employed a multinomial choice model to analyse determinants of farm-level climate adaptation measures in Africa. Results indicate that specialised crop cultivation (mono-cropping) is the most vulnerable agricultural practice in Africa in the face of climate change. Warming, especially in summer, poses the highest climate risk which tends to indicate switching away from mono-cropping towards the use of irrigation, multiple cropping and integration of livestock activities. Increased precipitation reduces the need for irrigation and will be beneficial to most African farming systems, especially in drier areas. Better access to markets, agricultural extension and credit services, technology and farm assets (such as labour, land and capital) are critical enabling factors to enhance the capacity of African farmers to adapt to climate change. Government policies and investment strategies that support the provision of and access to education, markets, credit, and information on climate and adaptation measures, including suitable technological and institutional mechanisms that facilitate climate adaptation, are therefore required for coping with climate change, particularly among poor resource farmers in the dry areas of Africa.

Key words: climate change, impacts, adaptation, agriculture, Africa, Ricardian approach, multinomial choice models

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ACRONYMS AND ABBREVIATIONS

AEZ	Agro Ecological Zone
AGRIM	Agriculture, Growth and Redistribution of Income Model
AOGCMs	Atmospheric-Oceanic Global Circulation Models
APN	Asia-Pacific Network for Global Change Research
ARTES	Africa Rainfall and Temperature Evaluation System
CCC	Canadian Climate Centre
CEEPA	Centre for Environmental Economics and Policy in Africa
CERES	Crop Estimation through Resources and Environmental Synthesis
CGE	Computable General Equilibrium
CO_2	Carbon Dioxide
CROPWAT	Crop Water
DES	Dietary Needs Supply
EASM	Egyptian Agricultural Sector Model
EPIC	Erosion Productivity Impact Calculator
FAO	Food and Agriculture Organization
FARM	Future Agricultural Resources Model
GEF	Global Environmental Facility
GCM	Global Circulation Model
GDP	Gross Domestic Product
GIS	Geographic Information System
LUT	Land Utilisation Types
IAC	InterAcademy Council
IPCC	Intergovernmental Panel on Climate Change
MINK	Missouri-Iowa-Nebraska-Kansas
MLCRDRY	Multiple crops under dryland
MLCRIRRG	Multiple crops under irrigation
MLCRLSIR	Multiple crop-livestock under irrigation
MLCRLSDR	Multiple crop-livestock under dryland

MOCRLSDR	Mono crop-livestock under dryland
MOCRLSIR	Mono crop-livestock under irrigation
MNL	Multinomial Logit
MNP	Multinomial Probit
PCM	Parallel Climate Model
SNM	Standard National Model
SRES	Special Report on Emissions Scenarios
SSA	Sub-Saharan Africa
SSMI	Special Sensor Microwave Imager
TAR	Third Assessment Report
UNEP	United Nations Environmental Programme
US	United States of America
VIF	Variance Inflation Factor
WB	World Bank

Chapter 1

Introduction

1.0 Background and statement of the problem

Higher temperatures and declining rainfall patterns, as well as increasing frequency of extreme climate events (such as droughts and floods), are the expected future climate in the tropics (IPCC, 2007; Mitchell & Tanner, 2006; IPCC, 2001). In southern Africa, for example, rainfall patterns show a declining trend of summer rainfall (about 20%) from 1950-1999 and a high frequency of droughts, predicted to intensify in the 21st century (Mitchell & Tanner, 2006). Predictions for 2050 by the US National Center for Atmospheric Research show that the declining trend in rainfall is set to continue and the region is expected to be 10–20 percent drier than the previous 50 years (Mitchell & Tanner, 2006). These predicted changes in climate are expected to have differential impacts on agricultural productivity, food security and other sectors, across spatial and temporal scales. In the tropics and Africa in particular, changes in climate are expected to be detrimental to agricultural livelihood (IPCC, 2007; IAC, 2004; Dixon, Gulliver & Gibbon, 2001; IPCC, 2001). Recent studies suggest that agricultural crop productivity in Africa will be adversely affected by any warming above current levels (Kurukulasuriya et al., 2006; Kurukulasuriya & Mendelsohn, 2007a; Seo & Mendelsohn, 2007a).

Local ecosystems provide the main source of livelihood for many of the world’s poor. Most of the rural poor in sub-Saharan Africa rely for their livelihood and food security on highly climate-sensitive rain-fed subsistence or small-scale farming, pastoral herding and direct harvesting of natural services of ecosystems such as forests and wetlands (Mitchell & Tanner, 2006; Leary et al., 2005; Roach, 2005; IPCC, 2001; Kandlinkar & Risbey, 2000). The productivity of this livelihood base is highly vulnerable to climate-related stresses, such as changes in temperature, precipitation (both amount and variability), and increased frequency of droughts and floods. The vulnerability of the majority of the poor in Africa to climate-related stresses is worsened by widespread poverty, HIV/AIDS, lack of access to resources (e.g. land and water) and management capabilities, wealth, technology, education, ineffective institutional arrangements, and lack of social safety nets (Leary et al., 2005; Nyong, 2005; APN, 2002; IPCC, 2001).

Studies based on the Global Environmental Facility (GEF) African Climate Project estimated the economic impacts of climate change on African agriculture (Dinar, Hassan, Mendelsohn & Benhin, 2008). These studies however, analysed impacts on dryland crops, irrigated crops and livestock separately. This is a significant limitation, since factors affecting the choice between crop and livestock production or their combination (mixed systems), cannot be separated. The selection must be an endogenous decision made by agricultural producers in response to varying climates and other circumstances. The decision of what to produce and how to produce it is accordingly an important adaptation mechanism in the face of changing climate and other ecological and economic circumstances. This is of special importance to Africa, where the majority of poor small-scale farmers practice mixed crop–livestock agriculture and few depend on crops or livestock alone.

One main objective of this study is therefore to measure the aggregate impact of climate change on income from all agricultural production systems (crop, livestock and mixed) in Africa, and to predict future impacts under various climate scenarios. In addition, the study also measures and compares impacts on specialised crop and livestock farms. The results are contrasted with findings of other regional studies using the same data but generating different climate response functions for crop and livestock farming separately (Kurukulasuriya et al., 2006; Kurukulasuriya & Mendelsohn, 2007a; Seo & Mendelsohn, 2007a).

Climate is changing and mitigation efforts to reduce the sources or enhance the sinks of greenhouse gases will take time and may also be very expensive (Stern, 2006). Empirical studies measuring the economic impacts of climate change on agriculture in Africa (Kurukulasuriya & Mendelsohn, 2007a; Seo & Mendelsohn, 2007a; Mano & Nhemachena, 2007; Benhin, 2006; Kabubo-Mariara & Karanja, 2007) showed that such impacts can be significantly reduced through adaptation. Adaptation is therefore critical and of major concern in developing countries which are most vulnerable, particularly Africa. While African farmers have low capacity to adapt to such risks, they have survived and have coped with climate change in various ways over time and under changing circumstances (Kurukulasuriya & Rosenthal, 2003). The second objective of this study is to analyse adaptation measures used by African farmers and determinants of their choices.

Better understanding of how farmers have coped with and adapted to climate change is essential for designing incentives to enhance private adaptation. This is also true for public adaptation as better understanding will help governments to design programmes to help farmers adapt. Supporting the coping strategies of local farmers through appropriate public policy, investment and collective actions has the potential to facilitate increased adoption of adaptation measures. Such adoption will reduce the negative consequences of predicted future climate changes, with great benefits to vulnerable rural communities in Africa. Our analysis is different from other adaptation studies in that we consider actual adaptation measures being taken by farmers, compared to the analysis conducted by Maddison (2007) on the same sample of African farmers, which is based on farmers' perceived adaptations. We also consider the choice between many adaptation measures simultaneously, compared to studies that analysed such joint endogenous decisions in separate analyses for crop selection (Kurukulasuriya & Mendelsohn, 2007b), irrigation modelling (Kurukulasuriya & Mendelsohn, 2007c) and livestock choice analysis (Seo & Mendelsohn, 2007b).

1.2 Objectives of the Study

The first main objective of this study is to measure the aggregate impact of climate change on income from all agricultural production systems (crop, livestock and mixed) in Africa, and to predict future impacts under various climate scenarios. The study analyses the impacts of global warming on African agriculture in terms of long-term changes in climate variables (temperature and precipitation). In addition to measuring economic impacts, the second main objective of the study is to analyse determinants of farmers' choices between alternative adaptation measures available to African farmers. Adaptation measures[1] refer to adjustments in management strategies to reduce risks or realise opportunities from actual or expected changes in climatic conditions.

Under these main objectives the following specific objectives were pursued:

1. Apply a cross-sectional model to measure the impacts of changes in seasonal climate attributes (rainfall and temperature levels) on net revenue from crop and livestock farming, while controlling for the effect of other factors.
2. Use estimated model parameters to predict impacts of future climate changes on net revenue from crop and livestock farming under various climate scenarios.
3. Estimate climatic response functions of different production systems under irrigation and dryland conditions.
4. Analyse the significance of seasonal climate, household and other socio-economic factors in influencing the use of adaptation measures at the farm level.
5. Suggest policy options that can reduce negative impacts of climate change and help improve regional food security in the face of anticipated changes in climate.

1.3 Hypotheses of the study

1. In regions in Africa that are already hot and dry, increases in warming and declining precipitation are expected to have negative effects on net revenue from crop and livestock farming, controlling for the effects of other factors.
2. In regions in Africa experiencing dry and average wet conditions, increases in seasonal rainfall are expected to increase net farm revenues, controlling for the effects of other factors.

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[1] See Chapter 5 section for more details on adaptation.

3. The adverse impacts of increases in warming and declining precipitation in Africa are expected to be higher for dryland, single-cropping and pastoralist systems than for irrigated and mixed crop–livestock farms.
4. Improved access of African farmers to resources such as credit, extension, information etc., enhances farm-level use of adaptation measures.

1.4 Approach and Methods of the Study

This study employs two main analytical techniques to attain the above objectives. It firstly adopts the cross-section (Ricardian) approach to measure the impacts of climate change attributes (rainfall and temperature levels) on income from all agricultural production systems (crop, livestock and mixed) in Africa, controlling for other production factors. Based on empirical estimates from the Ricardian model, future impacts under various climate scenarios are predicted. In addition to estimating impacts on mixed crop–livestock farms, impacts on specialised crop and livestock farms are also measured and compared. Responses of different production systems are analysed under irrigation and dryland conditions. Secondly, the study employs the multinomial logit approach to analyse determinants of farm-level adaptation measures of African farmers.

The empirical estimations are based primarily on existing survey and other data collected by the Global Environmental Facility/ World Bank/ Centre for Environmental Economics and Policy in Africa (GEF/WB/CEEPA) study on climate change and agriculture (Dinar et al., 2008). This data covers eleven countries: Burkina Faso, Cameroon, Egypt, Ethiopia, Ghana, Kenya, Niger, Senegal, South Africa, Zambia and Zimbabwe.

1.5 Organisation of the Thesis

Chapter 2 provides background information on the climate, farming systems and agricultural production in Africa. Chapter 3 presents a review of approaches for measuring the economic impacts of climate change and empirical studies that have estimated climate change impacts on agriculture. Specification of the Ricardian analytical model and results of the empirical analyses of climate change impacts on agriculture are presented and discussed in Chapter 4. Chapter 5 briefly reviews selected theoretical and empirical studies relating to the economics of climate change adaptation in agriculture. The empirical specification and estimation of the multinomial discrete choice model of determinants of farm strategies is presented in Chapter 6. A summary, conclusions and implications for policy and research are presented in Chapter 7.

Chapter 2

African climate, farming systems and agricultural production

2.0 Introduction

Agricultural production remains the main source of livelihood for most rural communities in developing countries. In sub-Saharan Africa in particular, agriculture provides a source of employment for more than 60% of the population and contributes about 30% of the Gross Domestic Product (GDP) (Kandlinkar & Risbey, 2000). In addition, agriculture provides an important source of export earnings, accounting for 16% of the total exports in sub-Saharan Africa (47% of total exports in East Africa, 14% in southern Africa and 10% in West Africa) (IAC, 2004; Dixon et al., 2001).

Agricultural production in Africa is vulnerable to climatic conditions due to a number of reasons: (i) most parts of the continent are already experiencing very high temperatures; (ii) most farmers depend on the quality of rain and production is mainly subsistence; and (iii) most parts of the continent are already water stressed[2] (IPCC, 2001). African farmers and systems have adapted in many ways to climate change through, for example, growing multiple crops, mixing crops and livestock, and using irrigation (Kurukulasuriya & Rosenthal, 2003). With respect to the main goals of the study, this chapter presents an overview assessment of the African climate and how it influences agricultural production in major farming systems.

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[2] Many parts of Africa are vulnerable to lack of access to safe water arising from multiple factors, with the situation exacerbated by climate change. For example, some assessments show severe increased water stress and possible increased drought risk for parts of northern and southern Africa, and increases in runoff in East Africa (IPCC, 2007). Further, Africa has the lowest conversion factor of precipitation to runoff, averaging 15%. Also, although the equatorial region and coastal areas of eastern and southern Africa are humid, the rest of the continent is dry sub-humid to arid (IPCC, 2001).

2.1 African climate and agricultural potential

According to the IPCC (2001), most parts of Africa are mainly tropical and experience hot and dry conditions. Temperate climatic conditions are found in the extreme south and north, and at high altitudes in between. Humid conditions are experienced in parts of West Africa, including the western part of Central Africa, throughout the year. The sub-humid region covers a large area north and south of the humid central region, and experiences substantial rainfall during the wet season and almost no rain during the dry season. Semi-arid climates are located from the sub-humid region further to the poles, and are characterised by extreme unreliability of rainfall. Most of the human population is located in the sub-humid and semi-arid zones (IPCC, 2001).

Scientific evidence on global warming shows that further increases in average temperatures of 1.4-5.8°C are expected in the 21st century (Wilson, 2001). These increases are expected to be more harmful in tropical areas such as Africa that are already experiencing very high temperatures. Most climate models predict more frequent and severe extreme weather events in the tropics generally, including both localised drought and flooding. Agricultural productivity in Africa is considered to be vulnerable to such extreme weather events.

An important example is the increased frequency of drought episodes over the last several decades particularly in southeast Africa that are associated with the El Niño-Southern Oscillation (ENSO[3]) phenomenon. In addition, arid and semi-arid sub-regions and the grassland areas of eastern and southern Africa, as well as areas currently under threat from land degradation and desertification, are particularly vulnerable to global

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[3] "The El Niño-Southern Oscillation (ENSO) is the atmosphere-ocean phenomenon responsible for interannual climate variability" (IPCC, 2007; Nicholson & Entekhapi, 1986). "The ENSO events have great impact on the wind, sea surface temperature, and precipitation patterns" (IPCC, 2007). "The typical rainfall anomaly associated with ENSO is a dipole rainfall pattern: some regions will experience warm ENSO episodes, whereas others will be negatively correlated with these events" (Nicholson & Kim, 1997).

warming, indicating reduced potential for agricultural activities in these regions. A reduction in rainfall projected by some climate models for the Sahel and southern Africa, if accompanied by high inter-annual variability, could be detrimental to the hydrological balance of the continent and disrupt various water-dependent socio-economic activities that include agricultural production systems (IAC, 2004).

Figures 2.1(a), (b) and (c) below show trends in temperature, precipitation and food production in Africa respectively. Trends in precipitation and temperature for the African region indicate that the region is warming and getting drier. Trends in variability of temperature in Africa over the 20th century show a rising trend in observational records at a rate of about 0.05°C per decade. Much of the warming has been recorded in the June-November seasons compared to the December-May seasons (Hulme, Doherty, Ngara, New & Lister, 2001). According to the IPCC (2001), temperatures are expected to increase most in southern and northwest Africa at a rate of about 0.6°C to 1°C per decade and around 0.4°C in East Africa. Precipitation trends show that Africa is going to experience drier conditions, with precipitation decreasing at a rate of between 10 and 20% in southern Africa and 10 to 50% in eastern and northern parts of Africa (IPCC, 2001). These trends are expected to negatively affect agricultural productivity and food security in the region, unless precautionary adaptive measures are taken. These adaptive measures, both at the local farm level and national levels are necessary to help reduce the potential negative effects associated with these changes in temperature and precipitation.

It is difficult to establish causality between climate variability and rain-fed crop and livestock production. It is however, true that for some countries and certain years, food production has been declining in the face of increasing temperature and decreasing precipitation regimes. The impact of these changes, in addition to other factors, is that food production in most of sub-Saharan Africa (SSA) has not kept pace with population growth over the past three decades. For example, in Africa as a whole, food consumption exceeded domestic production by 50% in drought-prone areas in the mid-1980s and by more than 30% in the mid-1990s (WRI, 1998). This has left many countries in Africa being net food importers, with food aid constituting a major proportion of net food trade in the region. For instance, food aid constituted two-thirds of food imports during the 1990s in Kenya and Tanzania (IPCC, 2001).

In addition, per capita dietary needs supply (DES) remains relatively low (Hulme, 1996). About one-third of the countries in Africa had per capita DES of less than 2000 kcal per day in the 1990s, which is lower than the minimum recommended intake of 2100 (Todd, 2004; Naiken, 2002). The results from the three graphs suggest a direct correlation between increasing temperatures, decreasing precipitation and declining food production. The implication of predicted further warming in Africa is that food production is going to be adversely affected, unless farmers use adaptation strategies such as irrigation. It is therefore important to find ways and strategies of reducing the vulnerability and improving the adaptive capacity of African agriculture in the face of the adversities of predicted climate changes.

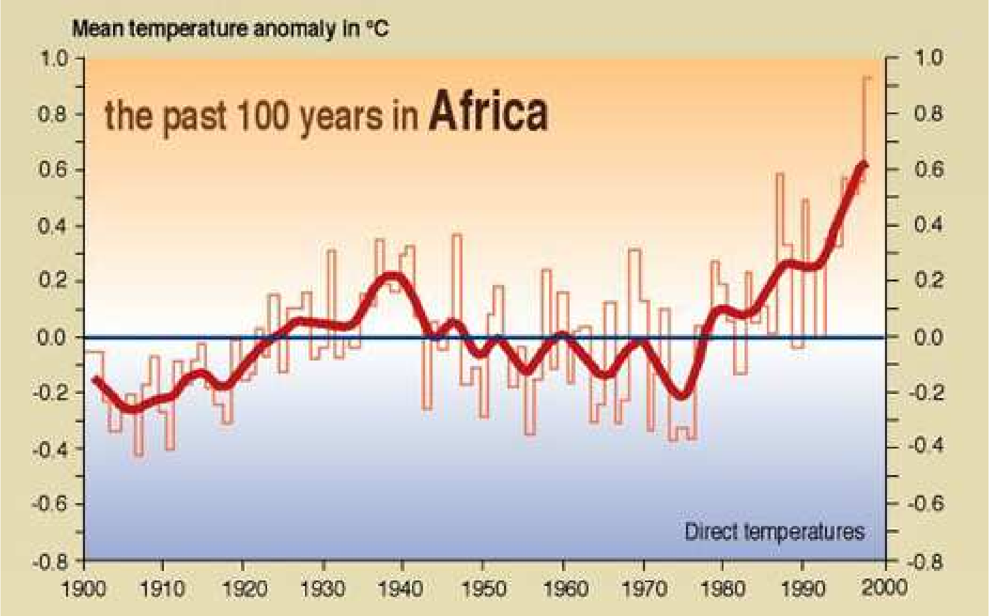

Figure 2.1 (a): Variations of the earth's surface temperature for the past 100 years in Africa

Source: UNEP Grid Arendal (2002).

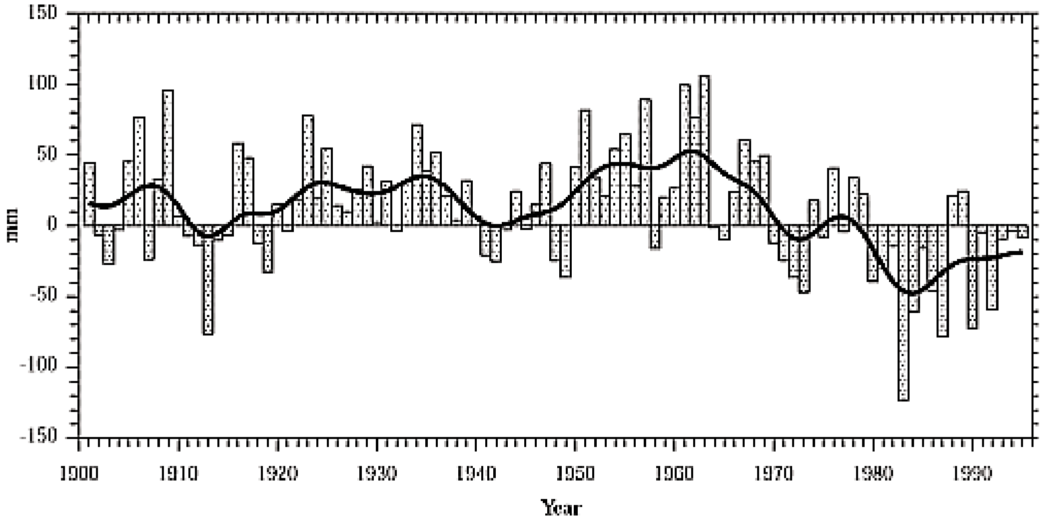

Figure 2.1 (b): Observed annual precipitation changes for the Africa region

Source: IPCC (2001)

Source: Food and Agriculture Organization (FAO), Statistical databases (FAOStats), 1995.

Figure 2.1 (c): Food production index in Africa

2.2 Agro-climates and farming systems in sub-Saharan Africa

A farming system is defined as “a population of individual farm systems that have broadly similar resource bases, enterprise patterns, household livelihood and constraints, and for which similar development strategies and interventions would be appropriate" (Dixon et al., 2001; FAO, 2001). Dixon et al. (2001) and FAO (2001) classified 15 major farming systems in SSA (see Figure 2.2 and Table 2.1). This classification of farming systems was based on: (a) natural resource base (e.g. water, land, grazing areas and forest); climatic conditions (e.g. altitude); landscape characteristics (e.g. slope); farm size, tenure and organisation) and (b) main farming activities and sources of livelihood (e.g. field crops, livestock, trees, aquaculture, hunting and gathering, processing and off-farm activities); intensity of production; and integration of crops, livestock and other activities based on technology use.

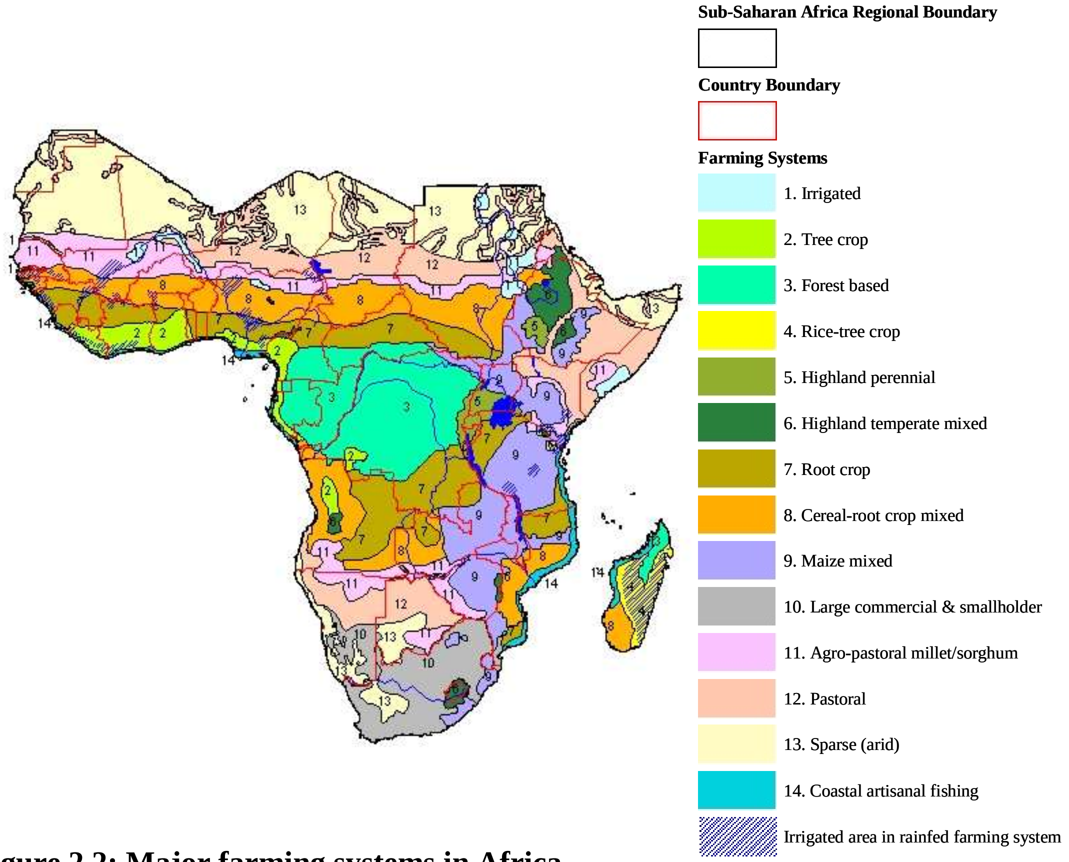

Figure 2.2: Major farming systems in Africa

Source: Dixon et al. (2001)

Table 2.1: Major farming systems in sub-Saharan Africa

Farming system	**Land area (% of region)**	**Agric. population (% of region)**	**Principal livelihood**	**Agro-ecological zone**	**Sources of Vulnerability**
Maize-mixed (9)	10	15	Maize, tobacco, cotton, cattle, goats, poultry, off-farm work	Semi-arid and dry sub-humid	Drought, market volatility
Cereal-root crop mixed (8)	13	15	Maize, sorghum, millet, cassava, yams, legumes, cattle	Dry sub-humid	Drought
Root crop (7)	11	11	Yams, cassava, legumes, off-farm work	Moist sub-humid and humid	Lack of appropriate technologies
Agro-pastoral millet/ sorghum (11)	8	9	Sorghum, pearl millet, pulses, sesame, cattle, sheep, goats, poultry, off-farm work	Semi-arid	Drought
Highland perennial (5)	1	8	Banana, plantain, enset, coffee, cassava, sweet potato, beans, cereals, livestock, poultry, off-farm work	Sub-humid and humid	Declining soil fertility, poor markets; infrastructure
Forest based (3)	11	7	Cassava, maize, beans, coco yams	Humid	Lack of physical infrastructure, markets
Highland temperate mixed (6)	2	7	Wheat, barley, teff, peas, lentils, broad beans, rape, potatoes, sheep, goats, cattle, poultry, off-farm work	Sub-humid and humid	Early and late frosts
Pastoral (12)	14	7	Cattle, camels, sheep, goats, remittances	Arid and semi-arid	Drought
Tree crop (2)	3	6	Cocoa, coffee, oil palm, rubber, yams, maize, off-farm work	Humid	Price fluctuations
Commercial large-scale and small-scale (10)	5	4	Maize, pulses, sunflower, cattle, sheep, goats, remittances	Semi-arid and dry sub-humid	Drought, poor soils
Coastal artisanal fishing (14)	2	3	Marine fish, coconuts, cashew, banana, yams, fruit, goats, poultry, off-farm work	Humid	
Irrigated (1)	1	2	Rice, cotton, vegetables, rain-fed crops, cattle, poultry	Various	Water shortages, scheme breakdowns, High costs
Rice/ tree crop (4)	1	2	Rice, banana, coffee, maize, cassava, legumes, livestock, off-farm work	Moist humid and humid	Shortage of appropriate technologies, small farm size, poor markets
Sparse agriculture (arid) (13)	18	1	Irrigated maize, vegetables, date palms, cattle, off-farm work	Arid	Drought
Urban based (15)	<1	3	Fruit, vegetables, dairy, cattle, goats, poultry, off-farm work	Various	

NB: Numbers in parenthesis represent the respective farming system numbers as indicated in Figure 2.2

Source: Dixon et al. (2001)

Despite the central role that agriculture plays in the region, most of the region has marginal conditions for productive agriculture. Forty-three percent of sub-Saharan Africa is located in the arid and semi-arid agro-ecological zones, thirteen percent is in the dry sub-humid zones and thirty-eight percent is covered jointly by the sub-humid and humid zones (IAC, 2004; Dixon et al., 2001; FAO, 2001). The arid, semi-arid and dry sub-humid areas are characterised by large marginal areas, which experience very high temperatures and very low and highly variable rainfall, all of which limit agricultural productivity. Farming systems in the arid, semi-arid and dry sub-humid zones are expected to suffer most from the adverse effects of climate change, such as increased frequency and severity of droughts, high temperatures and rainfall variability (IAC, 2004).

The major farming systems that support most of the agricultural population in Africa and in southern Africa in particular, are located in the dry sub-humid zone (cereal-root mixed, maize mixed, large commercial and smallholder systems), semi-arid zone (agro-pastoral, millet) and arid zone (pastoral). About half of the population in southern and eastern Africa lives in the sub-humid and humid zones, compared to about seventy percent living in the same areas in West Africa. The former areas are already experiencing very high temperatures with a significant proportion of the region receiving mean annual rainfall of less than 1000mm and having mean annual temperatures between 20 and 30 degrees Celsius and (Figure 2.3(a) and 2.3(b) below).

Changes in climate in terms of increasing frequency and severity of droughts are expected to have significant impacts on the arid, semi-arid and dry sub-humid agro-ecological zones. The impacts would translate into widespread crop failure, high and rising cereal prices, low and falling livestock prices, distress sales of animals, decapitalisation, impoverishment, hunger and eventually famine (Dixon et al., 2001; FAO, 2001). Mixed cropping systems are better able to cope with changes in climate and other stresses. They can reduce risk of crop failure, reduce incidence and losses from pests and diseases, and can make efficient use of labour (IAC, 2004).

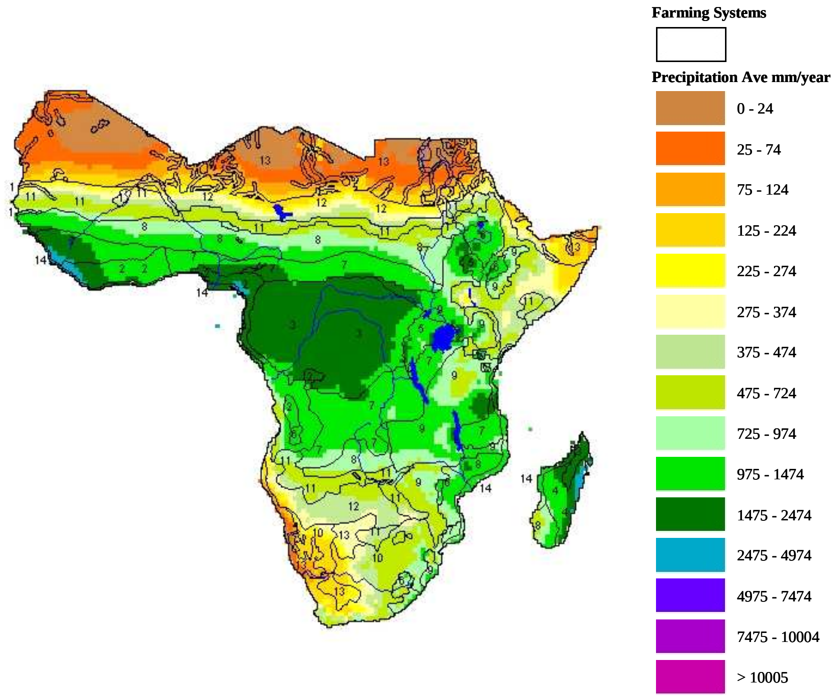

Figure 2.3(a): Average annual precipitation in major farming systems

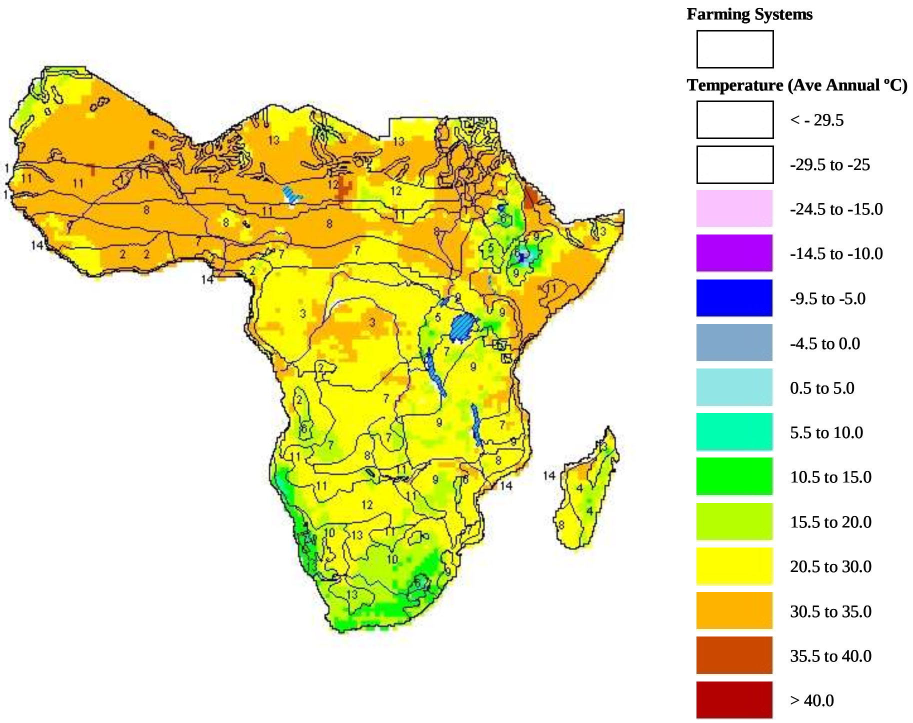

Figure 2.3(b): Average annual temperatures in major farming systems

Source: Dixon et al. (2001)

2.3 Characterisation of selected priority farming systems

Table 2.2 presents further information characterising the four priority farming systems: maize-mixed; cereal-root crop mixed; irrigated and root crops, which support about 41% of the agricultural population (IAC, 2004). Table 2.3 shows annual productivity growth for the major commodities over the last two decades (1980-2000) and the two preceding decades (1960-1980). Productivity trends for six of the major crops in the maize-mixed farming system have been declining since 1981. On the other hand, crops in the irrigated and tree crop systems that involve more commercial crops show increasing productivity trends from 1981. In the main systems examined, productivity was relatively higher for food crops (e.g. maize, wheat and cassava) than for other crops (e.g. coffee, palm oil and cocoa).

Table 2.2: Major characteristics of selected priority farming systems

	Maize-mixed	Irrigated	Cereal-root crop	Tree crop
A. Major characteristics*				
Total population ('000 000 people)	95	14	85	50
Agricultural population ('000 000 people)	60	7	59	25
Total area ('000 000 ha)	246	35	312	73
Cultivated area ('000 000 ha)	32	3	31	10
Irrigated area ('000 000 ha)	0.4	2	0.4	0.1
Agro-climatic zone	Dry sub-humid to moist sub-humid	Various	Dry sub-humid	Humid
Vulnerability	Drought and market volatility	High costs	Drought	Price fluctuations
Prevalence of poverty	Moderate	Limited	High	Limited-moderate
Agriculture growth potential	Good	High	Limited	Moderately high
B. Indices				
Malnutrition index	81	28	100	50
Agricultural added value index	73	100	28	67
C. Dominant (++) and other important (+) commodities				
Maize	++	++	++	+
Rice	+	++		+
Sorghum	+	+	++	+
Millet	+		++	+
Wheat		++		
Cassava	++		++	++
Yam			++	++
Cocoyam				++
Pulses	+		+	
Vegetables/Melon		++		
Banana/Plantain	+			
Cotton	+		+	
Coffee	+			+
Oil Palm				+
Cocoa				+
Rubber				+
Tobacco	+			
Groundnuts	+			
Sunflower	+			
Cattle population ('000 000 head)	36	3	42	2
Poultry	+	+		
Goats	+		+	+

Source: IAC, 2004

Table 2.3: Productivity trends for various commodities in the priority farming systems

Crop	Decades	Annual % yield increase over two periods of two decades			
		Maize-mixed	Irrigated	Cereal-root crop	Tree crop
Maize	1961-1980	2.63	1.97	-0.36	0.27
	1981-2002	-0.04	3.3	3.83	2.56
Rice	1961-1980	0.98	0.2	-0.94	1.28
	1981-2002	0.69	2.71	1.35	2.98
Sorghum	1961-1980	0.16	0.32	0.72	0.58
	1981-2002	0.64	2	1.68	2.28
Millet	1961-1980	1.22		0.04	-1.07
	1981-2002	0.54		1.92	0.11
Wheat	1961-1980	6.92	1.92		
	1981-2002	-0.08	3.19		
Cassava	1961-1980	2.8		1.37	-0.06
	1981-2002	0.03		2.09	1.75
Yam	1961-1980			1.29	
	1981-2002			0.92	
Pulses	1961-1980			0.9	
	1981-2002			4.48	
Vegetables/Melon	1961-1980		0.21		
	1981-2002		1.13		
Banana	1961-1980	-0.4			
	1981-2002	1.4			
Cotton	1961-1980	2.69			
	1981-2002	0.77			
Coffee	1961-1980				-0.34
	1981-2002				0.86
Oil Palm	1961-1980				0.44
	1981-2002				0.48
Cocoa	1961-1980				-0.15
	1981-2002				1.94

Source: IAC (2004). Indicator countries: Maize-mixed (Malawi and Zimbabwe: 70%; and Tanzania, Uganda and Zambia: 50%); Irrigated (Egypt); Cereal-root crop mixed (Gambia, Guinea-Bissau and Mozambique: 70%; and Benin and Burkina Faso: 50%) and tree crop based (Guinea and Liberia: 70%; and Ghana: 50%). The percentages refer to minimum proportions of the countries that are covered by the indicated systems.

Table 2.4 shows irrigated land in farming systems in Africa in 2000. Much of the agricultural output in Africa is produced from rain-fed agricultural systems and only a small area (about 1.2%) is under irrigation (IAC, 2004). These figures illustrate that the use of irrigation is very limited in Africa, despite its potential for increasing agricultural productivity in the face of frequent drought regimes in most parts of the region due to changes in climate. Irrigation offers an important adaptation strategy to water stresses and droughts that are being experienced in the region and it may be necessary to find ways of enhancing its expansion in Africa. In addition, there is great potential for raising productivity levels of agricultural systems currently under rain-fed agriculture, through the adoption of irrigation technologies.

Table 2.4: Irrigated land within the main farming systems in Africa in 2000

Farming system	Agricultural area (1 000 ha)		
	Land use	**Irrigation**	**Percent irrigated**
Cereal-root crop mixed	62,874	163	0.26
Highland perennial	3,890	79	2.03
Maize-mixed	108,629	360	0.33
Root crop	11,525	37	0.32
Forest based	38,594	27	0.07
Tree crop	49,289	182	0.37
Agro-pastoral	8,050	71	0.88
Sparse (arid)	111,395	1,145	1.03
Large commercial	99,640	1,498	1.5
Irrigated	3,291	3,291	100
Africa total	**1,101,166**	**12,680**	**1.15**

Source: IAC (2004)

Despite low productivity levels of rain-fed agriculture, baseline projections to 2021-25 (Table 2.5) indicate no significant changes in the proportion of land under irrigation for important food crops (Rosegrant, Cai & Cline, 2002). Table 2.5 shows that only soybean is expected to continue to derive most of its production from irrigated agriculture. Maize, which constitutes the main cereal in Africa, continues to derive most of its production from rain-fed agricultural systems.

Table 2.5: Proportions of rain-fed areas and production totals in 1995 and projected to 2021-25 in Africa for selected crops

Region/commodity	Percentage rain-fed			
	Area (%)		Production (%)	
	1995 actual	2021-25 baseline projection	1995 actual	2021-25 baseline projection
Sub-Saharan Africa				
Total cereals	96	95	89	89
Rice	81	77	68	64
Wheat	78	75	73	71
Maize	96	96	90	90
Soybean	25	27	49	52

Source: Rosegrant et al. (2002)

According to the IAC (2004), sustainable yield increases (e.g. through innovations in integrated water, soil and nutrient management) should be the driving force in future rain-fed agricultural strategies, rather than the former strategy of increasing production through area expansion. The limitations of this former strategy are that with population increases in the region and limited available agricultural land, further agricultural land expansion will extend into marginal areas, leading to further land degradation, erosion and loss of biodiversity.

The implication of expected dry and warm conditions in the future is that rain-fed agricultural systems need more water-efficient farm management systems, combined with drought-tolerant crops and varieties with higher water use efficiency. Recommended practices include water harvesting, supplementary irrigation, run-off management, conservation tillage and integration of more leguminous species into rotation systems. Improved soil surface management practices, small water harvesting systems and small irrigation systems have been shown to offer great potential for making maximum use of rainwater. In addition, such practices allow farmers to intensify their production activities and encourage increased diversity in production of high value crops (IAC, 2004).

2.4 Importance of livestock in African farming systems

Livestock provides an important source of livelihood for most of the rural poor. Livestock are important as a source of cash; a coping strategy against climate change and other stresses; and they provide a good source of social security capital and social networking instruments (IAC, 2004). Other important benefits of livestock include: draft power for land operations and post harvesting operations; soil fertility improvement from manure; source of transport to markets; source of diversifying income sources; and an important source of high quality proteins and energy (IAC, 2004).

Major animal production systems are presented in Table 2.6. Cattle are a major breed for most poor people in mixed crop–livestock systems in arid and semi-arid regions (MRA), humid/sub-humid regions (MRH) and the tropical highlands (MRT) of eastern, central and southern Africa. Other livestock in these farming systems are: sheep, goats, poultry, horses, donkeys, mules and pigs. In West Africa, sheep and goats are the most important, followed by poultry and cattle, horses, donkeys, mules and pigs. Sheep and goats are also of great importance for the poor in pastoral rangeland-based systems, as are cattle, camels, donkeys and mules (IAC, 2004).

Table 2.6: Major animal production systems in African agro-ecological zones

Abbreviation	Animal production system	Agro-ecological zone
LGA	Pastoral, livestock only, rangeland-based	arid/semi-arid
LGH	Pastoral, livestock only, rangeland-based	humid/sub-humid
LGT	Pastoral, livestock only, rangeland-based	temperate/tropical highland
MRA	Agro-pastoral, mixed rain-fed	arid/semi-arid
MRH	Agro-pastoral, mixed rain-fed	humid/sub-humid
MRT	Agro-pastoral, mixed rain-fed	temperate/tropical highland
MIA	Agro-pastoral, mixed irrigated	arid/semi-arid
MIH	Agro-pastoral, mixed irrigated	humid/sub-humid
LL	Peri-urban, landless	

Source: IAC (2004). Includes both sub-Saharan and North Africa.

More than 70% of the estimated 280 million poor people in sub-Saharan Africa base their livelihood on the three mixed rain-fed crop–livestock farming systems (MRA, MRH and MRT) and only 10% rely on the pastoral rangeland-based systems (IAC, 2004). Livestock production contributes most to the livelihood of many poor people in the pastoral rangeland-based systems of the arid and semi-arid regions (LGA). The contribution is relatively high in the mixed rain-fed crop–livestock systems in the humid/ sub-humid tropics (MRH), and relatively low in the mixed rain-fed crop–livestock systems in the arid and semi-arid tropics (MRA) (IAC, 2004).

2.5 Environmental constraints in major farming systems

Figure 2.4 presents environmental constraints in major farming systems in sub-Saharan Africa. Environmental factors such as soil moisture, temperature, soil quality and precipitation affect productivity of crop and livestock farming systems. For example, low to medium climatic production potential is the main environmental constraint affecting major farming systems such as maize-mixed, root crop, and cereal-root crop mixed farming systems that support about 41% of the agricultural population. Another key environmental constraint is erratic rainfall and cold stress risk, which is prevalent in the pastoral, agro-pastoral millet/sorghum, cereal-root crop mixed, large commercial and smallholder farming systems. The sparse arid farming system is located in dry and/or cold areas with low production potential.

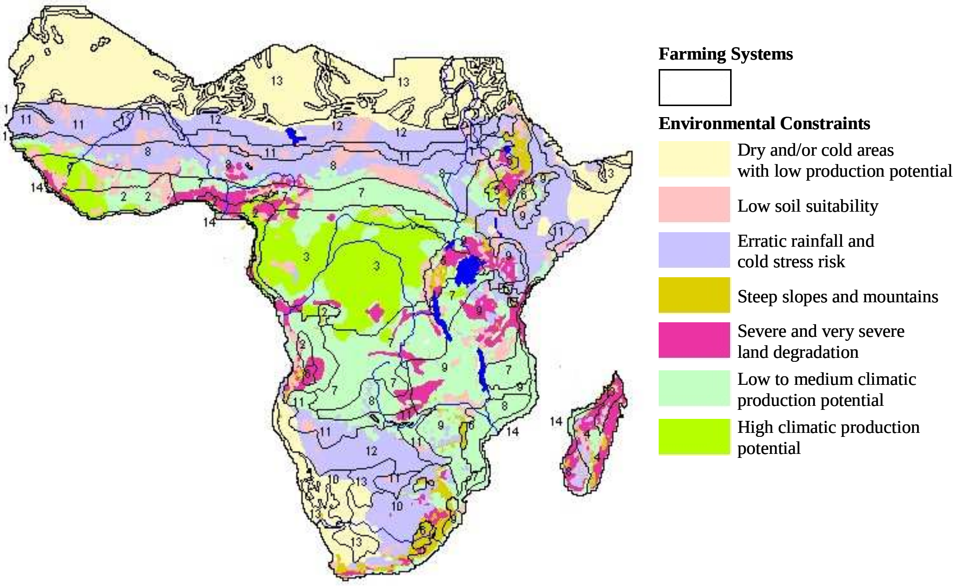

Figure 2.4: Environmental constraints in major farming systems

Source: Dixon et al. (2001)

Climate related factors (erratic rainfall and cold stress, climatic production potential and dry and/or cold areas) are the main limiting environmental factors for agricultural productivity in Africa. Farming systems, crop and livestock production and hydrological balances are expected to be greatly influenced by changes in climatic variables (temperature, precipitation) and the frequency and severity of extreme climate events (droughts and floods).

The relatively large extent of areas already experiencing climate related constraints implies that climatic factors have significant effects on performance of agricultural systems in Africa. Figures 2.3(a) and 2.3(b) showing rainfall and temperature maps indicate that these areas experience climate related constraints such as low to medium rainfall and very high temperatures. The combination of these factors and other economic factors such as low technology use, lack of inputs, and market access will negatively affect productivity of farming systems in major farming systems in Africa.

2.6 Summary

This chapter described the various agro-ecological regions and the location of major farming systems in Africa. Major farming systems in Africa are located in subtropical and tropical regions which have marginal conditions for productive agricultural production, with about 43% of the total land area being arid and semi-arid agro-ecological zones. These regions are characterised by large marginal areas, very high temperatures and very low and highly variable rainfall, all of which limit agricultural productivity. The implication is that changes in climate attributes will have significant impacts on agricultural production.

The maize-mixed, cereal-root crop mixed and root crop farming systems support about 41% of the agricultural population. Agro-pastoral millet/sorghum, highland perennial, pastoral, forest based and highland temperate mixed are also important systems. The mixed farming system is very important in Africa, which justifies the empirical analysis in this study for estimating the impacts of climate change on mixed crop–livestock systems.

It is difficult to establish causality between climate variability and rain-fed crop and livestock production. However, it is true that for some countries and years, food production has been declining in the face of increasing temperature and decreasing precipitation regimes. Generally, long term temperature and precipitation patterns show increasing and decreasing trends respectively, and food production trends show some direct correlation with trends in climate attributes (temperature and precipitation). Furthermore, maps of major farming systems and temperature and precipitation maps show that most of the region experiences warm and dry climatic conditions. The implication may be that climate change attributes have significant effects on agricultural productivity and food security in the region.

This chapter also presented the environmental constraints in major farming systems. Environmental factors such as soil moisture, temperature, soil quality and precipitation affect productivity of crop and livestock farming systems. Climate related factors (erratic rainfall and cold stress, climatic production potential, and dry and/or cold areas) affect most parts of the sub-Saharan region. This evidence further justifies the hypothesis that climate attributes (temperature and precipitation) have significant effects on agricultural performance in Africa.

Chapter 3

Review of literature on measuring the economic impacts of climate change on agriculture

3.0 Introduction

This chapter discusses the various approaches and methods that have been used to measure economic impacts of climate change on agriculture. Particular empirical studies that have measured economic impacts of climate change on agriculture are reviewed. The chapter concludes with a discussion of the approach chosen to implement the empirical economic analyses of this study and to yield its expected contributions.

3.1 Approaches to measuring economic impacts of climate change

Impacts of climate change on agriculture have been estimated using two main approaches: (a) *structural modelling* of crop and farmer response – this approach combines crop agronomic response with economic/farmer management decisions and practices; and (b) *spatial analogue models* that measure observed spatial differences in agricultural production (Adams, Hurd, Lenhart & Leary, 1998a; Schimmelpfenning, Lewandrowski, Reilly, Tsigas & Parry, 1996). Other impact assessment methods that have been used are the integrated impact assessment method and the agro-ecological zone (AEZ) method (Mendelsohn, 2000). All these approaches are discussed in more detail in the following sub-sections.

3.1.1 Structural approaches

Structural approaches (agronomic-economic models) start by using crop simulation models such as the CERES family of models (see Ritchie, Singh, Goodwin & Hunt, 1989 for a description of the CERES models), CROPWAT (FAO, 1993) or EPIC models (see Schneider, Easterling & Mearns, 2000). These models are based on detailed experiments to determine the response of specific crops and crop varieties to different climatic and other conditions. Farm management practices can be included in structural models, for example, modelling the impacts of changing timing of field operations, crop choices, adding irrigation etc. (Adams, 1999; Adams et al., 1998a; Schimmelpfenning et al., 1996). Economic impacts (e.g. changes in acreage, supply by crop and region, as well as resulting changes in prices) are then estimated by incorporating yield estimation results from crop simulation models e.g. from General Circulation Model (GCM) forecasts into economic models of the agricultural sector (Adams, 1999; Adams et al., 1998a). The objective of the economic model component is to optimise consumer and producer welfare, subject to climatic and other factors imposed in the model (Adams, 1999; Adams et al., 1998a). Examples of studies that have applied this approach include: Kaiser, Riha, Wilks, Rossier & Sampath (1993) at the farm-level; Adams and others (1998b; 1995; 1990) at the national level, and Easterling et al. (1993) at the regional level.

The types of economic models that have been used with agronomic models include: (a) computable general equilibrium (CGE) models that simulate economic wide impacts of climate change taking into account interactions between many economic agents and activities (e.g. Yates & Strzepek, 1996, 1998; Darwin, Lewandrowski, McDonald & Tsigas, 1994); (b) partial equilibrium models that include mathematical programming (e.g. Chang, 2002; Kumar & Parikh, 2001) and spatial equilibrium models of the agricultural sector (e.g. Adams et al., 1998b; Iglesias, Rosenzweig & Pereira, 1999); and (c) the basic linked system approach – an applied general equilibrium model for analysing global impacts of agricultural policies and food systems (e.g. Rosenzweig & Parry, 1994; Parry, Rosenzweig, Iglesias, Fischer & Livermore, 1999).

The strength of using *structural* approaches is that they allow for detailed understanding of the biophysical responses, as well as adjustments that farmers can make in response to changing climatic and other conditions (Adams, 1999; Adams et al., 1998a; Schimmelpfenning et al., 1996). In addition, economic models can estimate changes in clearing prices that can be translated into aggregate changes in well-being for consumers and producers (Adams, 1999; Adams et al., 1998a). This enables identification of the gainers and losers from changing climate conditions, as well as the distribution of the impacts. Such information might be important for focused policy and adaptation planning in identifying which group of people to target and in which ways they should be supported. Another strength of *structural* models compared to reduced form *statistical* (cross-sectional) models, is that they indicate the various technological and adaptation options that would offset the negative effects of climate change and positively increase yields.

One of the disadvantages of *structural* approaches is that adaptations included in agronomic models fail to account for economic considerations and limitations in human capital and other resources that affect actual farm-level decisions (Mendelsohn, 2000). In addition, if the economist fails to correctly anticipate the potential farmer adjustments and adaptations, the estimates might be biased (either overestimating the damages or underestimating the potential benefits of climate change) (Adams, 1999).

Furthermore, the problem of using such approaches is that in aggregate studies, inferences need to be made based on results from very few laboratory and experimental sites and crops analyses, to large areas and diverse agricultural production systems (Schimmelpfenning et al., 1996). Crop simulations models fail to account for the diversity of factors that affect production in the field (Adams et al., 1998a). Furthermore, *structural* models are usually associated with very high cost implications (Mendelsohn, 2000; Adams, 1999). This makes it difficult to implement them in poor and developing countries, implying that such countries need to rely on experiments conducted in developed countries.

Another disadvantage of agronomic models is that they have historically ignored the adoption of new technologies and most of them impose climate change scenarios on *current* agricultural systems (Mendelsohn, 2000). The problem with this is that the impact of climate change does not materialise for decades and by the time the climate actually changes, the farming systems could have changed from their current form. Including technical change in farming systems is important in assessing the damages that will be caused by climate change when it occurs (Mendelsohn, 2000). Adams et al. (1998) cited by Mendelsohn (2000), made attempts to capture technical change in the farming system by explicitly forecasting how farming would change in the United States by 2060. Modelling the adoption of new technologies and the transition from low input labour-intensive agriculture to high input modern farming is particularly important for developing countries. The sensitivity of climate change results to assumptions about baseline scenarios can be assessed through examining a range of assumptions concerning the speed of this transition.

The other disadvantages of *structural* approaches are the same as those for the cross-sectional approach. For instance, uncertainties surrounding economic development and political stability affect predictions of the nature of the future agricultural sector. Technical progress is often difficult to predict and very few agronomic efforts have considered the implications of projecting impacts into the future (Mendelsohn, 2000).

Generally as discussed above, the literature review reveals that agronomic models are associated with high cost implications (for data collection) and historical non-use of new technologies. However, more recent agronomic approaches make use of new global databases, do not have to rely on farm-level experiments, and have no problem with using advanced technologies. Furthermore, *structural* models, when combined with agricultural sector models, can present some types of autonomous adaptation triggered by price changes.

3.1.2 The Spatial analogue approach

The *spatial analogue* approach uses cross-sectional evidence to undertake statistical (econometric) estimations of how changes in climate would affect agricultural production across different climatic zones. Statistical and programming analyses across different geographic areas make it possible to make a comparative assessment of factors affecting production across different regions. In addition, this approach gives evidence of changes in farmer management practices and decisions in response to changing climatic conditions. Another advantage of the *spatial analogue* approach is that other factors that affect crop production, such as soil type and quality, are taken into account in statistical estimation. This cannot be done using the *structural* approach, since it depends on the quality of the data and how representative it is, as well as on the ability of the statistical analysis to separate the confounding effects (Adams et al., 1998a; Schimmelpfenning et al., 1996).

Two main *spatial analogue* methods have been developed to account for adaptation in response to changes in climate: (a) the Future Agricultural Resources Model (FARM) by Darwin et al. (1994, 1995); and (b) the Ricardian approach by Mendelsohn, Nordhaus and Shaw (1994). The basic underlying assumption for both the FARM and Ricardian methods is that similar climates mean similar production practices. This allows the two approaches to implicitly capture changes in crop or livestock outputs, production inputs or management practices that farmers are likely to take in response to changing climatic and other conditions (Darwin, 1999). Each of these approaches is discussed in more detail below.

3.1.2.1 The Future Agricultural Resources Model (FARM)

The FARM was developed by Darwin et al. (1994, 1995) to estimate the potential impacts of climate change on US agriculture, considering at the same time interactions with non-agricultural sectors and other global regions. The estimates in the FARM fully account for all responses by economic agents under global climate change, including estimates of Ricardian rents[4].

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[4] Ricardian rent refers to the estimates of land values from the 'Ricardian' approach named after David Ricardo (1772–1823), which relies upon the standard theory of land rent, as a way of identifying the impacts of changes on net economic welfare (Mendelsohn & Nordhaus, 1996).

The FARM makes use of geographic information systems (GIS) to link climatically derived land classes with other inputs and agricultural outputs in a computable general equilibrium (CGE) model of the world. The GIS component characterises regional differences in land, climate, water and agricultural suitability. Changes in climate are assumed to alter agricultural potentials of a given area by shifting regional land class and water characteristics. The resulting economic changes and effects on regional and global production and prices are then estimated in the CGE model (Adams et al., 1998a). The FARM's GIS is a *spatial analogue* model and the FARM's CGE is *structural* model (Darwin, 1999). Simulations using the FARM's CGE model capture further interactions that are likely to occur under climate change between farmers and downstream consumers (both domestic and foreign) of agricultural products (Darwin, 1999).

One of the limitations of the FARM is that the sensitivity of the Ricardian rents to changes in climate variables at grid levels is affected by the aggregation of climatic information into six land classes. In addition, it may be difficult to downscale the analysis to country level as some countries may be only one or two grids. Another limitation of the FARM is that it fails to capture some seasonal variations in climatic variables such as temperature, precipitation and coldness. Failure to include these variations might lead to biased estimates (Darwin, 1999).

3.1.2.2 Ricardian cross-sectional approach

Cross-sectional models measure farm performances across climatic zones (Dinar et al., 2008; Mendelsohn et al., 1994; 1996; Sanghi, Mendelsohn & Dinar, 1998; Mendelsohn, 2000, Mendelsohn & Dinar, 1999, 2003). The Ricardian approach is the cross-sectional method commonly used to measure the impact of climate change on agriculture. The Ricardian approach measures the performance of farmers, households and firms across spatial scales with different climates. Measured changes in farm performance are used to estimate long-run sensitivity of farm performance to climate (Dinar et al., 2008; Mendelsohn & Dinar, 1999, 2003, 2005; Mendelsohn et al., 1994, 1996). The technique draws heavily on the underlying observation by Ricardo that under competition, land values reflect the productivity of the land. The Ricardian approach has been applied in the United States (Mendelsohn et al., 1994, 1996) and in some developing countries: India (Sanghi et al., 1998; Kumar & Parikh, 1998) (using district level data), South Africa, (Gbetibouo & Hassan, 2005; Deressa et al., 2005) and eleven African countries[5] under the GEF/WB/CEEPA project (Dinar et al., 2008) using district level data to examine the economic impacts of climate change on agriculture.

The Ricardian approach regresses farmland values against climate, economic and other factors to estimate the economic impacts of climate change and other factors on farm performance (Mendelsohn & Dinar, 1999, 2003; Mendelsohn, 2000; Mendelsohn et al., 1994, 1996; Adams et al., 1998a). In a well-functioning market system, the value of a parcel of land should reflect its potential profitability, implying that spatial variations in climate derive spatial variations in land use, which in turn affects land values (Polsky, 2004). With this background, it should be possible to estimate a meaningful climate–land value relationship by specifying a multivariate regression model. The estimated coefficients for the climate variables would reflect the economic value of climate in agriculture, holding other factors constant.

The Ricardian cross-sectional approach automatically incorporates farmer adaptation by including decision making changes that farmers would make to tailor their operations to a changing climate. An important example of farmer adaptation strategies is crop choice, where a particular crop will become the optimal choice depending on the effects of a warmer climate. Optimal crop switching is therefore an important component of measuring the agricultural impact of climate change (Mendelsohn et al., 1994, 1996; Mendelsohn & Dinar, 1999). The Ricardian approach provides a framework to make comparative assessments of with and without adaptation scenarios, giving a valuable view of how adaptation measures may help to reduce the impact of climate change on agriculture.

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[5] Burkina Faso; Cameroon; Egypt; Ethiopia; Ghana; Kenya; Niger; Senegal; South Africa; Zambia and Zimbabwe.

Farmer adaptations that are implicit in the Ricardian model results are projected to largely offset the economic costs associated with climate change (Polsky, 2004). Farmers use available information to their maximum economic benefit in adapting to climatic shocks in any economy at equilibrium. For instance, a standard Ricardian model would imply that if growing citrus crops is more profitable than growing wheat, and if the climate becomes more suitable for citrus than for wheat, then farmers will adapt to the changed climate by drawing on the experiences of citrus farmers elsewhere and switching from wheat to citrus (Polsky, 2004).

The advantage of the *cross-sectional* approach is that it fully incorporates farmer adaptations. The first round adaptations by farmers are captured in the estimates of climate-induced changes that represent the economic value of climate change on agriculture (Mendelsohn et al., 1994, 1996). Measurement of long-term impacts of climate change considers the costs and benefits associated with changes in management decisions and practices taken by farmers in response to changes in local climate, as well as the effect of other explanatory variables such as soils, infrastructure, agricultural services and other socio-economic variables (Mendelsohn & Dinar, 2005; Mendelsohn et al., 1994, 1996). The underlying assumption is that farmers will automatically make adjustments in their management practices and respond to changes in climate (Mendelsohn & Dinar, 2003; Mendelsohn et al., 1994, 1996; Adams, 1999; Adams et al., 1998a). The assumption of implicit structural changes and farmer adaptations frees one from the burden of estimating the impacts of climate change on region-specific crops and farmer adaptations (Adams, 1999; Adams et al., 1998).

One limitation of the *cross-sectional* approach is the scarcity of good and reliable data, particularly in developing countries (Mendelsohn & Dinar, 2005; Adams, 1999). It is difficult to control for all variables that might affect the estimated relationship between climate and agricultural production using evidence from cross section data. For example, some variables might be included in the model but poorly measured, or might be excluded for lack of data (Reilly, 1999). The GEF/WB/CEEPA African climate and agriculture project provided a dataset that is very useful in addressing data limitation in developing countries (see Dinar et al., 2008). The empirical estimation for this study is based on this rich dataset that has not been fully utilised in country and regional studies for the GEF/WB/CEEPA African climate and agriculture project. The dataset contains detailed farm information across agro-climatic zones and farming systems in eleven Africa countries and provides an important source of information for assessing the effects of climate change on farm performance. In addition, the data contains useful information on farmer perceptions on changes in climate, and various farm-level adaptations they have made in response to changes in climate (e.g. planting different crops, changing planting and harvesting dates, changing livestock practices and using irrigation technologies).

Another limiting factor of the *cross-sectional* approach is trying to control for spatial variations in other physical (e.g. variations in soils across landscape), economic (e.g. proximity to markets, labour and technology) and policy variables (e.g. trade restrictions, subsidies and taxes) (Mendelsohn & Dinar, 2005). Making policy recommendations from estimations that fail to take these factors into account will produce biased estimates of impacts of and adaptation to climate change. Policy recommendations made based on such results will be inaccurate and might lead to misdirection and mismanagement of limited resources (Mendelsohn & Dinar, 2005). This study does control for these other factors, in order to ensure improved accuracy of estimation results and policy recommendations based on the results. A detailed description is provided in the section that discusses the independent variables used in the estimation.

A further limiting factor of the *cross-sectional* approach is that estimations of climate change impacts on farm performance are based on incremental changes in crop prices. Estimates would be inaccurate if large and widespread changes in climate result in long-term sustained changes in crop prices. Changes in prices would determine the magnitude and direction of error (Schimmelpfenning et al., 1996).

The statistical and programming methods used in the *spatial analogue* approach assume that farmers and other agents make costless structural adjustments and adaptations. Adaptation is however associated with costs, for example, research and development costs associated with changes in technologies, as well as costs of farm-level adoption and possible physical and human capital investments (Adams, 1999; Adams et al., 1998a).

Another limitation of using *cross-sectional* evidence is that it represents at best a long-run equilibrium response. Reilly (1999) argues that the cross-sectional Ricardian method and other similar reduced form approaches fail to explicitly define/describe how one gets from point A (current climate and current production activities) to point B (new climate and new production activities). Darwin et al. (1995), as cited by Reilly (1999), attempted to provide more information on possible ways of adaptation by dividing the response to climate change into three options: (a) on farm changes, (b) in the market changes and (c) land use changes. Despite being artificial, these categories provide more insight on the ways farmers respond to changes in climate and adapt. Using these categories, Darwin et al. were able to show that farmers can adjust their decisions even without much market response and without moving agricultural production to completely new areas (Reilly, 1999).

3.1.3 Integrated assessment models

Integrated assessment models of climate change impacts predict a range of impacts and climate sensitivity, starting with greenhouse gas emissions to final impacts. Using projections of economic development over the next century, global warming integrated assessment models can make predictions of future greenhouse gas concentrations. Changes in greenhouse gas concentrations are expected to lead to increasing global temperatures and hence global warming. Changing global temperatures will have differential effects on patterns of climate change and climate sensitivity across climatic regions (Mendelsohn, 2000).

Future agricultural impacts are predicted based on projected changes in climate and climate sensitivity. Impacts from global warming are expected to be evident as the climate changes. Changes in temperature, precipitation and carbon dioxide concentrations are all expected to affect agricultural production (Mendelsohn, 2000). Studies that have used integrated assessment methods in estimating climate change impacts on agriculture include: the Egyptian study (Yates & Strzepek, 1998); the MINK study on Minnesota, Iowa, Nebraska and Kansas (Crosson & Rosenburg, 1993); the US agriculture study (Adams et al., 1990, 1995); and the world food trade study (Rosenweig & Parry, 1993).

3.1.4 Agro-ecological zone (AEZ) method

The agro-ecological zone (AEZ) model uses detailed information about climate and soil conditions, crops and technologies to measure climate sensitivity of simulated crop yields. The AEZ model relies heavily on natural science relationships and develops a detailed eco-physiological process model. The model predicts Land Utilisation Types (LUT) based on combinations of existing technology, soil and climate to determine which crops are suitable for each cell. The AEZ model can simulate the impacts of changes in temperature and precipitation on potential agricultural output and cropping patterns on a global scale (Güther, van Velthuizen, Shah & Naehtergaele, 2002; Mendelsohn, 2000).

The AEZ model can be used to assess the impact of various aspects of climate change on potential crop production over wide geographic areas, although it was not created to model climate change. An important strength of the AEZ model is the widespread coverage of developing countries, where little climate research has been done, and where data constraints may make the use of other methods difficult. The AEZ model can simulate the impacts of changing precipitation and cloud cover on potential crop production and to a lesser extent, the impacts of temperature changes. Another advantage of the AEZ model is that with full knowledge of the potential impacts of future technology and genetic strains on specific parameters, modelling of future climate sensitivities can be done based on detailed eco-physiological relationships (Güther et al., 2002; Mendelsohn, 2000).

The main disadvantage of this method is that it is not possible to predict final outcomes without explicitly modelling all relevant components. It is also difficult to build a general model that will predict actual yields across locations, even with relatively simple agronomic systems. To address this problem the AEZ method compares simulated yields against reported yields and substitutes field data where there are major differences (Güther et al., 2002; Mendelsohn, 2000).

3.2 Empirical studies assessing impacts of climate change on agriculture

3.2.1 Empirical studies based on structural approaches

Chang (2002) adapted the *structural* approach to incorporate the yield effects of climate change directly into a sector-wide economic model with various levels of farm adaptation possibilities. He used a two-step procedure to estimate the impacts of climate change on the agricultural sector of Taiwan: (a) yield regression models were used to investigate the impact of climate change on sixty crops; and (b) an agricultural sector model was used to evaluate the impacts of crop yield changes (based on estimates from the regression models) on agricultural production, land use, welfare distribution, as well as the potential of agricultural adaptation in response to climate change.

The regression models for crop yields integrated the physical and social determinants of yield. Welfare results showed that an increase in temperature is not stressful for Taiwan's farmers, and may even be beneficial when adaptation is taken into account. However, the upward shift in rainfall intensity was found to have potentially devastating impacts on farmers' welfare. The welfare effects were shown to be different for producers and consumers, with producers expected to benefit from changes in climate. Variations in climate were shown to be significant in influencing crop yields and Chang (2002) highlighted the importance of incorporating these variations in impact assessment studies in sub-tropical and tropical regions.

In another study, the impact of climate change was estimated using an integrated modelling approach that included a crop simulation model and an applied general equilibrium model (Kumar & Parikh, 2001). The crop simulation model was used to estimate the impacts of changing climatic conditions on crop yields of wheat and rice. To estimate the economic and welfare implications of climate change, the authors integrated the predicted yield changes from the crop simulation model as supply shocks into an applied general equilibrium model (Agriculture, Growth and Redistribution of Income Model - AGRIM). Results from the study show that predicted changes in climate are expected to adversely affect crop yields and agricultural production. In addition, climate change will negatively affect welfare and the poor will be most affected.

Schneider et al. (2000) used an Erosion Productivity Impact Calculator (EPIC) crop model to examine the effects of natural variability on how farmers in the US Great Plains respond to changes in climate. The EPIC model, driven by a $2\times CO_2$ regional climate model scenario, was used to calculate changes in crop yields for three groups of farmers in terms of their adaptation practices: no adaptation; perfect adaptation; and 20-year lagged adaptation. The latter group was included to mimic the masking effects of natural variability on the ability of farmers to notice changes in climate. Adaptation options tested in the EPIC crop model included: varying planting dates, changing crop varieties, and regulating crop growth period. The results show that warmer temperatures enabled farmers to plant early in the spring so that critical reproductive periods avoided the risk of damage from high heat levels in mid-summer. In addition, with a longer growing period, farmers were able to grow long maturity varieties with longer grain filling periods and hence higher yields. The results from the EPIC crop model show that adaptation improves crop yields relative to the no adaptation case. These results support findings from other studies that adaptation serves to reduce potential negative effects from changes in climate.

Iglesias et al. (1999) estimated the impacts of climate change across spatial scales (seven sites) in major wheat growing regions in Spain, using CERES-Wheat, a dynamic process crop growth model. Using results from the crop model, the authors examined response of yield to changes in irrigation water, temperature, precipitation and CO_2 concentration. Results from the spatial analysis showed similar results to the CERES-Wheat crop growth model. An important finding from the empirical results is that crop water (both precipitation and irrigation) and temperature during the growing season significantly affect variability in simulated crop yields.

Yates and Strzepek (1998) assessed the integrated impacts of climate change on the Egyptian agricultural sector using a quadratic programming sector model. These authors used a forward-linkage sector approach to impact assessment that applied two economic models: (a) an Egyptian specific CGE sub-model (the Standard National Model-SNM) of the Basic Linked System to estimate impacts of climate change on crop yields, crop water use, water supply and land resources; and (b) results from the SNM were entered as inputs into the Egyptian Agricultural Sector Model (EASM) for assessing climate change impacts.

Simulations of the partial equilibrium, quadratic programming EASM model capture changes in water, land, crop, livestock, labour and other components at the sub-national scale. The results show that consumers and producers will be affected differently by changes in climate, with producers likely to experience more losses. Another important finding is that climate change impacts, coupled with changes in world markets as well as local and regional biophysical factors, would be more harmful to smaller food importing countries. Based on these findings, agricultural production will be vulnerable to changes in climate in African countries, most of which are net small food importers. This will impact negatively on national and regional food security efforts to support the fast growing populations.

The findings by Yates and Strzepek (1998) on climate change impacts on Egyptian farmers differ from those of Chang (2002) in terms of Taiwanese farmers. Although both studies used the structural approach and different methods, the latter study showed that farmers in Taiwan are likely to benefit from increases in temperature, while in Egypt (the former study), farmers will suffer from further warming. A possible explanation for this difference is the fact that Taiwan is already wetter and has cooler conditions compared to Egypt. Furthermore, Egypt is entirely dependent on irrigated crops because the climate is too dry to support crops without irrigation (Kurukulasuriya et al., 2006).

Kaiser et al. (1993) examined the potential economic and agronomic impacts of climate change and farm-level adaptation using three models of the relevant climatic, agronomic and economic processes based on a case study of a grain farm in southern Minnesota in the United States. The study simulated the sensitivity of crop yields, crop mix and farm revenue to climate change, based on a number of scenarios with different severity. The study simulated climate change in a dynamic way rather than the comparative static way of comparing a ‘doubled CO_2’ induced climate change with the current climate, which is important for analysing farm-level adaptations. The empirical estimation of climate change impacts included variability in climate variables as a way of capturing impact on agriculture performance.

The results by Kaiser et al (1993) show that climate change will affect growth and yield of agricultural crops, as well as length and timing of growing periods, all of which will contribute to reduction in the productivity of the agricultural sector of the southern Minnesota of the United States. The study also shows that farmers will adjust their management practices to reflect changes in the agricultural ecosystem due to climate change and other factors. The ‘tactical’ farm-level adaptation decisions included: changing crop varieties, changing planting and harvesting dates (to take advantage of a longer growing season due to climate change) and crop mix. These adaptation measures, even if they lag behind the evolution of climate change, were shown to be effective in helping reduce the negative effects of climate change on agriculture. Adaptation is therefore important in helping farmers to reduce the potential impacts of climate change, while at the same time achieving their farming goals (e.g. food security and higher incomes).

Empirical agronomic studies in Zimbabwe have revealed that climate change has a negative effect on the agricultural performance of major crops. Muchena (1994) and

Magadza (1994) showed that a 2º C rise in ambient temperature and a 4º C rise in mean temperature significantly lowered yields. In another study, Makadho (1996) assessed the potential effects of climate change on corn, using a Global Circulation Model (GCM) and the dynamic crop growth model CERES-Maize. The results indicated that maize production is expected to decrease significantly by approximately 11–17%, under conditions of both irrigation and non-irrigation. The above studies found that a reduced crop growth period due to increases in temperature, particularly during the grain filling and ripening stages, is the main factor contributing to decreased yields.

Schulze, Kiker and Kunz (1993), and Du Toit, Prinsloo, Durand and Kiker (2002) applied a CERES-Maize simulation model to estimate the impacts of climate change on maize production in South Africa. The former study considered the effects of increasing carbon dioxide concentrations and subsequent increases in temperature and did not consider changes in precipitation due to uncertainty of predicted changes. The results show that potential maize production increased with varied intensity across geographic areas. Increases in temperature and carbon dioxide strongly increased yields in low yielding areas (below 4 tonnes per hectare), and had less impact in high yielding areas (at least 8 tonnes per hectare). The latter study showed that seasonal changes in precipitation strongly affected maize yields. Simulation results showed that under current management practices, some parts of South Africa, such as the marginal western region, may become unsuitable for maize production, whereas the eastern region may remain unchanged or increase production.

New research and knowledge since the Third Assessment Report (TAR) show that many studies have estimated climate change impacts on agriculture (e.g. agricultural productivity, food security etc) at regional and global scales (IPCC, 2007). Examples include: Fischer and others (2002; 2005); Parry (2004); Parry et al., (2005); and Tubiello & Fischer (2006). The methodologies applied were based on agro-ecological zone data and/or dynamic crop models and socio-economic models. These studies first estimate climate change impacts on agronomic production potentials, followed by estimations of the effects on food supply, demand and consumption at regional to global levels that take into account different socio-economic future scenarios (typically SRES) (IPCC, 2007).

Further highlights of new research and knowledge since the TAR confirm that developing countries will suffer from potentially large negative impacts, while developed regions will experience small changes (IPCC, 2007). The studies cited in the IPCC (2007) report show that the aggregate impacts on world food production would be small based on the projected impacts of climate change in developing and developed countries (Fisher et al. 2002, 2005; Parry, 2004; Parry et al., 2005). However, contrasting findings from regional studies (e.g. Reilly et al. 2003; Olesen & Bindi, 2002) cited by the IPCC report show that the impacts of climate change could be significantly negative in key production regions even in developed countries.

Furthermore, the IPPC (2007) reports that climate change (especially increased frequency of extreme events) is projected to have adverse impacts on long-term agricultural yields (e.g. Antle, Capalbo, Elliott & Paustian, 2004; Porter & Semenov, 2005). These losses are expected crop damages at specific developmental stages (e.g. temperature thresholds during flowering) and reduced efficiency of farm inputs as timing of field applications becomes more difficult.

Despite some limitations and uncertainties associated with these studies, they are reported to provide fairly robust findings for policy formulation. The projections from the studies show that the number of people at risk of hunger is likely to increase with climate change, compared to reference scenarios with no climate change. For example, climate change is projected to increase the number of undernourished people in 2080 by 5-26% relative to the no climate change case, or by between 5 and 10 million people (SRES B1) and 120-170 million people (SRES A2) (Fischer et al. 2002, 2005).

3.2.2 Empirical studies based on the cross-sectional (Ricardian) approach

Polsky (2004) explored the variations in human-environment relationships associated with climate change in the US Great Plains from 1969 to 1992 using spatial Ricardian econometric models. The study included effects of spatial and temporal scales in the estimation of variations in human-environment interactions. The estimation results show that climate sensitivities are significantly influenced by spatial effects such as extra-local communication processes and proximity to and regulation of irrigation water. These results indicate the importance of accounting for spatial and temporal scales in estimating the impacts of climate change on agriculture.

Mendelsohn and Dinar (2003) explored the interaction between climate, water and agriculture. The study tested the impacts of surface water withdrawal on the variation of farm values across the United States, as well as the impact of adding these variables to the standard Ricardian model on climate sensitivity of agriculture. The results of the study show that the value of irrigated cropland is not sensitive to precipitation, but increases in value with temperature. A key recommendation from the study is that irrigation is an important potential adaptation measure for agriculture.

Mendelsohn et al. (1996) measured the economic impact of climate change on land prices. An important contribution of the study is that it developed the Ricardian approach for measuring the economic impacts of climate change on agriculture. The study was based on cross-sectional data on climate, farmland prices and other economic and geographical data, for almost 3000 counties in the United States. The results show that seasonal temperatures in all seasons except autumn reduced average farm values, while more precipitation outside autumn increased farm values. Another key result from the study was that estimated impacts of global warming on US agriculture were significantly lower than estimates from the traditional production-function approach.

Polsky and Easterling (2001) modelled the influences of factors from multiple spatial scales on climate sensitivity of the Ricardian estimates in the US Great Plains. The study extended the Ricardian approach to take into account social factors at large scales that condition farm-level responses to changes in climate. An important contribution of the study is that it included the large-scale social context missing from most impact assessment studies. The Ricardian climate sensitivity results show that social factors associated with large scale agro-climatic zones significantly affect local level climate sensitivity. The study also showed that farmers and institutions in highly variable climates have adapted and are more resistant, compared to those in relatively stable climates. An important recommendation from this study is the necessity to investigate the precise forms of local and other adaptations and their effects on sustainability of the agricultural system.

Gbetibouo and Hassan (2005) applied the Ricardian approach to measure the impact of climate change on South Africa’s field crops. The study regressed farm net revenue on climate, soil and other socio-economic variables based on agricultural data for seven field crops (maize, wheat, sorghum, sugarcane, groundnuts, sunflowers and soy beans), across 300 districts in South Africa. The results of the study show that production of field crops is sensitive to marginal changes in temperature compared to changes in precipitation. Increases in temperature were shown to be beneficial as they increased net farm revenues, while reductions in precipitation were shown to be detrimental to crop production as they led to reductions in net farm revenues. Potential adaptation options identified in the study to respond to further changes in climate include: shifts in crop calendars and growing seasons, and switching between crops to the extent of the possible complete disappearance of some field crops in some regions.

In another study, Deressa, Hassan and Poonyth (2005) used a Ricardian model to estimate climate change impacts on sugarcane production in South Africa. The study was based on a time series data set for the period 1977-1998. The results show that predicted changes in temperature strongly affected net revenue from sugarcane production compared to changes in precipitation.

Kurukulasuriya et al. (2006) used a Ricardian method to estimate the likely impacts of climate change on net farm revenues in African agriculture using farm-level data collected for the GEF/WB African climate project coordinated by CEEPA. The study measured total net farm revenue as the sum of three main activities: (a) dryland crops that rely on natural rainfall; (b) irrigated crops that depend at least on some irrigated water; and (c) livestock. Net farm revenues for both dryland and irrigated crops were measured per hectare as the area planted could be accurately measured. This was difficult for the livestock which is based largely on common grazing lands and had to be measured on a per farm basis. The study estimated separately the impacts on dryland crops, irrigated crops and livestock. The results show that dryland crops and livestock will experience more adverse impacts from increases in temperature and decreases in precipitation, compared to irrigated crops which will benefit from warming in terms of irrigation. Using the same approach and dataset, Kurukulasuriya and Mendelsohn (2007a) also found that dryland crops suffered more from increased warming compared to irrigated crops. In both studies irrigation offered an important adaptation option for buffering the negative impacts associated with warming.

Seo and Mendelsohn (2007a) used the cross-sectional Ricardian approach to estimate the impacts of climate change on large and small livestock farms. The results show that large specialised farms were more vulnerable to changes in temperature and precipitation, compared to small farms. The reason for this is that large farms tend to rely on commercial beef and other species that are not tolerant to high temperatures, compared to small farms that have more traditional livestock species such as goats and sheep that can do well in dry and warm environments.

Studies using the Ricardian approach in southern African countries also found that dryland crops will be more affected by changes in temperature and precipitation (Mano & Nhemachena (2007) in Zimbabwe; Benhin (2006) in South Africa). Jain (2007) found that crop production is adversely affected by increases in temperature in November and December and reduction of rainfall in January and February, which coincide with the crop maturing stage. The above studies identified the following important adaptation measures in the region: use of different crop varieties, crop diversification, different planting dates (given the high perception that the timing of rains is changing), diversifying from farming to non–farming activities, increased use of irrigation, increased use of water and soil conservation techniques.

A study by Molua and Lambi (2007) in West Africa found that agriculture in Cameroon is adversely affected by decreases in precipitation and increases in temperature. Future climate scenarios predicted declines in farm net revenues due to increased warming and decreased precipitation. In Senegal, small rain-fed farms were found to be highly vulnerable to changes in climate variables (temperature and precipitation) (Sene, Diop & Dieng, 2006). The study also identified some adaptation strategies being used by farmers, such as crop diversification and growing short season crops.

In East Africa, Kabubo-Mariara and Karanga (2007) applied the Ricardian approach to measure the economic impacts of climate change in Kenya. The results show that changes in temperature are harmful to agricultural productivity. Predicted future impacts indicate that agriculture production will be adversely affected by expected warming in temperatures. The study also identified some important adaptation strategies being used by farmers to help reduce the negative impacts of climate change: crop diversification, water conservation, irrigation and shading. Poverty and lack of information were identified as the major limiting factors in using different adaptation measures. Other East African studies by Deressa (2007) in Ethiopia, and Eid, El-Marsafawy and Ouda (2007) in Egypt, show that increases in temperature and decreases in precipitation are generally detrimental to agricultural production in Ethiopia. Net farm revenues were reported to fall due to increases in temperatures and decreases in precipitation.

3.3 Summary

The various approaches and methods that have been used to measure economic impacts of climate change on agriculture were discussed in this chapter, as well as empirical studies that applied the reviewed approaches. Two main approaches have been used in the literature to measure climate change impacts on agriculture: (a) *structural modelling* of crop and farmer response, which combines crop agronomic response with economic/ farmer management decisions and practices; and (b) *spatial analogue models* that measure observed spatial differences in agricultural production. Other impact assessment methods that have been used are the integrated impact assessment method and the agro-ecological zone method.

The review of empirical studies shows that the various approaches have been applied at different levels (district, national and regional). For example, the structural approach has been applied at the farm-level (e.g. Kaiser et al., 1993; Muchena, 1994; Magadza, 1994); the national level (e.g. Adams et al., 1990, 1995, 1998b) and the regional level (e.g. Easterling et al., 1993). Similarly the Ricardian approach has been applied at different levels: regional (e.g. Kurukulasuriya et al., 2006; Kurukulasuriya & Mendelsohn, 2007a; Seo & Mendelsohn, 2007a), and national and farm level (e.g. Dinar et al., 2008; Gbetibouo & Hassan, 2005).

The results of the various studies exhibit similar findings on the general impacts of temperature and precipitation. For example, studies based on structural approaches in Zimbabwe (e.g. Muchena, 1994; Magadza, 1994) show that warming and drying will result in significantly low yields for maize. Similarly, Mano and Nhemachena (2007), using a cross-sectional Ricardian approach, found that net farm revenues will be adversely affected by further warming and decreases in precipitation. However, the magnitude of the estimated impacts from studies using different approaches varies, possibly due to the underlying assumptions of the studies. For example, structural approaches tend to overestimate the impacts of climate change, as they do not include adaptation mechanisms, as opposed to the cross-sectional Ricardian approach which does.

This study applies the Ricardian approach to measure the impact of changes in climate attributes (rainfall and temperature levels) on net revenue from crop and livestock farming, controlling for other production factors. The justification of this choice over other models is that it helps to achieve the stated objectives of this study, and has several advantages over other models (as discussed above), such as the incorporation of farmer adaptations. Furthermore, measuring economic impacts of climate change in African agriculture is limited by the scarcity of reliable data. The available data from the GEF/WB/CEEPA African Climate and Agriculture Project provided a very useful cross-sectional dataset that addresses typical limitations in developing countries, for estimation of the Ricardian model (see Dinar et al., 2008).

Recent efforts have measured the impacts of climate change in Africa. Other studies based on the Global Environmental Facility (GEF) African Climate Project estimated the economic impacts of climate change on African agriculture (Dinar et al., 2008), using district level data. Before the GEF/WB/CEEPA African climate study, other studies applied the same approach: Gbetibouo and Hassan (2005) on South African field crops and Deressa et al. (2005) on sugarcane production in South Africa.

However, these studies analysed impacts on dryland crops, irrigated crops and livestock separately. This represents an important limitation of the cited studies, since the choice between crop and livestock production, or the combination of both (mixed systems), is an endogenous decision made by agricultural producers in response to varying climates and other circumstances. The decision as to what to produce is motivated by climate and other determinants and is accordingly an important adaptation mechanism of farmers. It is therefore considered appropriate not to separate choices and responses of crop and livestock farmers, but to analyse them jointly and to compare adaptive capacities of such choices (the degree of vulnerability to climate change). This is of special importance for Africa, where the majority of poor small-scale farmers practise mixed crop–livestock agriculture and few depend on livestock only.

This study therefore measures the aggregate impact of climate change on income from all agricultural production systems (crop, livestock and mixed) in Africa and predicts future impacts under various climate scenarios. In addition to estimating impacts on mixed crop–livestock farms, the study also measures and compares impacts on specialised crop and livestock farms. The results are contrasted with findings of other regional studies using the same data but generating different climate response functions for crop and livestock farming separately (Kurukulasuriya et al., 2007; Kurukulasuriya & Mendelsohn, 2007a; Seo & Mendelsohn, 2007a). In this study, the responses of different production systems are analysed under irrigation and dryland conditions.

Chapter 4

Measuring the economic impact of climate change on African agricultural production systems

4.0 Introduction

This chapter reports on how this study measured the economic impacts of climate change on agriculture in Africa. The specification of the empirical model, the model variables, data sources and econometric procedures are presented in the following sections.

4.1 Specification of the empirical Ricardian model for measuring economic impacts of climate change

This study applied the Ricardian approach to assist in measuring the economic impacts of climate variables (temperature and precipitation) on African agricultural production systems (see section 3.3 for justification in choosing the Ricardian model). In the Ricardian model, net revenue or capitalised net revenue (land value (*V*)) and not yield, accounts for the costs and benefits of adaptation. Direct measurement of farm prices or revenues allows the Ricardian approach to account for the direct impacts of climate on yields of different crops, as well as the indirect substitution of different activities and other potential adaptations to different climates (Mendelsohn et al., 1994). As in other Ricardian studies applied elsewhere, a number of variables – climatic, soil, socio-economic and hydrological – were examined to determine the effects of climate on farmland. Following Mendelsohn and Dinar (2003), the farmland value (*V*) reflects the present value of future net productivity, captured by the following equation:

$$V = \int P_{LE} e^{\delta t} dt = \int \left[\sum P_i Q_i \left(X, F, Z, H, G \right) - \sum RX \right] e^{\delta t} dt \qquad (4.1)$$

where P_{LE} is the net revenue per hectare, P_i is the market price of crop *i*, Q_i is output of crop *i*, F is a vector of climate variables, Z is a set of soil variables, H is a set of hydrological variables, G is a set of economic variables, X is a vector of purchased input prices, t is time, and δ is the discount rate. The Ricardian approach assumes that the farmer maximises net revenue by choosing inputs (X) given the characteristics of the farm and market prices. The resulting net revenue function observes the loci of maximum profits subject to a set of climate, soil and economic factors, and the Ricardian model is a reduced form hedonic price model of the observed loci of profits (Kurukulasuriya & Mendelsohn 2007a; Kurukulasuriya et al., 2006).

The standard Ricardian model relies on a quadratic formulation of climatic variables:

$$V = \beta_0 + \beta_1 F + \beta_2 F^2 + \beta_3 Z + \beta_4 G + \beta_5 \log(H) + u \qquad (4.2)$$

where u is the error term.

To capture the non-linear relationship between net farm revenues and climate variables, the estimation includes both the linear and quadratic terms for the climate variables, F (temperature and precipitation) (Mendelsohn & Dinar, 2003; Mendelsohn et al., 1994, 1996). A negative quadratic term reflects an inverted U-shaped relationship between net farm revenue and the climate variable and a positive quadratic term means a U-shaped relationship (Mendelsohn & Dinar, 2003; Mendelsohn et al., 1994, 1996). Net farm revenue is expected to have an inverted U-shaped relationship with temperature based on agronomic research and previous cross-sectional studies. Following Kurukulasuriya et al. (2006), water flow is introduced in a log form because the benefits from flow diminish as flow increases. Based on other Ricardian studies (see Dinar et al., 2008; Kurukulasuriya et al., 2006), water flow is used as a proxy for the hydrological variable (*H*). Water flow is included because it is particularly important for irrigation (Mendelsohn & Dinar 2003).

Following Kurukulasuriya et al. (2006) and Mendelsohn and Dinar (2003), the marginal impact of a climate variable (f_i) on net farm revenue evaluated at the mean of that variable is:

$$E\left[\frac{dV}{df_i}\right] = \beta_{1,i} + 2 * \beta_{2,i} * E\left[f_i\right] \tag{4.3}$$

and because flow is expressed in logarithmic terms, the marginal impact of flow (*H*) on net farm revenue is given by:

$$E\left[\frac{dV}{dH}\right] = \frac{\beta_5}{H} \tag{4.4}$$

Again following Kurukulasuriya et al. (2006), the above marginal effects can be evaluated at any level of climate or flow, but the focus is on showing effects at mean climate levels for Africa. Furthermore, the linear formulation of the model assumes that these marginal effects (equations (4.3) and (4.4)) are independent of future technological change. Despite this assumption, future technological change could make crops (or other farming activities) more susceptible to temperature or precipitation changes — or less so (Kurukulasuriya et al., 2006).

4.2 The data and model variables

This study is based on the cross-section data obtained from the Global Environment Facility/World Bank (GEF/WB)-CEEPA funded Climate Change and African Agriculture Project: *Climate, Water and Agriculture: Impacts on and Adaptations of Agro-ecological Systems in Africa.* The study involved eleven African countries: Burkina Faso; Cameroon; Egypt; Ethiopia; Ghana; Kenya; Niger; Senegal; South Africa; Zambia and Zimbabwe (Figure 4.1).

Figure 4.1: Map of study countries

The selected countries cover all the eight agro-ecological zones in Africa and farming systems in the continent (Dinar et al., 2008). Within each selected country, districts were selected to further increase the representation across climatic zones. The sampling process provided good coverage across climatic zones and vegetation types of all countries in the continent allowing for extrapolation of the outcomes of the study across the whole continent. For more information on the survey method and the data collected see Dinar et al. (2008) and Kurukulasuriya et al. (2006).

The surveys were conducted in 2002–04 of randomly selected farms (seven countries were surveyed in the 2002–03 season and four countries were added in 2003–04). Between 30 and 50 districts were sampled in each country. Sampling was clustered in villages to reduce the cost of administering the survey (see Kurukulasuriya et al., 2006). Over 9000 household surveys were conducted in the study and after data cleaning, about 8000 surveys were found to be useable. It is important to note that none of the farmers interviewed kept livestock only. However, we attempted to separate those specialising in livestock production from those practising mixed crop–livestock farming, as discussed below (see categorisation of farm types in the entire sample (Table 4.2) and the accompanying discussion).

Due to lack of African data on land rents, the study used total net farm revenue as the measure of farm performance (similar to the approach used by Kurukulasuriya et al., 2006). Total net farm revenue is defined as the sum of net revenues from three main farming activities: (a) dryland crops, (b) irrigated crops, and (c) livestock[6]. Farm net revenue (*R*) is assumed to reflect the present value of future net productivity and costs of individual crops and livestock. For this study, crop net revenue is defined as gross revenue less costs of fertilizer and pesticide, hired labour (valued at the median market wage rate), transport, packaging and marketing, storage and post harvest losses. Livestock net revenue is defined as gross revenue from livestock sales less costs of livestock production.

Dryland crops rely only on rainfall that falls on the farm, while irrigated crops rely on at least some irrigated water (from surface flows or ground water). Livestock in Africa depend largely on grazing on natural lands or pasture. The amount of land that was planted could be accurately measured for the crop revenues to estimate net revenue per hectare. However, the same could not be done for livestock revenues, since most African

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[6] We considered impacts of climate change on two main datasets, one including negative net revenues up to -US$200 and another set with only positive net revenues. The results of the two samples were not all that different and the analyses in this study are based on the sample with positive net revenues.

farmers rely on common land for livestock grazing, making it difficult to determine how much land was used (Kurukulasuriya et al., 2006).

Studies based on the Global Environmental Facility (GEF) African Climate Project estimated the economic impacts of climate change on African agriculture (e.g. Dinar et al., 2008). These studies however, analysed impacts on dryland crops, irrigated crops and livestock separately. This is a significant limitation since the choice between crop and livestock production, or their combination (mixed systems), must be considered an endogenous decision made by agricultural producers in response to varying climates and other circumstances. The decision as to what to produce and how to produce it is accordingly an important adaptation mechanism in the face of changing climate and other ecological and economic circumstances. This is of special importance for Africa, where the majority of poor small-scale farmers practise mixed crop–livestock agriculture and few depend on crops or livestock only.

This study therefore measures the aggregate impact of climate change on income from all agricultural production systems (crop, livestock and mixed) in Africa and predicts future impacts under various climate scenarios. The results are contrasted with findings of other regional studies using the same data but generating different climate response functions for crop and livestock farming separately (Kurukulasuriya et al., 2006; Kurukulasuriya & Mendelsohn, 2007a; Seo & Mendelsohn, 2007a).

The Ricardian approach is traditionally based on analysing net revenue or land value per hectare. As most farmers in Africa graze livestock on open access communal land it is very difficult to measure the amount of land farmers allocate to livestock production. Therefore, since this study combined net revenue for both crop and livestock production, we could not use net revenue per hectare and instead used net revenue per farm, thus making the unit of analysis in this study the farm.

The study relied on long-term average climate (normals) for districts in Africa gathered from two sources (see Dinar et al., 2008; Kurukulasuriya et al., 2006 for details). Satellite data on temperature was measured by a Special Sensor Microwave Imager (SSMI) on

U.S. Department of Defence satellites (Basist et al., 2001) for 1988 to 2003. The SSMI detects microwaves through clouds and estimates surface temperature (Weng & Grody, 1998). The satellites conduct daily overpasses at 6 a.m. and 6 p.m. across the globe. The precipitation data come from the Africa Rainfall and Temperature Evaluation System (World Bank, 2003). The data was created by the Climate Prediction Centre of the U.S. National Oceanic and Atmospheric Administration based on ground station measurements of precipitation for 1977 to 2000. Thus, the temperature and precipitation data cover slightly different periods. This discrepancy might be a problem for measuring variance or higher moments of the climate distribution, but it should not affect the use of the mean of the distribution (Kurukulasuriya et al., 2006).

Soil data from the Food and Agriculture Organization (FAO, 2003) containing information about the major and minor soils in each location, as well as slope and texture, were utilised in this study. Data on hydrological variables (e.g. flow and runoff for each district) were obtained from Strzepek and McCluskey (2007).

Table 4.1 shows the distribution of useable surveys, net revenues and climate variables by country. Table 4.2 presents the categorisation of farm types in the entire sample. The tables also present the distribution of dryland and irrigated farms in each country and farm type. The analyses in this study distinguish between the impacts of climate change on these two main farm types. This helps us assess the importance of irrigation in responding to changes in climate.

The study considered farms with only crops and livestock as specialised. None of the farmers interviewed kept livestock only. However, the study attempted to separate those specialising in livestock production from those practising mixed crop–livestock farming. Specialised livestock farmers were identified as those with a very small share of their total land area under crops and with relatively large numbers of head of cattle, goats or sheep. The share of income from livestock production in the total income was also considered, with a very high share implying that the farm specialised in livestock production. Based on this classification, only 1% of the farms were classified as specialised livestock production. All of these specialised livestock farms were under dryland farming and none had irrigation.

Specialised crop production was defined as farms with crops only and no livestock, as well as those with small livestock numbers such as two sheep or a few chickens. Mixed crop–livestock farms were defined as farms were neither of the two production types clearly dominated enough to be identified as specialised.

Table 4.1: Summary statistics of the survey sample

Country	Useable surveys			Temperature and Precipitation Normals (sample means)							
	Dryland	Irrigated	Total	Winter		Spring		Summer		Fall	
				Temp	Precip	Temp	Precip	Temp	Precip	Temp	Precip
Burkina Faso	765	94	859	26.1	2.4	30	14.9	29.9	110.8	28.3	129.1
Cameroon	583	91	674	24.2	57.4	25.9	97.4	24.2	180.5	24.3	221.9
Egypt	0	495	495	16.6	12.5	19.1	7.2	27.8	3.7	26.7	4.8
Ethiopia	170	491	661	20.9	19.4	22.1	48.4	22.7	127.5	19.4	120.3
Ghana	713	41	754	25.5	31.3	27.5	60.4	25.8	112.4	25.1	111.2
Kenya	547	78	625	22.1	86.8	22.8	104.8	20	89.5	21	65.4
Niger	560	125	685	24.5	0.7	29	3.1	31.8	64.8	29.6	71.5
Senegal	812	70	882	26.4	2.2	29.1	1.1	30.8	49.6	29.3	112.4
South Africa	73	48	121	13.9	35.2	17.8	62.9	22.2	96.7	20.9	76.2
Zambia	813	20	833	22.1	48.1	23.5	58	24.3	108.3	24.9	100.3
Zimbabwe	318	59	377	16.5	7.3	20.6	15.4	23.5	137.9	22	88.9
Total	5354	1612	6966	22.7	25.4	25.2	39.5	26.4	95.9	25.6	103.6

NB: Precipitation = (mm/mo) Normals (Sample Mean) and Temperature = (°C) Normals (Sample Mean)

Table 4.2: Characterisation of farm types

	Specialised crops	**Specialised livestock**	**Mixed crop–livestock**	**All farms**	**Average farm size (ha)**	**Net revenue ($)**
Total sample (% of row total)	21%	1%	78%	100% (6966)	26.44	1894.25
Irrigated (% of column total)	20%	0	24%	23% (1612)	33.25	3175.97
Dryland (% of column total)	80%	100%	76%	77% (5354)	24.40	1507.39
Average farm size (ha)	28.55	384.28	21.51		26.44	
Average Net revenue per farm ($)	1832.83	7107.60	1839.20	1894.25		1894.25

NB: Results are based on the positive net revenue sample

The economic impacts of climate change were estimated on each of the classified farming systems (mixed crop–livestock and specialised crops or livestock), as well as the total sample. The analyses presented in this study start with the impacts on all farms (the entire sample) and then each farming system is examined separately. Multiple regression models of net revenue were estimated across three samples for each farm type (dryland, irrigation and total sample).

The explanatory variables consist of seasonal climate variables, soils, water flow and socio-economic factors. The regression models estimate the impacts of these factors on farm net revenues. Rainfall and temperature are unevenly distributed in Africa between distinct wet and dry seasons. To capture the impacts of these seasonal variations in climate on net revenue, the empirical models included seasonal temperature and precipitation variables. Presentation of monthly temperatures and precipitation data in a Ricardian regression model is not self-evident and the correlation between adjacent months is too high to include every month (Kurukulasuriya & Mendelsohn, 2007a). The temperature and precipitation data were thus grouped into three-month average seasons winter, spring, summer, and fall. The seasons were adjusted for the fact that seasons in the southern hemisphere occur at exactly the opposite months of the year compared to the northern hemisphere (for more details see Kurukulasuriya & Mendelsohn, 2007a).

Altogether four soil types – jcMFU (calcaric fluvisols), lcU (chromic luvisols), lfCU (ferric luvisols), and qlCU (luvic arenosols) – were identified as significant in the empirical models. The arenosols are extensively developed and are usually high productivity soils. Fluvisols and luvisols were also identified as high productivity soils. The chromic luvisols were identified as unproductive soils. Some other soil types were unique to small areas and could therefore not be included in the analyses.

Other studies based on the same GEF/WB/CEEPA dataset found different results on the impacts of soils on net revenues. For example, Kurukulasuriya and Mendelsohn (2007a) found 12 soil types to be significant in the Africa sample for cropland regressions, while Kurukulasuriya et al. (2006) found only nine soil types to be significant for dryland regressions: six for irrigated regressions and eleven for livestock regressions. Seo and Mendelsohn (2007a) dropped all soil variables as they were found to be statistically insignificant.

The mean water flow variable (long run flow in m^3 across the continent) was included to determine the impacts of additional water sources on net farm revenue. The hydrological variable was obtained from the University of Colorado (IWMI/University of Colorado 2003). The hydrology team used a hydrological model for Africa to calculate flow and runoff for each district in the surveyed countries.

Socio-economic factors in the empirical model include household ownership of farm assets (farmland, tractors); household access to agricultural extension services; household size; and technology variables (household access to electricity; household access to tractors and irrigation technologies). Dummy variables for mixed crop–livestock and specialised crops were included. Regional dummies were included to control for regional differences across agro-ecosystems in Africa. These factors were selected based on literature on similar climate impact studies (see Kurukulasuriya & Mendelsohn, 2007a; Seo & Mendelsohn, 2007a; Mano & Nhemachena, 2007).

The explanatory variables included in this study have been shown to affect net farm revenue in many other African Ricardian models (Kurukulasuriya et al., 2006; Kurukulasuriya & Mendelsohn, 2007a; Mano & Nhemachena, 2007; Benhin, 2006). Table 4.3 presents a summary of the explanatory variables and their expected impacts on net farm revenues.

Table 4.3: Variables used in the empirical analysis and their expected effects

Variable Name	Values	Expected sign
Winter temperature	°C	±
Spring temperature	°C	±
Summer temperature	°C	±
Fall temperature	°C	±
Winter precipitation	mm/mo	±
Spring precipitation	mm/mo	±
Summer precipitation	mm/mo	±
Fall precipitation	mm/mo	±
Winter precipitation squared	squared °C	±
Spring precipitation squared	squared °C	±
Summer precipitation squared	squared °C	±
Fall precipitation squared	squared °C	±
Winter temperature squared	squared mm/mo	±
Spring temperature squared	squared mm/mo	±
Summer temperature squared	squared mm/mo	±
Fall temperature squared	squared mm/mo	±
Orthic Ferralsols (foFU)		±
Fluvisol (jcMFU)		±
Ferric Luvisols (lfU)		±
Ferric Luvisols (lfCU)		±
Cambic Arenosols (qc)		±
Luvic Arenosols (qlCU)		±
Chromic luvisols (lCU)		±
Farmland (ha)	ha	+
Mean water flow	m^3	+
Household has tractor (Yes/No)	1=yes and 0=no	+
Household access to extension (Yes/No)	1=yes and 0=no	+
Household access to electricity (Yes/No)	1=yes and 0=no	+
Household size (Num. of people)	Num. of people	+
Using irrigation (Yes/No)	1=yes and 0=no	+
Mixed crop–livestock (Yes/No)	1=yes and 0=no	+
Specialised crop (Yes/No)	1=yes and 0=no	±
North & East Africa (Yes/No)	1=yes and 0=no	±
Southern Africa (Yes/No)	1=yes and 0=no	±

Econometric estimation of empirical model parameters

Econometric analysis with cross-sectional data is usually associated with problems of heteroscedasticity and multicollinearity (Cameron & Trivedi, 2005; Green, 2003). Multicollinearity among explanatory variables can lead to imprecise parameter estimates. To explore potential multicollinearity among the explanatory variables, the correlation between continuous independent variables was calculated. The results of the correlation analysis indicate that climate variables were highly correlated. To address this problem, temperature and precipitation data were grouped into three-month average seasons: winter, spring, summer, and fall (see Kurukulasuriya & Mendelsohn, 2007a). These seasonal definitions provided the best fit with the data and reflected the mid-point for key rainy seasons in the sample.

An Ordinary Least Squares model was fitted and tested for multicollinearity using the variance inflation factor (VIF). The variance inflation factors of the final estimated variables were less than 10 which indicate that multicollinearity is not a serious problem in the reduced model. For dummy variables the chi-square test for independence was used to determine dependencies between variables. To address the possibilities of heteroscedacity in the model, a robust model was estimated that computes a robust variance estimator based on a variable list of equation-level scores and a covariance matrix (StataCorp, 2005).

4.3 Results and discussion

Table 4.4 presents results from the Ricardian regressions for the whole sample, mixed crop–livestock, specialised crop and specialised livestock samples. The impacts on dryland and irrigated farms were estimated for each farming system and the results are presented in Appendix 1A and 1B. The results show the effect of climate, soils, flow and socio-economic variables on net revenue per farm for each farm type. The results indicate that the explanatory variables have differential impacts on dryland, irrigated farms and the total sample across farm types. The effects of some soils, as well as household characteristics (e.g. age, gender and education of head) were found to be not significant and were therefore dropped from the analyses.

Table 4.4: Ricardian regression results

Variable Name	All farms	Mixed crop–livestock farms	Specialised crop farms	Specialised livestock farms
Winter temperature	-1.641***	-1.692***	-2.056***	
Spring temperature	1.255***	1.257***	1.277*	
Summer temperature	-0.824***	-0.426	-1.937***	7.116
Fall temperature	1.794***	0.797	4.143***	
Winter precipitation	0.036***	0.033***	0.036***	5.787*
Spring precipitation	-0.011**	-0.012*	-0.005	-5.721*
Summer precipitation	0.015***	0.024***	-0.003	-1.804*
Fall precipitation	-0.003	-0.012***	0.017***	3.254*
Winter precipitation squared	-0.000***	-0.000***	-0.000*	-0.054*
Spring precipitation squared	0.000*	0.000	0.000	0.079*
Summer precipitation squared	-0.000***	-0.000***	0.000	0.014*
Fall precipitation squared	0.000***	0.000***	-0.000	-0.011*
Winter temperature squared	0.019***	0.019***	0.027***	-0.838**
Spring temperature squared	-0.015***	-0.014***	-0.017*	0.549**
Summer temperature squared	0.005	-0.002	0.027***	-0.614*
Fall temperature squared	-0.018***	-0.002	-0.057***	0.726**
Orthic Ferralsols (foFU)	-0.278	-0.378	0.030	
Fluvisol (jcMFU)	0.443**	0.446**	0.582	
Ferric Luvisols (lfU)	-0.372**	-0.533***	-0.076	
Ferric Luvisols (lfCU)	0.488***	0.315**	1.096***	1.603
Cambic Arenosols (qc)	-0.111	-0.053	-0.617	0.311
Luvic Arenosols (qlCU)	0.730***	0.647***	1.352***	0.556
Chromic luvisols (lCU)	-0.469***	-0.495***	-2.033**	0.000
Farmland (ha)	0.643***	0.642***	0.693***	0.154
Mean water flow	0.010***	0.009***	-0.011***	-0.111*
Household has tractor (Yes/No)	0.331***	0.271***	0.395*	-1.089
Household access to extension (Yes/No)	0.169***	0.168***	0.177*	0.158
Household access to electricity (Yes/No)	0.333***	0.378***	0.150	-0.267
Household size (Num. of people)	0.183***	0.154***	0.283***	0.626
Using irrigation (Yes/No)	0.053	0.091	0.092	-3.280*
Mixed crop-livestock Yes/No)	0.447***			
Specialised crop (Yes/No)	0.455**			
North & East Africa (Yes/No)	-0.029	-0.007	0.180	-6.409
Southern Africa (Yes/No)	-2.011***	-1.846***	-2.025***	
Constant	-6.667	4.923	-23.161**	-272.491
R Square	0.5102	0.4537	0.6490	0.7343
N	5607	4317	1226	64

***; **; * significant at 1%, 5% and 10% level respectively

The models account for about 45% to 73% of the variability in net revenues from farm to farm. Note that a relatively high proportion of the variation in net revenue is not accounted for by the explanatory variables in the models. The important sources of error accounting for this unmeasured variation include omitted variables and misreporting of net revenue.

This same dataset was used to conduct parallel regional studies of climate change impacts on crops and livestock separately. Kurukulasuriya and Mendelsohn (2007a) analysed the economic impacts of climate change on African cropland, and Seo and Mendelsohn (2007a) studied the economic impacts of climate change on African livestock. As mentioned earlier, this study combined analyses of both crop and livestock systems. The results of these combined analyses are now compared with results from the earlier specialised studies.

The results show that most of the explanatory variables are statistically significant at 10 percent or lower and the signs on most variables are as expected except for a few, which are discussed below. Larger farm size appears to have a strong positive influence on net farm revenues across all farm types, suggesting that more land allows farmers to diversify crop and livestock enterprises per farm, leading to more income although per hectare value may be low. The previous studies found contrasting results of the impact of farm size on net revenue. For example, Kurukulasuriya and Mendelsohn (2007a) found that farm area reduces the value per hectare of farms at a decreasing rate, implying that they small farms are more productive on a per hectare basis. In contrast Seo and Mendelsohn (2007a) found that the dummy for large farms was insignificant, implying no difference in the net revenue per animal for small and big farms.

Larger families seem to be associated with higher net farm revenues across all farm types. This suggests that agriculture in Africa is more labour demanding. Better access to other farm assets, such as heavy machinery like tractors, appears to strongly and positively influence net farm revenues for all farms, mixed crop–livestock farms and specialised crop farms. These results suggest that capital, land and labour serve as important production factors in African agriculture. Attaining higher net farm revenues strongly depends on factor endowments (i.e. family size, land area and capital resources) at the disposal of farming households. Kurukulasuriya and Mendelsohn (2007a), Seo and Mendelsohn (2007a), and Kurukulasuriya et al. (2006) found similar positive effects of access to technology variables (electricity and heavy machinery) on net revenue. In terms of the impact of household size, Kurukulasuriya & Mendelsohn (2007a) and Kurukulasuriya et al. (2006) found similar positive effects. In contrast, Seo and Mendelsohn (2007a) found that large households tend to have lower livestock net revenues per farm.

Better access to agricultural extension services seems to have a strong positive influence on net farm revenue on all farms, mixed crop–livestock farms and specialised crop farms. The effect on net revenue from specialised livestock farms, though positive, is insignificant. Access to electricity is strongly associated with higher net farm revenue on all farms and mixed crop–livestock farms. Both mixed crop–livestock and specialised crop variables positively affect net farm revenues. Among the regional dummies, southern Africa appears to have a strong negative influence on net farm revenue. On the other hand, North and East Africa show negative or insignificant effects on all farm types except specialised crops. These results suggest that the climatic, soil and other conditions in the southern, east and north African regions are less favourable for highly productive agricultural production.

Water flow has a significant positive effect on the total sample and mixed crop–livestock farms. Kurukulasuriya and Mendelsohn (2007a) also found that water flow strongly influences net farm revenue, especially for irrigated farms. Using irrigation appears to positively influence net farm revenue for all farm types, except specialised livestock farms. The possible explanation is that during the dry season water flow provides water for livestock watering and irrigation systems.

The soils variables show that arenosols (qlCU), fluvisols (jcMFU) and ferric luvisols (lfCU) that are extensively developed and are usually high productive soils, appear to have a strong positive influence on net farm revenues across all farming systems. Net farm revenues increase in areas that exhibit these high productivity soils. On the other hand, soil types lcU (chromic luvisols) and lfU (ferric luvisols) that are unproductive show a strong negative influence on net farm revenues across all farming systems.

The seasonal climate variables show that climate effects vary across models and farm types. The coefficients of the linear and quadratic terms of climate variables are significant in some seasons, indicating a non-linear relationship between these variables and net revenue. Although a positive/negative sign of the quadratic term shows that the relationship between climate variables and net revenue is an inverted U-shaped/U-shaped respectively, the effect of quadratic seasonal climate variables on net revenue cannot be easily inferred, as both linear and quadratic terms influence net revenue.

To interpret the climate coefficients, marginal climate impacts at the mean temperature and precipitation were calculated for the all farm types and results from the dryland and irrigation farms shown in Appendix 1 (Table 4.5). In each case, the marginal effect of temperature and precipitation was evaluated at the mean for each sample. For example, the marginal effect of temperature on mixed crop–livestock farms was evaluated at the mean temperature of mixed crop–livestock farms, and the marginal effect of precipitation on specialised crop farms was evaluated at the mean precipitation for specialised crop farms. The results suggest that better watered regions (i.e. in all wetter seasons) strongly influence net farm revenues for all farms, mixed crop–livestock and specialised crops.

For example, a wetter summer season increases net revenue per farm by $99 and $93 per mm of monthly precipitation for mixed crop–livestock and specialised crop farms respectively. The effect is strongest for mixed crop–livestock farms, suggesting that more water allows farmers to diversify crop and livestock enterprises throughout the year. Kurukulasuriya and Mendelsohn (2007a) found similar results on marginal impacts of summer precipitation on crop revenue. Their study found that the marginal precipitation effects for dryland and irrigated farms are similar ($3.8/mm/mo for irrigated farms and $2.7/mm/mo for dryland) because irrigated farms are located in dry locations.

Warmer winter and spring appears to positively influence net farm revenues for all farms and mixed crop–livestock farms, especially for irrigated farms. Warming in summer tends to be associated with a strong negative influence on net farm revenues across all farming systems. The magnitudes of the marginal effects show that the negative effects are strongest for specialised farm types, compared to mixed crop–livestock farms, suggesting that the combined farming systems offers an important adaptation option for farmers. Also dryland farms are strongly affected compared to all farms and irrigated farms. Similar results were noted by Seo and Mendelsohn (2007a) who found that the income of small farms is stable over a range of temperatures, while that of large farms declines sharply as temperatures rise. Larger farms tend to be more specialised compared to small farms which tend to exhibit diverse farm enterprises.

In addition to marginal effects, climate elasticities (the percentage change in net revenue as a result of percentage change in climate variables) were computed. The elasticities are given in parentheses in Table 4.5. The temperature elasticities for dryland farms, as well as for specialised crop or livestock farms, are relatively higher compared to irrigated farms and mixed crop–livestock farms. Since irrigated farms and mixed crop–livestock farms are buffered from temperature changes as a result of irrigation and diversity of options respectively, it is expected that they are less sensitive to warming. Kurukulasuriya and Mendelsohn (2007a) and Seo and Mendelsohn (2007a) also found that warmer temperatures increase the net revenues of irrigated farms because the mean temperature of irrigated farms is relatively cool and thus irrigation buffers net revenues from temperature effects.

A marginal increase in precipitation increases net revenue for all farm types. The precipitation elasticity is relatively high for dryland farms in each farm type category and for specialised crop and livestock farms. Because mixed crop–livestock farms are more diverse in their enterprises and options, they are expected to be less sensitive to drying. Mixed crop–livestock enterprises can easily shift between crop and livestock options.

From an adaptation perspective, mixed crop–livestock farming becomes a good alternative compared to specialised crop or livestock farming.

An interesting observation from the results is that net revenue decreases with falling precipitation (in spring, summer and fall seasons) for specialised livestock farms. This is in contrast to findings from the regional Ricardian livestock analyses, in which Seo and Mendelsohn (2007a) found that net revenue increased with falling precipitation, as farmers shifted from livestock to crops, from forests to grasslands, and diseases became less prevalent. Note that while wet conditions are expected to improve quantity and quality of grazing pastures, they may also be associated with high levels of diseases that may reduce the gains from improved pastures. The sensitivity of dryland farms and specialised crop or livestock farms to warming and drying is relatively higher compared to irrigated farms.

Table 4.5: Marginal impacts and elasticities of climate variables on net revenue ($/farm)

Season	All farms		Mixed crop livestock farms		Specialised crop farms		Specialised livestock farms	
	Temperature	Precipitation	Temperature	Precipitation	Temperature	Precipitation	Temperature	Precipitation
Winter	154.20***	12.86***	132.11***	54.73***	-155.99**	32.67**		
	(2.24)	(0.10)	(1.52)	(0.09)	(-2.27)	(0.14)		
Spring	126.08***	-9.36**	-113.23***	84.12**	128.87	39.79		
	(1.29)	(-0.04)	(-0.73)	(0.04)	(1.40)	(0.02)		
Summer	-156.78***	29.53***	-104.62***	99.25**	-172.47**	92.94*		
	(-2.56)	(0.07)	(-0.27)	(0.10)	(-3.08)	(0.01)		
Fall	176.13***	10.49	121.55***	70.18*	192.08	58.93		
	(3.16)	(0.05)	(1.14)	(0.03)	(3.61)	(0.19)		
Dryland farms								
Winter	-85.34***	17.65**	139.18***	19.60***	-130.40*	36.85**	259.76**	56.08***
	(-2.04)	(0.11)	(2.30)	(0.10)	(-4.70)	(0.21)	(4.38)	(0.03)
Spring	122.31**	-14.36	-125.43***	-21.93**	135.62	-17.79**	193.49**	-39.18***
	(4.40)	(-0.10)	(-1.66)	(-0.09)	(2.08)	(-0.16)	(3.01)	(0.15)
Summer	-61.85***	103.53***	-97.55***	98.81***	-188.99**	29.21***	-195.11**	-78.19*
	(-3.34)	(0.13)	-0.18)	(0.14)	(-4.37)	(0.20)	(-0.36)	(-0.73)
Fall	137.66***	15.49*	-124.32***	-9.88**	162.97*	15.98*	262.44***	-52.47*
	(2.19)	(0.04)	(1.57)	(-0.02)	(3.30)	(0.13)	(1.42)	(0.07)
Irrigated farms								
Winter	59.62***	74.03***	168.31***	93.70**	41.12**	91.12**		
	(1.77)	(0.07)	(1.80)	(0.07)	(2.68)	(0.09)		
Spring	128.61***	57.29**	116.84**	69.08	233.16	49.38		
	(1.44)	(0.09)	(0.89)	(0.03)	(2.80)	(0.02)		
Summer	-40.55***	102.60***	-226.37***	112.19***	-55.20**	76.80*		
	(-2.58)	(0.20)	(-1.05)	(0.18)	(-1.69)	(0.08)		
Fall	347.28***	69.73**	340.18***	89.88**	210.37*	68.61		
	(1.52)	(0.03)	(1.41)	(0.01)	(0.51)	(0.22)		

Note: Values calculated at the mean of the sample using OLS coefficients from Table 4.4 and from Appendix 1 for dryland and irrigated farms. Numbers in parenthesis are elasticities.

***; **; * significant at 1%, 5% and 10% level respectively

To provide a more complete analysis of the impacts of climate, this study estimated climate response functions based on the regression results in Table 4.4 and Appendix 1. The net revenues of an average farm at different temperature and rainfall levels were plotted. Figures 4.1 to 4.8 below present the climate response functions for the entire sample (combining specialised crop, livestock and mixed farms), and each of the farming systems separately. The response functions show a hill-shaped response of net revenue to temperature and rainfall.

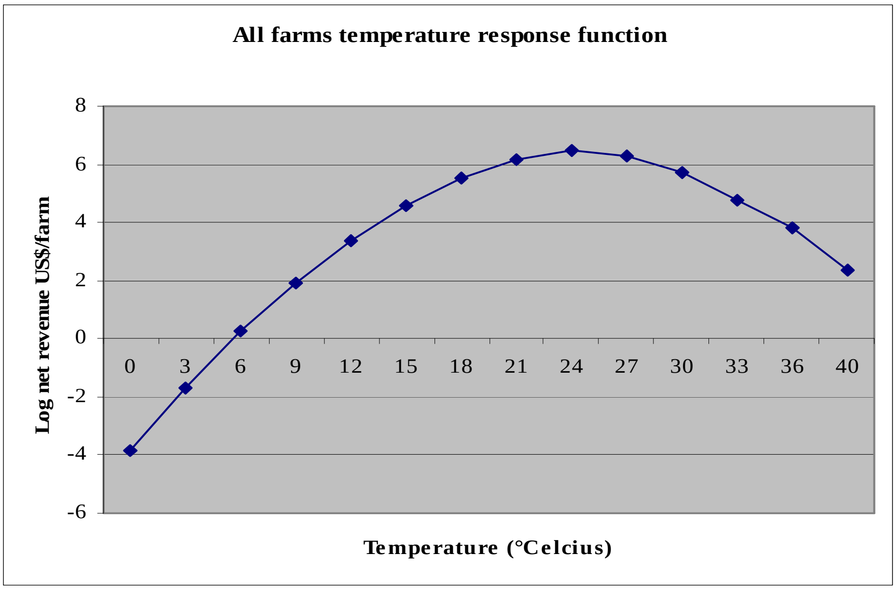

Figure 4.2: Temperature response function – all farms

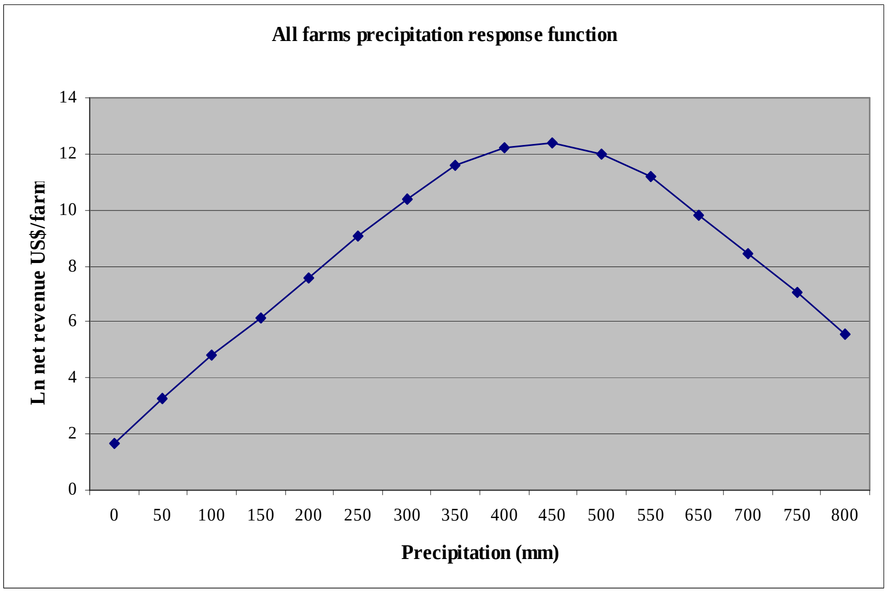

Figure 4.3: Precipitation response function – all farms

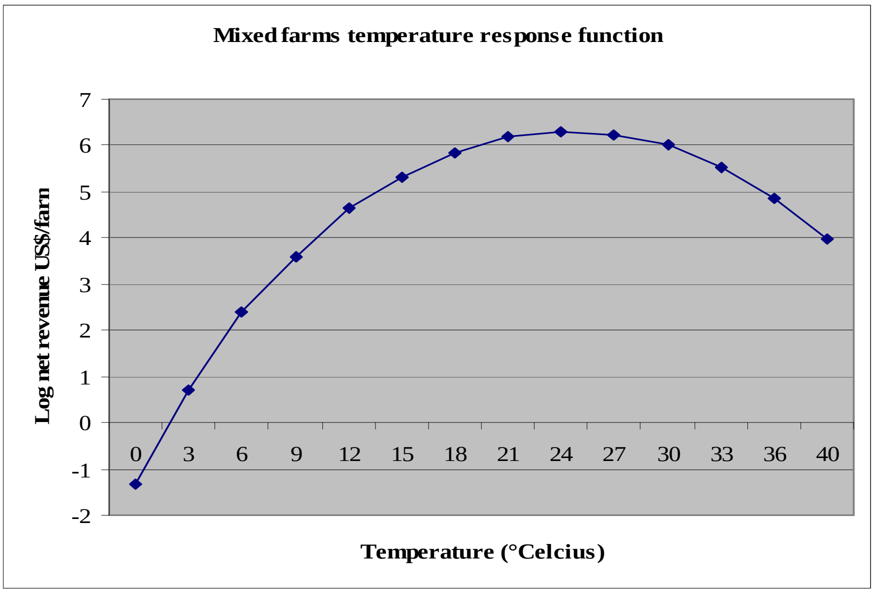

Figure 4.4: Temperature response function – mixed crop–livestock farms

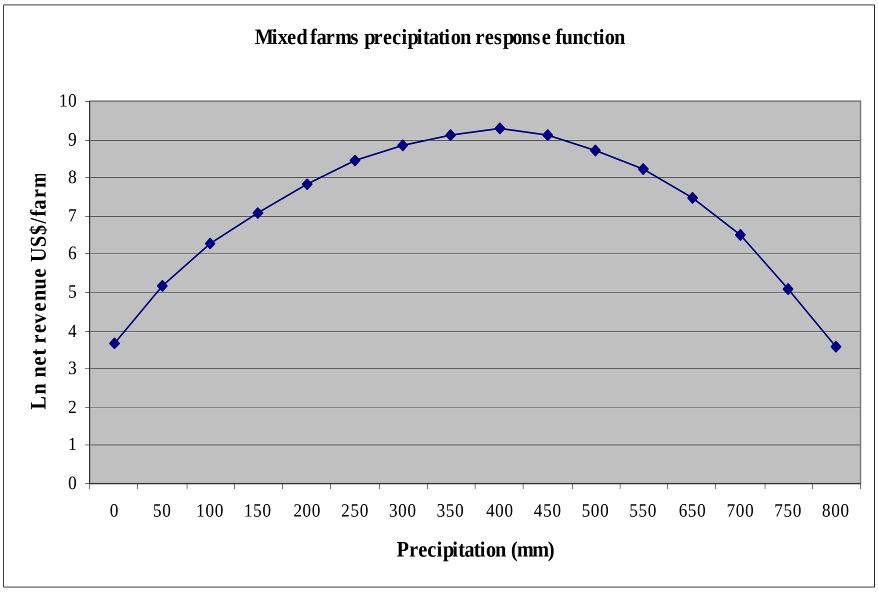

Figure 4.5: Precipitation response function – mixed crop–livestock farms

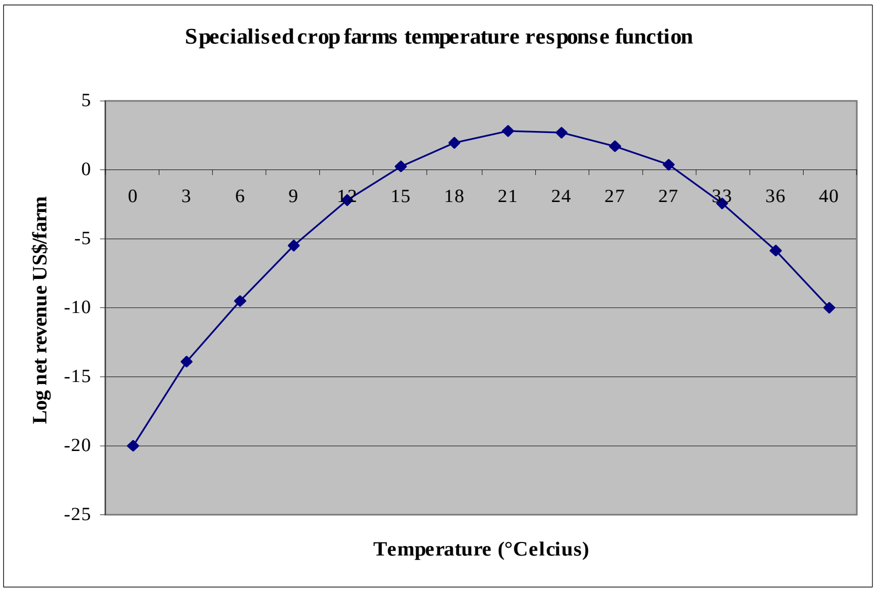

Figure 4.6: Temperature response function – specialised crop farms

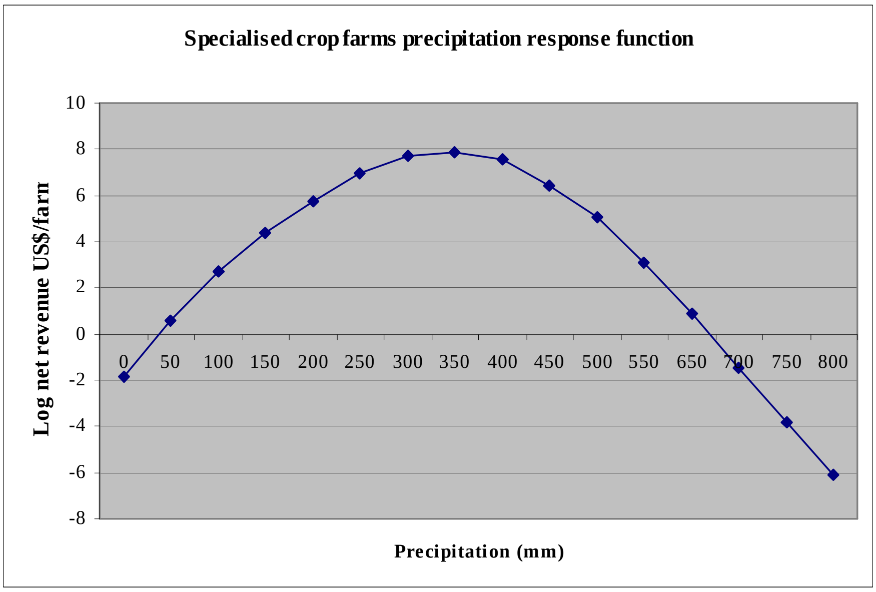

Figure 4.7: Precipitation response function – specialised crop farms

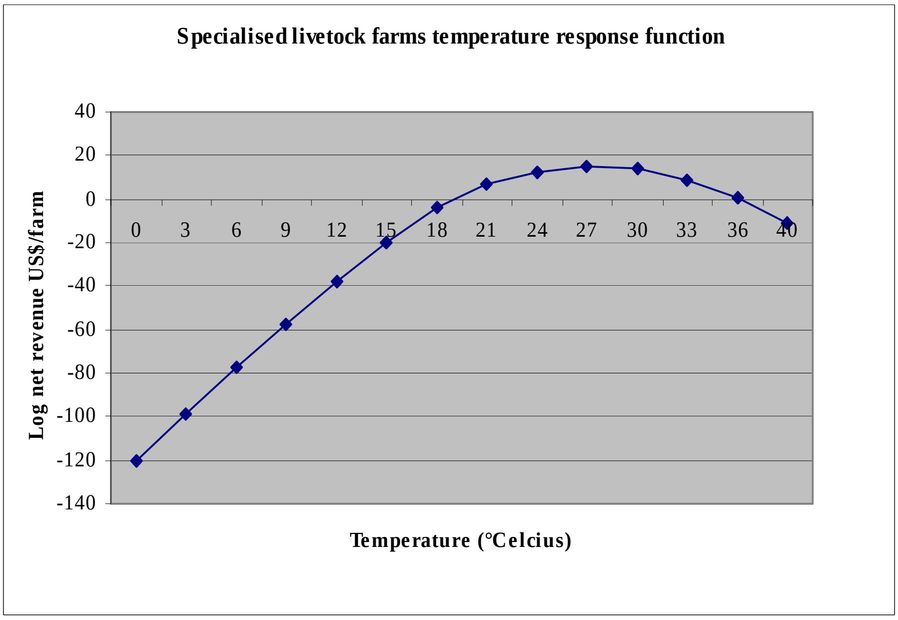

Figure 4.8: Temperature response function – specialised livestock farms

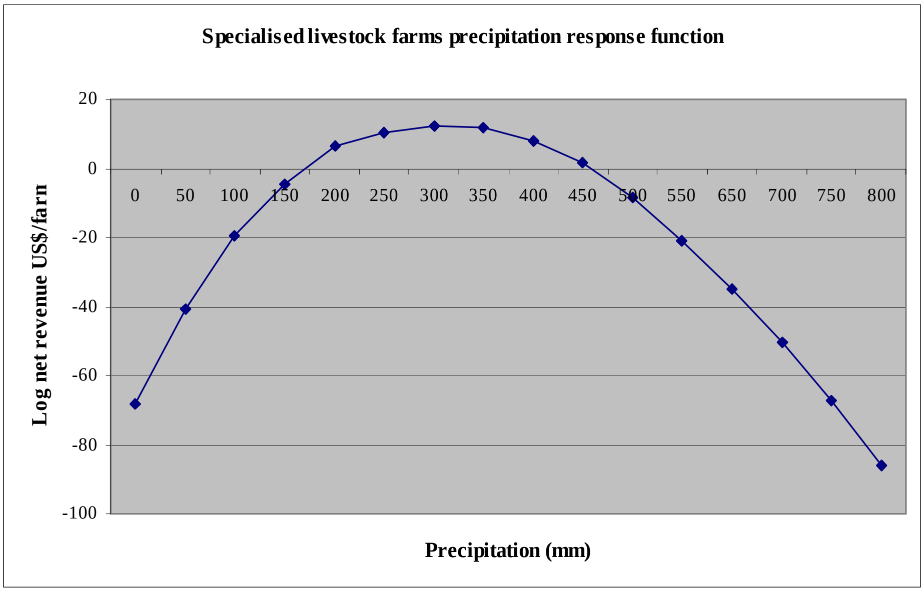

Figure 4.9: Precipitation response function – specialised livestock farms

The results show that net revenues for all farms increase with increasing temperature up to 24°C, while further increases in temperature are associated with declines in net revenue (Figure 4.2). The annual mean average temperature in Africa is currently about 24°C, indicating that further warming will be harmful to African agriculture. The response to precipitation shows that net revenues increase with increasing rainfall up to 450mm and then decline with further wetness (Figure 4.3). This implies that above 450mm seasonal average, wetter conditions become harmful to agricultural production. The response functions for temperature and rainfall show that reductions in net revenues with further warming are higher than with wetter conditions. These results confirm the findings from the earlier Ricardian analysis on Africa cropland conducted by Kurukulasuriya and Mendelsohn (2007a).

This study also examined the response functions for mixed crop–livestock farms, specialised crop and livestock farms as well as dryland and irrigation farms in each system separately. Figure 4.4 shows that for mixed farms, net revenues increase with increasing temperature up to 25°C, after which they decline with further warming. For specialised crop farms (Figure 4.6) and specialised livestock farms (Figure 4.8), net revenues also increase with increasing temperature and decline with further warming above 23°C and 27°C respectively. The results from the temperature response functions show that the net revenue curve for mixed farms covers a larger area compared to specialised crop and livestock response curves. This implies that mixed farms are less affected by temperature changes compared to the specialised systems. In addition, results show that net revenues for mixed farms (Figure 4.5) increase with increasing rainfall up to about 450mm and decline with increasing wet conditions. Precipitation response curves for specialised crop (Figure 4.7) and livestock (Figure 4.9) farms show that net revenues increase with increasing rainfall up to 350mm and 300mm respectively. Further wetness above these levels has negative impacts of net farm revenues.

The shapes of the response functions are worth noting. These results show that specialised crop (Figures 4.6 and 4.7) and livestock systems (Figures 4.8 and 4.9) in Africa are highly sensitive to climate. The climate sensitivity varies, however, according to whether farming depends entirely on rainfall or uses irrigation. Irrigation acts as a buffer against adverse impacts from harsh climatic conditions and hence irrigated farms are less sensitive to climate. Mixed crop–livestock farms (Figures 4.4 and 4.5) and irrigated farms appear to be more resilient to harsh climate conditions. The results suggest that specialised crop or livestock agriculture is more vulnerable to climate change than mixed systems. Generally, response curves for temperature and precipitation show that net revenues are more sensitive to temperature changes. This implies that temperature changes are more harmful to agricultural production in the region.

4.4 Forecasting impacts of climate change on net revenue

This section predicts impacts of future climate changes on net revenue from crop and livestock farming under various climate scenarios. Estimated model parameters from the Ricardian analyses above were used to predict the potential impacts of future climate changes on net farm revenue across different farming systems. To make a comparative assessment with other regional studies (Kurukulasuriya et al., 2006; Kurukulasuriya & Mendelsohn, 2007a; Seo & Mendelsohn, 2007a), this study uses the same sets of scenarios as the cited studies. This study examined the impacts of future changes in climate both for a set of simple scenarios (section 4.4.1), as well as a set of climate change scenarios predicted by the Atmospheric-Oceanic Global Circulation Models (AOGCMs) (section 4.4.2).

4.4.1 Climate sensitivity scenarios

This study tested four climate change scenarios: +2.5°C and +5°C increases in temperature and -7% and -14% decreases in precipitation. The simulations allowed only one climate variable to change at a time. Although these assumptions are not realistic in the real world, they provide important insights into likely responses to changes in climate variables.

Table 4.6 presents the results of the four climate scenarios compared to the baseline income for each farm type and category. The results show that increases in warming of 2.5°C and 5°C seem to predict losses in net farm revenue per farm for all farms, mixed crop–livestock farms and specialised crop and livestock systems. The losses are strongest for specialised crop systems, for example at 5°C warming specialised crop farms lose 87% net farm revenue per farm, compared to losses of 57% and 49% for mixed crop–livestock systems and specialised livestock farms respectively.

Reductions in precipitation (7% and 14%) predict higher losses in net farm revenue per farm for specialised crop and livestock systems, compared to all farms and mixed crop–livestock farms. For example, 14% reduction in precipitation predicts 65% and 46% losses in net revenue per farm for specialised crop and livestock systems respectively, compared to losses of 26% for all farms and 19% for mixed crop–livestock farms. These results suggest that specialised crop or livestock systems tend to suffer most from increases in warming and drying. Mixed crop–livestock farms that are less sensitive to climate changes suffer minimal damages compared to other farm types.

Results also show that warmer temperatures, namely increases of both 2.5°C and 5°C, tend to predict losses for dryland systems and gains for irrigated systems. The magnitudes of the losses are highest for specialised crop systems compared to all farms and mixed crop–livestock systems, suggesting that the risk of specialised systems is higher with warming in general. Reductions in precipitations of 7% and 14% appear to predict losses both for dryland and irrigated farming systems. Similarly, the magnitudes of the predicted losses suggest that drying has strong negative effects for specialised crop systems compared to all farms and mixed crop–livestock farms.

Table 4.6: Predicted impacts of climate change on net revenue from simple scenarios

Climate scenario	All farms		Mixed crop livestock farms		Specialised crop farms		Specialised livestock farms	
	ΔNet Revenue (USD per farm)	% of net farm income	ΔNet Revenue (USD per farm)	% of net farm income	ΔNet Revenue (USD per farm)	% of net farm income	ΔNet Revenue (USD per farm)	% of net farm income
	Baseline: 506.42		**Baseline: 563.39**		**Baseline: 333.18**		**Baseline: 569.95**	
2.5˚C Warming	-214.49	-42.35	-165.65	-29.40	-76.08	-22.84	-120.82	-21.20
5˚C Warming	-51.36	-10.14	-318.31	-56.50	-291.30	-87.43	-276.46	-48.51
7% Decreased Precipitation	-64.83	-12.80	-52.02	-9.23	-75.55	-22.68	-186.28	-32.68
14% Decreased Precipitation	-130.86	-25.84	-105.56	-18.74	-152.48	-45.76	-370.49	-65.00
Dryland farms	**Baseline: 443.58**		**Baseline 502.21**		**Baseline: 283.86**			
2.5˚C Warming	-87.34	-19.69	-337.22	-67.15	-238.71	-84.09		
5˚C Warming	-110.01	-24.80	-54.86	-10.92	-263.28	-92.75		
7% Decreased Precipitation	60.77	13.70	-175.00	-34.85	-226.76	-79.88		
14% Decreased Precipitation	-78.48	-17.69	-221.92	-44.19	-234.36	-82.56		
Irrigated farms	**Baseline: 777.83**		**Baseline: 790.36**		**Baseline: 669.42**			
2.5˚C Warming	201.58	25.92	154.89	19.60	192.30	28.73		
5˚C Warming	232.59	29.90	172.93	21.88	228.69	34.16		
7% Decreased Precipitation	-158.85	-20.42	-120.66	-15.27	-131.56	-19.65		
14% Decreased Precipitation	-167.42	-21.52	-130.63	-16.53	-146.27	-21.85		

Note: Estimated using coefficients from regression results (Table 4.4 and the other models presented in Appendix 1)

4.4.2 AOGCM climate scenarios

This study also examined a set of climate change scenarios from AOGCMs, in particular two scenarios that predict a wide range of outcomes consistent with the most recent IPCC report (Houghton et al., 2001). The specific scenarios used in this study are A1[7] scenarios from the following models: PCM (Parallel Climate Model) (Washington et al., 2000), and the CCC (Canadian Climate Centre) (Boer, Flato & Ramsden, 2000). Country level impacts for each of these scenarios for the year 2100 were examined. The climate model predicted change in temperature was added to the baseline temperature in each district under each climate scenario. For changes in precipitation, the climate model predicted change was multiplied by the baseline precipitation in each district.

Table 4.7 summarises the mean temperature and precipitation predicted by the two models for the year 2100. The models have a range of predictions: the PCM predicts a 3°C increase in temperature for 2100 and the CCC an increase of 6°C. For both models temperature shows a rising trend over time.

Table 4.7: Climate predictions of AOGCM models for 2100

Model		**CURRENT**	**2100**
CCC	**TEMP**	23.29	29.96
PCM		23.29	25.79
CCC	**PRECIP**	79.75	65.08
PCM		79.75	83.18

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[7] "The difference between the A1 and B1 worlds which share identical population growth projections is primarily due to the higher level of economic development in the A1 world which allows higher market prices" (Parry et al., 2004).

In terms of rainfall, PCM predicts an increase in precipitation of 4% by 2100 and the CCC a reduction of 15% for the same year. Despite these predictions, rainfall distribution varies greatly across countries. An important point to note is that there is spatial and temporal variability in predictions of temperature and precipitation in Africa.

To predict the impact of each climate scenario on net revenue, the changes in net farm revenues from baseline values in Table 4.6 and under each new climate scenario were calculated. The difference between the two levels of net revenues yields the change in net revenue per farm in each district. The predictions were based on the Ricardian regression results in Table 4.4 and Appendix 1.

Table 4.8 presents the results of the changes in net revenue per farm predicted using the two climate scenarios for the year 2100. The PCM scenario that forecasts mild changes in climate predicts some increases in net revenue. The CCC scenario that forecasts substantial increases in warming and drying, predicts severe losses in net farm revenues across Africa. Dryland farms and specialised crop or livestock farms tend to suffer most from harsh climatic conditions. On the other hand, irrigated farms and mixed crop–livestock farms are less sensitive to changes in climate and experience fewer negative impacts from increases in warming and drying. These results support the observation that irrigation and mixed crop–livestock farms offer an important adaptation alternative for farmers.

Table 4.8: Predicted impacts from AOGM climate scenarios (PCM and CCC) for the year 2100

Climate scenarios	All farms		Mixed crop livestock farms		Specialised crop farms		Specialised livestock farms	
	ΔNet Revenue (USD per farm)	% of net farm income	ΔNet Revenue (USD per farm)	% of net farm income	ΔNet Revenue (USD per farm)	% of net farm income	ΔNet Revenue (USD per farm)	% of net farm income
	Baseline: 506.42		**Baseline: 563.39**		**Baseline: 333.18**		**Baseline: 569.95**	
PCM 2100	14.92	2.95	15.90	2.82	-120.08	-36.04	405.06	25.70
CCC 2100	-298.17	-58.88	-107.55	-19.09	-189.61	-56.91	-357.35	-22.68
Dryland farms	**Baseline: 443.58**		**Baseline: 502.21**		**Baseline: 283.86**			
PCM 2100	-62.81	-14.16	-66.91	-13.32	-181.39	-63.90		
CCC 2100	-76.14	-17.17	-245.02	-48.79	-224.21	-78.99		
Irrigated farms	**Baseline: 777.83**		**Baseline: 790.36**		**Baseline: 669.42**			
PCM 2100	255.91	32.90	172.33	21.80	209.70	31.32		
CCC 2100	-219.54	-28.22	-110.49	-13.98	-232.85	-33.29		

Note: Estimated using coefficients from regression results (Table 4.4 and Appendix 1) and AOGCM country specific climate scenarios

4.5 Summary and policy implications

This chapter analysed the impacts of changes in climate on net farm revenues in Africa. The empirical analyses were based on a cross-sectional database of over 6900 surveys from 11 African countries. Additional climate, soils and flow variables were obtained from other sources and combined with the cross-sectional survey data.

The study used a Ricardian approach to measure the impacts of climate change on combined crop and livestock net revenue. Net revenue per farm was regressed against climate, soils, hydrological and socio-economic variables to measure the effects of each variable on net farm revenue. The impacts of climate change were examined for the total sample as well as for three main farming types: specialised crop; specialised livestock; and mixed crop and livestock; and for dryland and irrigated farms within each farm type. The study also examined four particular climate sensitivity scenarios, as well as two climate scenarios from the Atmospheric Oceanic General Circulation Models (AOGCMs).

The results show that larger farm sizes appear to have a strong positive influence on net farm revenues across all farm types, suggesting that more land allows more crop and livestock enterprises per farm, thus leading to more income, although per hectare value may be low. Larger families seem to be associated with higher net farm revenues across all farm types. Better access to other farm assets, such as heavy machinery like tractors, appears to strongly and positively influence net farm revenues for all farms, mixed crop–livestock farms and specialised crop farms. These results suggest that capital, land and labour serve as important production factors in African agriculture. National policies need to invest more in improving factor endowments (i.e. family size, land area and capital resources) at the disposal of farming households in order to enhance farm performance in the face of climate change.

Better access to extension services seems to have a strong positive influence on net farm revenue on all farms, mixed crop–livestock farms and specialised crop farms. Improving access to extension ensures that farmers have the information for decision making to improve their production activities. Policies aimed at improving farm-level performance need to emphasise the critical role of providing information (through extension services) to enhance farm-level decision making.

Improving access to technology (in this case electricity) has significant potential in improving farm-level production activities and hence net revenues. For example, the use of irrigation and intensive livestock production systems (which are usually capital intensive), increases when farmers have access to electricity and machinery. Improving access to technology such as electricity and machines is therefore important to enhance agricultural production in the face of climate change.

The arenosols, fluvisols and ferric luvisols soils that are extensively developed and are usually high productive soils, appear to have a strong positive influence on net farm revenues across all farming systems. On the other hand, the soil type chromic luvisols that is unproductive shows a strong negative influence on net farm revenues across all farming systems.

Marginal analyses of the impacts of seasonal climate variables show that African net farm revenues are highly sensitive to changes in climate. The sensitivity is relatively higher for changes in temperature than for changes in precipitation. Further warming and drying will have severe adverse effects on farm net revenues. The results show variations in sensitivity to climate, based on farm type and whether a farm is dryland or irrigated. Dryland and specialised crop or livestock farms suffer most from increases in warming and drying, compared to irrigated and mixed crop–livestock farms. Predictions of future climate impacts also indicate that mixed crop–livestock and irrigated farms are less sensitive to climate changes and will experience less damages, compared to highly sensitive dryland and specialised crop or livestock farms. Results show that net farm revenues are in general negatively affected by warmer and dryer climates. The small-scale mixed crop and livestock system predominant in Africa is the most tolerant system, whereas specialised crop production is the most vulnerable to warming and lower rainfall.

Generally farming systems located in dry semi-arid and arid regions (for example most southern parts of the continent) will suffer most from increases in warming and drying compared to more humid regions. It is therefore important for Africa to enhance adaptation efforts both at the micro (farm) and macro (national) levels. Governments need to integrate adaptation strategies into national economic policies and strengthen community based adaptations to help farmers reduce potential damage from climate change. These results have important policy implications, especially regarding the suitability of the increasing tendency toward large-scale mono-cropping strategies for agricultural development in Africa and other parts of the developing world, in the light of expected climate changes. Mixed crop and livestock farming and irrigation offer better adaptation options for farmers against further warming and drying predicted under various future climate scenarios.

Chapter 5

Theoretical and empirical studies relating to the economics of climate change adaptation in agriculture

5.0 Introduction

This chapter briefly reviews selected theoretical and empirical studies relating to the economics of climate change adaptation in agriculture, starting by defining and discussing climate change adaptation in agriculture. This is followed by a discussion of the various approaches and methods that have been used for assessing adaptation to climate change in agriculture (section 5.2). Empirical studies that have analysed determinants of adaptation strategies in agriculture are discussed in section 5.3. The chapter concludes with a summary of the approach chosen to implement the empirical analysis of determinants of climate change adaptation strategies of African farmers and the expected contributions of this study.

5.1 Adaptation to climate change in agriculture

Adaptation to climate change refers to adjustments in management strategies to reduce risks or realise opportunities from actual or expected changes in climatic conditions (IPCC, 2001; Smit, Burton, Klein & Wandel, 2000; Kandlinkar & Risbey, 2000). Agricultural adaptations to climate change involve modifications in farm-level practices due to changing climatic and non-climatic conditions (Wall & Smit, 2005; Kurukulasuriya & Rosenthal, 2003; Kandlinkar & Risbey, 2000). Adaptation occurs at two main scales: (a) the farm (or micro) level that focuses on micro analysis of farmer decision making; and (b) the national (or macro) level that is concerned about agricultural production at national and regional scales and its relationships with domestic and international policy (Bradshaw, Dolan & Smit, 2004; Kurukulasuriya & Rosenthal, 2003;

Kandlinkar & Risbey, 2000). Micro-level analysis of adaptation[8] focuses on tactical decisions farmers make in response to seasonal variations in climatic, economic, and other factors. Macro-level analysis, on the other hand, focuses on strategic national decisions and policies on local to regional scales, taking into account long term changes in climatic, market and other conditions (Bradshaw et al., 2004; Kurukulasuriya & Rosenthal, 2003; Kandlinkar & Risbey, 2000).

Further changes in climate are unavoidable even under stringent mitigation[9] measures over the next few decades (IPCC, 2007; Houghton et al., 1996). These changes are unavoidable due to high concentrations of greenhouse gasses (higher than pre-industrial levels), and high residual levels of greenhouse gasses in the atmosphere (Klein et al., 2007). Mitigation efforts to reduce the sources of or to enhance the sinks of greenhouse gasses will take time. Furthermore, effective mitigation requires collaboration and commitment from many countries (Klein et al., 2007).

Adaptation is therefore critical and of concern in developing countries, particularly in Africa where vulnerability is high because ability to adapt is low. Adaptation helps reduce the impacts of climate change in the short to medium term, and is motivated from local priorities or regional risks, without requiring multi-country commitments. The benefits of adaptation are realised in the short term and are felt at the local community level. Adaptation measures are therefore critical in the short to medium term, while in the long run mitigation efforts are required to reduce risks and create sinks for further greenhouse gas emissions. Human and natural risks associated with climate change are determined by both adaptation and mitigation actions (Smit et al., 2000). Therefore,

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[8] "Adaptation strategies are defined as longer-term (beyond a single season) strategies that are needed for people to respond to a new set of evolving conditions (biophysical, social and economic) that they have not previously experienced. Coping strategies are defined as strategies that have evolved over time through people's long experience in dealing with the known and understood natural variation that they expect in seasons combined with their specific responses to the season as it unfolds" (Dinar et al., 2008).

[9] Mitigation to climate change refers to responses aimed at reducing greenhouse gas emissions and enhancing sinks (IPCC, 2007).

effective climate policy must integrate diverse adaptation and mitigation actions to reduce the adverse effects of climate change on human and natural systems (Klein et al., 2007).

Climate change is expected to affect food and water resources that are critical for livelihood in Africa where much of the population, especially the poor, rely on local supply systems that are sensitive to climate variation. Disruptions of the existing food and water systems will have devastating implications for development and livelihood, and are expected to add to the challenges climate change already poses for poverty eradication (De Wit & Stankiewicz, 2006; IISD, 2007). Adaptation helps farmers achieve their food, income and livelihood security objectives in the face of changing climatic and socioeconomic conditions, including climate variability, extreme weather conditions such as droughts and floods, and volatile short-term changes in local and large-scale markets (Kurukulasuriya & Rosenthal, 2003; Kandlinkar & Risbey, 2000). Farmers can reduce potential damage by making tactical responses to climate changes. Analysing adaptation mechanisms is therefore important in finding ways to help farmers adapt in the rural economies of Africa.

Although African farmers have a low capacity to adapt to such changes, they have survived and coped in various ways over time. Better understanding of how they have done this is essential for designing incentives to enhance private adaptation. Supporting the coping strategies of local farmers through appropriate public policy and investment and collective actions can help increase the adoption of adaptation measures. Such measures will reduce the negative consequences of predicted changes in future climate conditions, with great benefits to vulnerable rural communities in Africa.

5.2 Approaches for assessing adaptation to climate change in agriculture

Adaptation to climate change at the macro and micro levels defined above has been studied and analysed employing different approaches which were discussed in chapter 3 on measuring the impacts of climate change. Macro level analyses of adaptation have been based on regional structural (agronomic-economic) models (e.g. Adams et al., 1990, 1995; 1998b; Easterling et al., 1993), integrated assessment models (e.g. Yates & Strzepek, 1998; Crosson & Rosenburg, 1993; Rosenzweig & Parry, 1993) and the Future Agricultural Resources Model (FARM) (Darwin et al., 1994, 1995).

At the micro level, cross-section (Ricardian) models (e.g. Kurukulasuriya & Mendelsohn, 2007a; Seo & Mendelsohn, 2007ba; Gbetibouo & Hassan, 2005; Deressa et al., 2005; Mano & Nhemachena, 2007), agronomic-economic models (e.g. Kaiser et al., 1993) and multinomial choice (adoption) models (e.g. Kurukulasuriya & Mendelsohn, 2007b, 2007c; Seo & Mendelsohn, 2007b; Maddison, 2007) have been employed to analyse adaptation. Adoption literature at the farm level has been based on multinomial choice (adoption) models. The present study accordingly employs the multinomial logit (MNL) approach to conduct the intended analyses. The reason for the choice of the MNL logit model to analyse the determinants of farmers' decisions is that it is widely used in adoption decision studies involving multiple choices (see section 6.3).

5.2.1 Agronomic-economic models

The *structural* approaches (agronomic-economic models) start by using crop simulation models (e.g. the CERES family models, CROPWAT or EPIC models), based on detailed experiments to determine the response of specific crops and crop varieties to different climatic and other conditions. Farm management practices can be included in structural models, for example, modelling the impacts of changing timing of field operations, crop choices, adding irrigation (Adams, 1999; Adams et al., 1998a; Schimmelpfenning et al., 1996).

Agronomic-economic models successfully incorporate adaptation into crop simulation models (Mendelsohn, 2000). Mendelsohn cites a number of farm-level studies based on this approach that have examined efficient responses by farmers to climate change. Examples include: Kaiser et al. (1993) who showed that altering crop mixes, crop varieties, sowing and harvesting dates, and water saving technologies in the United States can reduce the negative impacts of climate change on agriculture. These farm-level studies and others (Reilly, 1994, 1995) showed that adaptation can reduce the damage from warming on crop yields by up to 50 percent. The strength of using this approach is that it allows for detailed understanding of the physical, biological responses, as well as adjustments that farmers can make in response to changing climatic and other conditions (Adams 1999; Schimmelpfenning et al., 1996). Such information might be important for focused policy and adaptation planning in identifying which group of people to target and in which ways they should be supported.

However, Mendelsohn (2000) argues that it is very expensive to carefully include microeconomic farm responses and thus it is rarely done. Only a few studies have been able to carefully include adaptation in developing countries, with current examples coming from the developed world, especially the United States. The other limitation of this approach is the failure to take into account economic considerations and human capital limitations which affect farm-level decision making (Mendelsohn, 2000). Mendelsohn (2000) cites a number of studies that examined various adaptation strategies, but failed to estimate the effects on net revenue. Examples include Elshar et al. (1997) who examined climate adaptation strategies (changes in water, land and crop management) in Egypt, and Iglesias and Minguez (1997) who examined changes in sowing dates, new hybrids and double cropping for wheat and maize in Spain. None of these studies measured the effects on net revenues from taking these adaptation strategies into account (Mendelsohn, 2000). In addition, if an economist fails to correctly anticipate potential farmer adjustments and adaptations, the estimates might be biased (either overestimating the damages or underestimating the potential benefits of climate change) (Adams, 1999).

5.2.2 Cross-sectional methods

The two main cross-sectional methods developed to account for adaptation in response to changes in climate are: (a) the Ricardian approach by Mendelsohn et al. (1994), and (b) the Future Agricultural Resources Model (FARM) by Darwin et al. (1994, 1995). The basic assumption underlying both these methods is that similar climates mean similar production practices. This assumption allows both approaches to implicitly capture changes in crop or livestock outputs, production inputs or management practices that farmers are likely to take in response to changing climatic and other conditions (Darwin, 1999).

The cross-sectional methods fully incorporate farmer adaptations. First round adaptations by farmers are captured in the estimates of climate-induced changes that represent the economic value of climate change on agriculture (Mendelsohn et al., 1996, 1994). The measurement of long-term impacts of climate change considers the costs and benefits associated with changes in management decisions and practices taken by farmers in response to changes in local climate, as well as the effect of other explanatory variables such as soils, infrastructure, agricultural services and other socio-economic variables (Mendelsohn & Dinar, 2005; Mendelsohn et al., 1996, 1994). The underlying assumption is that farmers will automatically make adjustments in their management practices in response to changes in climate (Mendelsohn & Dinar 2003; Mendelsohn et al., 1996, 1994; Adams 1999; Adams et al., 1998a).

5.2.3 Discrete multinomial choice models

Although both agronomic and cross-sectional models address adaptation issues, they both fail to explicitly consider issues related to farmer adoption of the various adaptation strategies. Adaptation to climate change in agriculture involves the adoption of new technologies such as new crop varieties and irrigation technologies. Maddison (2007) reviewed the adoption process of new agricultural technologies in detail. He cites various other studies and their approaches in investigating the adoption of agricultural innovations. The two main approaches reported in the literature that have been used to analyse the determinants of adoption of agricultural innovations are the probit and logit models. Recent studies that have addressed adoption related issues in adaptation to climate change in agriculture include Kurukulasuriya and Mendelsohn (2007b; 2007c) Seo and Mendelsohn (2007b) and Maddison (2007). These studies were based on discrete choice models addressing the determinants of adoption of various adaptation strategies. The next chapter discusses some of the determinants of adoption of adaptation measures from these and other studies (see section 6.4).

Kurukulasuriya and Mendelsohn (2007b), and Seo and Mendelsohn (2007b) used multinomial logit models to analyse respectively crop and livestock choice as adaptation options. The study on crop choice shows that crop type is climate sensitive and farmers adapt to changes in climate by switching crops. The results from the choice models in the livestock study show that farmers in warmer temperatures tend to choose goats and sheep as opposed to beef cattle and chicken. Goats and sheep can do better in dry and harsher conditions than beef cattle.

Kurukulasuriya and Mendelsohn (2007c), and Mendelsohn and Dinar (2003) explored the importance of water availability in the Ricardian model by estimating the role of irrigation as an adaptation measure against unfavourable climatic conditions. This was a significant step in addressing the shortcomings of past Ricardian studies of agriculture (Mendelsohn et al., 1994, 1996) that were criticised for failing to take into account the effects of irrigation and other water supplies (Cline 1996; Darwin, 1999). The recent studies showed that irrigation is an important adaptation measure that can significantly help reduce the negative impacts associated with changes in climate.

Maddison (2007) applied a Heckman selection probit model to help explain determinants of African farmers’ adaptation strategies using the GEF data set. The empirical results indicate that farmers with the greatest farming experience are more likely to notice changes in climatic conditions which are consistent with farmers engaging in Bayesian updating of their prior beliefs. The study also reported that farmer experience, access to free extension services and markets are some of the important determinants of adaptation.

Bradshaw et al. (2004) assessed the adoption of crop diversification in Canadian prairie agriculture for the period 1994-2002, reflecting upon its strengths and limitations for managing a variety of risks, including climatic ones. Results based on data from over 15000 operations show that individual farms have become more specialised in their cropping patterns since 1994. This trend is unlikely to change in the immediate future, notwithstanding anticipated climate change, due to the known risk-reducing benefits of crop diversification. The recommendation from that study was that there is a need to assess and understand the wider strengths and limitations of various ‘suitable’ and ‘possible’ adaptations to changes in climate.

5.3 Summary

Empirical studies measuring the economic impacts of climate change on agriculture in Africa discussed above show that such impacts can be significantly reduced through adaptation. The present study adds to these analyses by studying the determinants of farmers’ choices between alternative adaptation measures available to rural households in Africa. This analysis is different from other adaptation studies in that farmers’ *actual* adaptation[10] measures are considered. This can be compared with Maddison’s (2007) analysis of farmers’ perceptions of climate change and the adaptations they perceive as appropriate, using the same sample of African farmers.

This study considers the choice between many adaptation measures simultaneously, whereas other studies analysed such joint endogenous decisions in separate analyses for crop selection (Kurukulasuriya & Mendelsohn, 2007b), irrigation modelling (Kurukulasuriya & Mendelsohn, 2007c), and livestock choice (Seo & Mendelsohn, 2007b). Other important contributions of this study include identification of relevant adaptation options for farmers in Africa and assessment of the probability of farmers’ choice among these adaptation options, given certain relevant factors. The present study

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[10] The different combinations of *actual* measures and practices may be grouped into the following adaptation options: diversifying into multiple crops and mixed crop–livestock systems, switching from crops to livestock and from dryland to irrigation (For details see section 6.2).

accordingly employs the multinomial logit approach to conduct the required analyses. The level of analysis for this study is the local farm level where micro analysis of adaptation mechanisms was applied to find potential ways of improving agricultural production at this level.

Chapter 6

Determinants of climate adaptation strategies of African farmers: Multinomial choice analysis

6.0 Introduction

This chapter analyses adaptation measures used by African farmers and the determinants of their choices. The chapter begins by presenting a brief analytical summary of the perceptions of African farmers on climate change and commonly followed measures for coping with it (section 6.1). Section 6.2 discusses the classification of actual farmers' adaptation decisions. The analytical framework for studying actual farmers' choices of adaptation measures and determinants of their decisions are discussed in section 6.3. Section 6.4 develops the empirical components for implementing the analytical model and results are discussed in section 6.5. Conclusions and implications are distilled in section 6.6.

6.1 Perceived adaptation strategies of African farmers

Based on data from a comprehensive survey of agricultural households across 11 countries in Africa, this section presents brief summaries of farmers' perceptions of climate change and what strategies they perceive to be suitable for adapting to those changes. Details of the sample of more than 8000 questionnaires are given in chapter 4, section 4.2. In this survey farmers were asked questions about their perceptions of long-term temperature and precipitation changes, as well as what measures and practices they have typically opted for in order to cope with such changes over the years[11]. The results

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[11] In this study, these options typically stated by farmers in response to changes in short-term and long-term changes in climate are defined as 'perceived' adaptation measures (see Table 6.2). The assumption for this study is that farmers might have stated adaptation options which they did not actually implement. 'Actual' adaptation measures analysed in this study refer to practices farmers were using at the time of

(Table 6.1) show that the majority (50%) of farmers perceive that long-term temperatures are warming, precipitation is declining, and there are pronounced changes in the timing of rains (32%) and frequency of droughts (16%).

Table 6.1: Farmer perceptions on long term temperature and precipitation changes (% of respondents)

Variable	Percentage of respondents
(a) Temperature	
Increased temperature	51
Decreased temperature	5
Altered climatic range	9
Other changes	7
No change	14
Don't know	6
(b) Precipitation	
Increase precipitation	5
Decreased precipitation	50
Changed timing of rains	32
Frequency of droughts	16
Other changes	5
No change	13
Don't know	4
Number of observations	**8208**

Farmers' perceived adaptation strategies in responding to the changing climate include: crop diversification, using different crop varieties, varying planting and harvesting dates,

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the interviews. The study by Maddison (2007), based on the same data set, used stated adaptation measures (referred to as 'perceived' adaptation options in this study) as opposed to actual farmer practices (for example, a farmer may actually have had multiple crops and livestock, irrigation etc, as opposed to listed adjustments in farming activities which might not have been implemented) (see Table 6.3).

increased use of irrigation, increased use of water and soil conservation techniques, shading and shelter, shortening length of growing season and some farmers are diversifying from farming to non–farming activities (Table 6.2).

Table 6.2: Perceived farm-level adaptation strategies in Africa (% of respondents)

Variable	Percentage of respondents (%)
Different crops	11
Different varieties	17
Crop diversification	8
Different planting dates	16
Shortening length of growing period	13
Moving to different site	4
Changing amount of land	3
Crops to livestock	2
Livestock to crops	1
Adjust livestock management practices	1
Farming to non-farming	9
Non-farming to farming	1
Increasing irrigation	10
Changing use of chemicals, fertilisers and pesticides	5
Increasing water conservation	18
Soil conservation	15
Shading and shelter	21
Use insurance	7
Prayer	5
Other adaptations	22
No adaptation	37
Number of observations	**8217**

6.2 Classification of actual farmers' adaptation decisions

This section moves to analyse actual adaptation measures used by farmers, as opposed to perceived adaptations described above. The main practices actually followed by farmers during the survey year (2002) are grouped into eleven combinations of choices (Table 6.3). It is important to note that many of the adaptation strategies identified by farmers in Table 6.2 form components of their observed actual practices reported in Table 6.3. Those measures however, are mostly implemented in combination with other measures and not alone.

The different combinations of measures and practices may be grouped into the following adaptation options: diversifying into multiple crops and mixed crop–livestock systems, switching from crops to livestock and from dryland to irrigation. It is clear from Table 6.3 that multiple cropping mixed with livestock rearing under dryland conditions is the most dominant system in Africa (52% of farms). Multiple cropping with livestock under irrigation has the second highest frequency (14%) and multiple cropping without livestock under dryland conditions comes third (13%). Mixing livestock with crops is by far the most common practice of African farmers (79%), whether under irrigation or dryland. Also note that while about 24% of African farms irrigate, using irrigation to support specialised livestock production is very rare (Table 6.3).

It is clear that African farmers rarely specialise in rearing livestock only, whether under irrigation or dryland conditions (Table 6.3)[12]. However, a possible explanation for the observation that specialised livestock is rarely practised might be a limitation of the original survey design and data collection, as there are some farmers specialising in livestock only. While specialising in livestock production is not a feature of African agriculture, it can be observed that specialised rain-fed and irrigated crop cultivation

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[12] It is common that smallholder African farmers typically cultivate part of their own farm land with at least one staple food crop besides the farm animals they keep. Even large commercial diary and beef farms in Africa also produce some fodder crops for animal feed.

(mono-cropping) is practised, albeit by a small proportion of the farming population (about 3% - Table 6.3)[13].

Table 6.3: Categorised adaptation measures used by farmers

Adaptation measure	Percentage of respondents (%)
Mono-crop under dryland	2.21
Mono-crop under irrigation	1.03
Livestock under dryland	1.00
Livestock under irrigation	0.00
Multiple crops under dryland	13.51
Multiple crops under irrigation	4.27
Crop–livestock, mono-crop under dryland	7.79
Crop–livestock, mono-crop under irrigation	4.04
Crop–livestock, multiple crops under dryland	51.75
Crop–livestock, multiple crops under irrigation	14.24
Number of observations	**8,217**

There are other adaptation options available to farmers that are not considered in the above groupings. For instance, under the above combinations, farmers may be varying planting dates, using different crop varieties, fertilizers, pesticides, soil and water conservation and insurance measures. Considering these options however, would lead to a very large number of factorial combinations that would be hard to analyse within one empirical model.

Moreover, the above categories considered in this study represent the main strategic adaptation measures reflected in the main farming systems in Africa according to the FAO classification (Dixon et al., 2001). According to the FAO classification (Figure 2.2),

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[13] Examples include tea, coffee, tobacco and sugarcane in rain-fed plantations in mid-altitude zones of eastern and southern Africa, and irrigated sugarcane, wheat and fruit crops in lower lands that are relatively dry and warm.

the maize-mixed, cereal-root crop mixed and root crops are the principal farming systems in sub-Saharan Africa, supporting about 41% of the agricultural population. Other important farming systems include: agro-pastoral millet/sorghum, highland perennial, pastoral, forest based and highland temperate mixed. The irrigated farming system occupies only 1% of the total land area and supports 2% of the agricultural population (Dixon et al., 2001). The principal farming systems in southern Africa are: maize-mixed; large scale commercial, pastoral, sparse arid root crop, agro-pastoral millet and cereal root crop mixed. In east and central Africa the main farming systems are: maize-mixed, forest based, root crop, pastoral, agro-pastoral, and highland temperate mixed. Root crop, cereal-root crop mixed, tree crop, pastoral, agro-pastoral millet/sorghum, and sparse (arid) are the major farming systems in north and West Africa.

The present study therefore focuses on the ten combination options listed in Table 6.3 as the main adaptation choices of African farmers for coping with climate change. Based on this classification, this study assumes that the mono-crop (either on rain-fed or irrigated lands) is the base category that represents ‘no adaptation’ and hence in this study ‘no adaptation’ refers to those farmers who do mono-cropping. This however should not be understood as suggesting that mono-cropping is not an adapted system where it is practised in Africa. It is only used as the reference point against which other more complex adaptation regimes are contrasted, to reflect the fact that African farmers have had to adapt to a world that is hotter and dryer than where well adapted mono-cropping systems continue to be practised in wetter temperate climates (e.g. France and Midwestern USA). While irrigation and choice of livestock may be considered as adaptations, our sample did not include farmers practising these options under specialised systems, as observed earlier.

6.3 The analytical framework

Adaptation measures help farmers to reduce losses due to warming temperatures and declining precipitation. The analyses presented in this study identify the important determinants of adoption of various adaptation measures. The results provide policy information on which factors to target and influence, and in which way, in order to increase the use of different adaptation measures by farmers.

The analytical approaches that are commonly used in adoption decision studies involving multiple choices are the multinomial logit (MNL) and multinomial probit (MNP) models. Both the MNL and MNP models are important for analysing farmer adaptation decisions as these are usually made jointly. These approaches are also appropriate for evaluating alternative combinations of adaptation strategies including individual strategies (Hausman & Wise, 1978; Wu & Babcock, 1998).

This study uses a MNL model to analyse the determinants of the decision problem of farmers in choosing between alternative measures to adapt to climate change. The MNL model is chosen in this study as it is widely used in adoption decision problems involving multiple choices, and it is easier to compute than its alternative, the MNP model.

The advantage of using a MNL model is its computational simplicity in calculating the choice probabilities that are expressible in analytical form (Tse, 1987). The MNL model provides a convenient closed form for underlying choice probabilities, with no need for multivariate integration, thus making it simple to compute choice situations characterised by many alternatives. In addition, the computational burden of the MNL specification is made easier by its likelihood function which is globally concave (Hausman & McFadden, 1984). The main limitation of the MNL model is the independence of irrelevant alternatives property (IIA), which states that the ratio of the probabilities of choosing any two alternatives is independent of the attributes of any other alternative in the choice set[14] (Tse, 1987; Hausman & McFadden, 1984).

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[14] A ‘universal’ logit model avoids the independence of irrelevant alternatives property while maintaining the multinomial logit form, by making each ratio of probabilities a function of attributes of all alternatives. It is difficult, however, to give an economic interpretation of this model other than “a flexible approximation to a general functional form” (Hausman & McFadden, 1984).

On the other hand, the multinomial probit (MNP) model specification for discrete choice models does not require the assumption of the independence of irrelevant alternatives (Hausman & Wise, 1978). Also a test for the independence of irrelevant alternatives assumption can be provided by a test of the 'covariance' probit specification versus the 'independent' probit specification, which is very similar to the logit specification. The main drawback of using the MNP model is the requirement that multivariate normal integrals must be evaluated to estimate the unknown parameters. This complexity makes the MNP model an inconvenient specification test for the MNL model (Hausman & McFadden, 1984).

Let A_i be a random variable representing the adaptation measure chosen by any farming household. Assume that each farmer faces a set of discrete, mutually exclusive choices of adaptation measures. The adaptation measures are assumed to depend on a number of climate attributes, socio-economic characteristics and other factors x_i. The MNL model for adaptation choice specifies the following relationship between the probability of choosing option A_i (0, 1, 2…J) and the set of explanatory variables x_i (Green, 2003):

$$\text{Prob}(\text{A}_\text{i} = j) = \frac{e^{\beta'_j x_i}}{\sum_{k=0}^{j} e^{\beta'_k x_i}}, j = 0,1 \cdots J \qquad (6.1)$$

where β_j is a vector of coefficients on each of the independent variables x_i; β_k is the vector of coefficients of the base alternative; j denotes the specific one of the $J+1$ possible unordered choices, and A_i is the indicator variable of choices. Equation (6.1) can be normalised to remove indeterminacy in the model by assuming that $\beta_0 = 0$ and the probabilities can be estimated as:

$$\text{Prob}(\text{A}_\text{i} = jx_i) = \frac{e^{\beta'_j x_i}}{1 + \sum_{k=1}^{J} e^{\beta'_k x_i}}, j = 0,2 \cdots J, \beta_0 = 0 \qquad (6.2)$$

Estimating equation (6.2) yields the J log-odds ratios:

$$\ln\left(\frac{P_{ij}}{P_{ik}}\right) = x_i'(\beta_j - \beta_k) = x_i'\beta_j\text{, if } k = 0 \tag{6.3}$$

The dependent variable is therefore the log of one alternative relative to the base alternative.

The MNL coefficients are difficult to interpret and associating the β_j with the *jth* outcome is tempting and misleading. To interpret the effects of the explanatory variables on the probabilities, marginal effects are usually derived as follows (Green, 2003):

$$\delta_j = \frac{\partial P_j}{\partial x_i} = P_j\left[\beta_j - \sum_{k=0}^{J} P_k \beta_k\right] = P_j\left(\beta_j - \bar{\beta}\right) \tag{6.4}$$

The marginal effects measure the expected change in probability of a particular choice being made with respect to a unit change in an explanatory variable (Green, 2000; Long, 1997). The signs of the marginal effects and respective coefficients may be different as the former depend on the sign and magnitude of all other coefficients.

6.4 The data and empirical specifications of the model variables

This part of the study is based on the same dataset used for measuring the economic impacts of climate change on agriculture (see chapter 4, section 4.2). The dependent variable in the empirical estimation for this study is the choice of an adaptation option from the set of adaptation measures listed in Table 6.3. For the purposes of this study, specialised crop cultivation (mono-cropping under both irrigation and rain-fed systems) is used as the base category as a measure of no adaptation. Also note that other specialised systems (specialised irrigated and rain-fed livestock) were dropped as they had no observations. The choice of explanatory variables is dictated by theoretical behavioural hypotheses, empirical literature and data availability. Explanatory variables considered in this study consist of *seasonal climate variables* and *socio-economic factors*. Resource limitations, coupled with household characteristics and poor infrastructure, limit the ability of most farmers to take up adaptation measures in response to changes in climatic conditions (Kandlinkar & Risbey, 2000). Table 6.4 summarises the explanatory variables used for the empirical estimation. A brief description of these variables is presented below and some hypotheses are developed on their expected influence on farm level adaptations.

Table 6.4: Definition of variables used in the empirical analysis

Variable	Definition	Values/measure	Expected sign
Wintertemp	Winter temperature	°C	±
Springtemp	Spring temperature	°C	±
Summertemp	Summer temperature	°C	±
Falltemp	Fall temperature	°C	±
Winterprecip	Winter precipitation	Mm	±
Springprecip	Spring precipitation	Mm	±
Summerprecip	Summer precipitation	Mm	±
Fallprecip	Fall precipitation	Mm	±
Noticed_climate_change	Farmer noticed changes in climate	1=yes and 0=no	+
Male_head	Sex of household head	1=male and 0=female	±
Household_size	Size household	number of members	+
Head_age	Age of household head	number of years	±
Farming_ experience	Farming experience	number of years	+
Extension	Access to extension services	1=yes and 0=no	+
Credit	Access to credit	1=yes and 0=no	+
Electricity	Access to electricity	1=yes and 0=no	+
Markets	Distance to markets	Km	-
Heavy_machines	Own heavy machines	1=yes and 0=no	+
Farm_size	Farm size	hectares	+

Seasonal climate variables: Differences in seasonal temperature and precipitation across regions influence farmers' choices of adaptation measures. Empirical studies measuring the economic impacts of climate change on agriculture in Africa (Kurukulasuriya & Mendelsohn 2007a; Seo & Mendelsohn 2007a; Mano & Nhemachena, 2007; Benhin, 2006) showed that climate attributes (temperature and precipitation) significantly affect net farm revenue and such impacts can be significantly reduced through adaptation. Regional African studies have shown that choice of different crops and livestock species is sensitive to seasonal climate variables (Kurukulasuriya & Mendelsohn, 2007b; Seo & Mendelsohn, 2007b). Crop choice analysis by Kurukulasuriya and Mendelsohn (2007b) found that the choice of different crops is affected in various ways by seasonal climate variables. Livestock choice analysis by Seo and Mendelsohn (2007b) found that the choice of beef cattle had an inverted U-shaped shaped probability response to summer temperature, while winter temperature had a U-shaped response for both beef cattle and sheep, and was an inverted U-shaped for dairy cattle and goats.

The studies cited illustrate the importance of seasonal climate variables in influencing farmers' choice decisions. To capture the effects of seasonal variations in climate on the uptake of adaptation measures, this study included seasonal temperature and precipitation variables in the empirical specification. The same definitions and adjustments of seasons used by Kurukulasuriya and Mendelsohn (2007a), as indicated in chapter 4, were used in this study to cater for uneven distribution of rainfall and temperature across Africa, as well as seasonal differences in the southern and northern hemispheres. It is a hypothesis of this study that dryer and warmer climates favour livestock production and irrigation but reduce the incidence of crop cultivation, especially under rain-fed conditions.

Farmer socioeconomic attributes: Empirical adoption literature shows that *household size* has mixed impacts on farmers' adoption of agricultural technologies. Larger family size is expected to enable farmers to implement various adaptation measures when these are labour intensive (Nyangena, 2006; Dolisca, Carter, McDaniel, Shannon & Jolly, 2006; Anley et al., 2007; Birungi, 2007). Alternatively, large families might be forced to divert part of their labour force to non-farm activities to generate more income and reduce consumption demands of the large family (Tizale, 2007). However, the opportunity cost of labour might be low in most smallholder farming systems as off-farm opportunities are rare. Although farmers can hire extra labour, most rural farmers are cannot afford to do so, thus limiting their ability to take on labour intensive crop and livestock activities. The current study hypothesise that multiple cropping, irrigation and mixed farming systems are more labour intensive and hence expects a positive influence of family size on the adoption of such adaptation options. This implies that farm households with more labour are better able to take on adaptations in response to changes in climatic conditions.

The influence of *age* on adoption decision has been found in the literature to be varied. Some studies found that age had no influence on a farmer's decision to participate in forest, soil and water management activities (Bekele & Drake, 2003; Zhang & Flick, 2001; Anim 1999; Thacher, Lee & Schelhas, 1997). Other studies, however, found that age is significantly and negatively related to farmers' decisions to adapt (Anley et al., 2007; Dolisca et al., 2006; Nyangena 2006; Burton et al., 1999; Lapar & Pandely, 1999; Featherstone & Goodwin, 1993; Gould, Saupe & Klemme, 1989). However Bayard, Jolly and Shannon (2007), and Okoye (1998) found that age is positively related to the adoption of conservation measures. This study hypothesises that the age of the head of household has both positive and negative impacts on different adaptation measures. One assumes that old age is associated with more experience and we expect older farmers to adapt to changes in climate. However, we also expect young farmers to have a longer planning horizon and to thus take up long-term adaptation measures such as irrigation and mixed crop–livestock systems.

Various studies have shown that *gender* is an important variable affecting adoption decision at the farm level. Female farmers have been found to be more likely to adopt natural resource management and conservation practices (Bayard et al., 2007; Dolisca et al., 2006; Burton et al., 1999; Newmark, Leonard, Sariko & Gamassa, 1993). However, some studies found that household gender was not a significant factor influencing farmers' decision to adopt conservation measures (Bekele & Drake, 2003). This study hypothesises that there are significant differences between female and male headed households in their ability to adapt to climate change, due to major differences between them in terms of access to assets, education and other critical services such as credit, technology and input supply.

Education, farming experience and perceptions are important factors influencing adoption decisions. Several studies have shown that improving education and knowledge are important policy measures for stimulating local participation in various development and natural resource management initiatives (Anley et al., 2007; Tizale, 2007; Dolisca et al., 2006; Glendinning, Mahapatra & Mitchell, 2001; Higman, Bass, Judd, Mayers & Nussbaum, 1999; Anim, 1999; Lapar & Pandely, 1999; Traore, Landry & Amara, 1998; Heinen, 1996; Shields et al., 1993; Anderson & Thampallai, 1990; Bultena & Hoiberg, 1983). Better education and more farming experience improve awareness of potential benefits and willingness to participate in local natural resource management and conservation activities. However Clay, Reardon and Kangasniemi (1998) found that education was an insignificant determinant in influencing adoption decisions, while Okoye (1998) and Gould et al. (1989) found that education was negatively correlated with adoption. Educated and experienced farmers are expected to have more knowledge and information about climate change and agronomic practices that they can use in response to climate challenges (Maddison, 2007). This study expects that improved knowledge and farming experience will positively influence farmers' decisions to adopt different adaptation measures.

Awareness of the problem and potential benefits of taking action is another important determinant of adoption of agricultural technologies. Maddison (2007) found that farmers' awareness of changes in climate attributes (temperature and precipitation) is important for adaptation decision making. Several studies found that farmers' awareness and perceptions of soil erosion problems positively and significantly affected their decisions to adopt soil conservation measures (Araya & Adjaye, 2001; Anim, 1999; Traore et al., 1998; Gould et al., 1989). This study expects that farmers who notice and are aware of changes in climate will take up adaptation measures that help them reduce losses or take advantage of the opportunities associated with these changes. In this study *awareness* is represented by the variable "Noticed_climate_change" in Table 6.4

Farm assets and wealth factors: Empirical adoption studies have found mixed effects of *farm size* on adoption. For example, a study on soil conservation measures in South Africa showed that farm size was not a significant adoption factor (Anim, 1999). Other studies, however, found that farmers with larger farms had more land to allocate for the construction of soil bund and improved cut-off drains in Haiti (Anley et al., 2007) and Nigeria (Okoye, 1998). On the contrary, Nyangena (2006) found that farmers with small land sizes were more likely to invest in soil conservation practices, compared to those with large land sizes. This study hypothesises that farmers with more land will adopt measures that require more land such as livestock systems, while farmers with small farms are expected to diversify their options.

Various studies of determinants of soil and water conservation technologies have shown that *farm assets* (e.g. machinery) significantly affect adoption decisions (e.g. Lapar & Pandely, 1999; Barbier, 1998; Pender & Kerr, 1998). Kurukulasuriya and Mendelsohn (2007a) found that ownership of heavy machinery significantly and positively increased net farm revenue on African cropland. This study expects that ownership of more farm assets (land and machinery) improves the ability of farmers to adapt.

Access to agricultural services: Extension services are an important source of information on agronomic practices as well as on climate. Extension education was found to be an important factor motivating increased intensity of use of specific soil and water conservation practices (De Harrera & Sain, 1999; Traore et al., 1998; Tizale, 2007; Baidu-Forson, 1999; Anderson & Thampallai, 1990; Bekele & Drake, 2003). In Haiti farmers with better access to extension services were more likely to adopt improved cut-off drain and fanyajuu[15] technologies (Anley et al., 2007). Other adoption studies,

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[15] Kiswahili: 'Throw it upwards.' 'Terrace bund in association with a ditch, along the contour or on a gentle lateral gradient. Soil is thrown on the upper side of the ditch to form the bund, which is often stabilised by planting a fodder grass.' WOCAT (World Overview of Conservation Approaches and Technologies).

however, have found that extension is not a significant factor affecting adoption of soil conservation measures (Birungi, 2007; Nkonya, Pender, Kaizzi, Kato & Mugarura, 2005; Pender, Ssewanyana, Kato & Nkonya, 2004). This study postulates that availability of better climate and agricultural information helps farmers to make comparative decisions among alternative crop management practices and hence to choose those that enable them to cope better with changes in climatic conditions (Baethgen, Meinke & Gimene, 2003; Jones, 2003; Kandlinkar & Risbey, 2000).

Several studies have shown that *access to credit* is an important determinant enhancing the adoption of various technologies (Tizale, 2007; Hassan, Kiarie, Mugo, Robin & Laboso, 1998; Yirga, Shapiro & Demeke, 1996; Anderson & Thampallai, 1990; Kandlinkar & Risbey, 2000). With more financial and other resources at their disposal, farmers are able to make use of all available information they might have to change their management practices in response to changing climatic and other conditions. For instance, with financial resources and access to markets, farmers are able to buy new crop varieties, new irrigation technologies and other important inputs they may need to change their practices to suit forecasted climatic changes.

Market access [16] is another important factor affecting the adoption of agricultural technologies (Feder, Just & Zilberman, 1985). Input markets allow farmers to acquire the necessary inputs they might need for their farming operations, such as different seed varieties, fertilizers, and irrigation technologies. Furthermore, access to output markets provides farmers with positive incentives to produce cash crops that can help improve their resource base and hence their ability to respond to changes in climatic conditions (Mano, Isaacson & Dardel, 2003). Long distances to markets decreased the probability of farm adaptation measures in Africa (Maddison, 2007). Madison (2007) also noted that markets provide an important platform for information gathering and sharing for farmers. Lapar and Pandely (1999) found that in the Philippines, access to markets significantly

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http://www.fao.org/ag/agl/agll/wocat/wqtsum2.asp?questid=KEN05 Accessed 3 March 2008.

[16] For this study the assumption is that farmers used the same market for purchasing input and selling output.

affected use of conservation technologies by farmers. Nyangena (2006) showed that in Kenya, distance to markets negatively and significantly affected use of soil and water conservation technologies.

Access to *electricity* was found to be an important factor explaining crop choice (Kurukulasuriya & Mendelsohn, 2007b) and livestock choice (Seo & Mendelsohn, 2007). Household access to electricity and ownership of heavy machinery may reflect either higher levels of technology use and/or market access. Farmers with better access to higher levels of technology and market access are expected to be able to take up adaptation measures that require high levels of technology use, such as irrigation systems.

Econometric estimation of empirical model parameters

Econometric analysis with cross-sectional data is usually associated with problems of heteroscedacity and multicollinearity (Cameron & Trivedi, 2005; Green, 2003). Multicollinearity among explanatory variables can lead to imprecise parameter estimates. To explore potential multicollinearity among the explanatory variables, the correlation between continuous independent variables was calculated (Appendix 2). The results of the correlation analysis indicated that seasonal climate variables were highly correlated and therefore spring had to be combined with the winter season, and fall with the summer season. For dummy variables the chi-square test for independence was used to determine dependencies between variables. An Ordinary Least Squares model was fitted and the model was tested for multicollinearity using the variance inflation factor (VIF) (see Appendix 3). The variance inflation factors of all included variables are less than 10, which indicate that multicollinearity is not a serious problem in the reduced model.

In spite of the high multicollinearity detected between seasonal climate attributes, the empirical model was estimated with: (a) all four seasons separately, and (b) combined seasonal variables that collapsed the four seasons into two. As expected, empirical model estimation results confirmed the superiority of the combined season variables, and hence subsequent sections report only results obtained from this specification. Moreover, high multicollinearity was also observed between measures of perceptions of long-term changes in climate and a number of key explanatory variables, particularly farmers' characteristics such as education, age, experience and access to extension and credit, suggesting that perceptions may be endogenous to farmers' choices. This was confirmed by the poor statistical performance of preliminary regression runs, including perception factors which were accordingly excluded from the final empirical specifications.

To address the possibilities of heteroscedacity in the model, a robust model was estimated, that computes a robust variance estimator based on a variable list of equation-level scores and a covariance matrix (StataCorp, 2005).

Another potential limitation associated with estimating a MNL model is its restrictive assumption of independence of irrelevant alternatives (IIA). Based on the IIA assumption, the ratio of the utility levels between two choices (such as multiple crops under irrigation and mixed crop–livestock under dryland) remains constant, irrespective of choices made (Hausman & McFadden, 1984). We used the Hausman test (Hausman & McFadden, 1984) to check for the validity of the IIA assumption using STATA software (StataCorp, 2005). The results from the Hausman test indicate that we fail to reject the null hypothesis of independence of the adaptation measures under consideration. The results imply that the application of the MNL specification to model the determinants of adaptation measures is justified.

6.5 Results and discussions

Table 6.5 presents the estimated marginal effects and P-levels from the multinomial logit model and the estimated coefficients are given in Appendix 4. The results show that most of the explanatory variables are statistically significant at 10 percent or lower, and the signs on most variables are as expected, except for a few, which are discussed below. The chi-square results show that the likelihood ratio statistics is highly significant (P<00001) suggesting a strong explanatory power of the model.

Table 6.5: Marginal effects of explanatory variables from the multinomial logit adaptation model

Variable	**MLCRIRRIG**	**MLCRDRY**	**MOCRLSDR**	**MOCRLSIR**	**MLCRLSIR**	**MLCRLSDR**
	Marginal effects	**Marginal effects**	**Marginal effects**	**Marginal effects**	**Marginal effects**	**Marginal effects**
Winter-spring temp (°C)	0.0634***	-0.1490***	-0.0259	0.0732***	0.0982***	0.0403***
Summer-fall temp (°C)	0.0774***	0.1041**	-0.0031	0.0965***	0.0791***	0.0828***
Winter-spring precip (mm)	-0.0034***	0.0128***	0.0005	-0.0013*	0.0058***	0.0130***
Summer-fall precip (mm)	-0.0008	0.0531***	0.0412**	-0.0003	-0.0012	0.0649***
Extension contact (1/0)	0.0950***	0.0311	0.4847***	0.1212**	0.2521***	0.0518*
Access to credit (1/0)	0.0363*	0.0013	0.3593***	0.0713*	0.3324*	0.1383*
Distance to market (km)	-0.0086*	0.0009	0.0033***	-0.0024***	-0.0050***	0.0037
Male-headed household (1/0)	0.1443***	-0.2796	-0.0242	-0.2065***	0.0913***	-0.0493**
Household head age (years)	-0.0012	-0.0055	0.0017	-0.0018*	0.0042	0.0024
Household size	0.0146***	0.0148*	-0.0617***	-0.0208***	0.0462***	0.0316**
Farming experience (years)	0.0032***	0.0109***	0.0147***	0.0051***	0.0103***	0.0291***
Farm size (ha)	-0.0005*	0.0019**	0.0008**	0.0001	-0.0048***	0.0024
Own heavy machines (1/0)	0.1147***	-0.1520	-0.2981***	0.1579***	0.1185***	-0.0593***
Access to electricity (1/0)	0.2150***	-0.0414***	0.0209***	0.0938***	0.1019***	-0.0999***
Number of observations	**7327**					

*; **; *** significant at 10%; 5% and 1% respectively

Key: MLCRIRRG: Multiple crops under irrigation; MLCRDRY: Multiple crops under dryland; MOCRLSDR: Mono crop-livestock under dryland; MOCRLSIR: Mono crop-livestock under irrigation; MLCRLSIR: Multiple crop-livestock under irrigation; MLCRLSDR: Multiple crop-livestock under dryland.

As mentioned earlier, this analysis uses *specialised (mono) cropping* as the base category for no adaptation and evaluates the other choices as alternatives to this option. The first column of Table 6.5 for instance, compares the choice of multiple crops under irrigation (MLCRIRRIG) over no adaptation, where the marginal effects and their signs reflect the expected change in probability of preferring to grow multiple crops under irrigation over mono cropping (the base) per unit change in an explanatory variable. The same applies to the remaining choices in the table.

The marginal effects measure the expected change in probability of a particular choice being made with respect to a unit change in an explanatory variable (Green, 2000; Long, 1997). The signs of the marginal effects and respective coefficients may be different, as the former depend on the sign and magnitude of all other coefficients. The marginal probabilities in the MNL model as a result of a unit change in an independent variable sum to zero, since expected increases in marginal probabilities for a certain option induce concomitant decreases for the other option(s) within the choice set. The interpretation of the marginal effects is dependent on the units of measurement of the independent variables. For instance, a unit increase in the winter-spring temperature would result in a 6.3% and 9.8% increase in the probability of using multiple crops under irrigation (MLCRIRRG) and multiple crop–livestock under irrigation (MLCRLSIR). Also, a unit increase in access to extension for an average farmer would result in a 9.5%, 4.8% and 25.21% increase in the probability of using multiple crops under irrigation (MLCRIRRG), mono crop–livestock under dryland (MOCRLSDR) and multiple crop–livestock under irrigation (MLCRLSIR). In all cases, the estimated coefficients should be compared with mono cropping (the base alternative).

The results suggest that warmer winter–spring promotes switching to use of irrigation, multiple cropping and mixing crop and livestock activities, especially under irrigation (MLCRIRRG, MOCRLSIR and MLCRLSIR). Warming in summer–fall also tends to be associated with shifting away from mono-cropping (MOCRLSDR and MOCRLSIR). While it is clear that irrigation is the strongest adaptation measure against warming for all systems, mixing livestock with crop cultivation seems to work only with multiple cropping under dryland conditions (MLCRDRY).

Dryland farming (MLCRDRY, MOCRLSDR and MLCRLSDR) tends to dominate in better watered regions (i.e. in wetter summer-fall and winter-spring seasons). In other words, the dryer it gets the higher the demand for irrigation. The biggest influence on the probability of switching away from mono-cropping (MOCRLSDR and MOCRLSIR) is associated with changes in summer-fall precipitation compared to changes in winter-spring rainfall levels. Similarly, the magnitude of the marginal coefficients suggests that warming is the stronger factor influencing the probability of switching to more adapted systems based on changes in precipitation. That means the risks of mono-cropping are higher with warming in general.

Better access to extension and credit services seems to have strong positive influence on the probability of adopting all adaptation measures and abandoning the relatively risky mono-cropping systems (MOCRLSDR and MOCRLSIR). Access to electricity is strongly associated with the use of irrigation (MLCRIRRG, MOCRLSIR and MLCRLSIR). This could be due to the fact that the bulk of irrigation water in Africa is supplied from dams that are also used for power generation. Similar to the effect of electricity, proximity to markets appears to be associated with the use of irrigation.

The results indicate a positive relationship between distance to market and adaptation to dryland farming. That is, the further away the market the higher the probability to adapt to dryland farming. Based on this finding, dryland farmers appear to have relatively poorer access to markets (i.e. market development tends to concentrate within irrigation areas). At the same time, remoteness from markets tends to favour multiple cropping and mixing of livestock and crops over specialised crop cultivation. This is an indication that more market integration promotes specialisation in production and hence is an important area for public investment in adaptation infrastructure.

Larger families are able to practice multiple cropping, whereas smaller families tend to practice only mono-cropping with a livestock activity, whether under dryland or irrigation (MOCRLSDR and MOCRLSIR). This suggests that multiple cropping is more labour demanding. Larger farm sizes appear to be associated with dryland systems (MLCRDRY, MOCRLSDR and MLCRLSDR), suggesting a relatively higher population density or scarcer land resources within irrigation agriculture in Africa. This probably reflects the effect of Egypt, which is the typical case of a very high man-to-land ratio and 100% irrigation agriculture. Better access to other farm assets, such as heavy machinery, is found to promote the use of irrigation and mixing of livestock with cropping activities. These results suggest that capital, land and labour serve as important factors for coping with and adapting to climate change. The choice of the suitable adaptation measure depends on factor endowments (i.e. family size, land area and capital resources) at the disposal of farming households.

More experienced farmers are more likely to adapt, compared to those with less farming experience. The age of the farmer, on the other hand, does not seem to be of significance in influencing adaptation, as almost all marginal effect coefficients are statistically insignificant and their signs do not suggest any particular pattern. These results suggest that it is experience rather than age that matters for adapting to climate change. The data do not suggest a clear cut effect for the gender factor, other than that male-headed households are more likely to adapt by switching from mono cropping to irrigation, multiple cropping and mixed systems (MLCRIRRG, MLCRLSIR), compared to female-headed farming families who tend to switch to mono crop–livestock under irrigation (MOCRLSIR) and multiple crop–livestock under dryland (MLCRLSDR).

6.6 Summary and policy implications

This chapter analysed actual adaptation choices made by farmers based on a cross-section survey of over 8000 farming households from 11 countries in Africa. The main practices actually followed by farmers during the survey year (2002) are implemented mostly in combination with other measures and not alone. The different combinations of measures and practices are grouped into three major adaptation options: diversifying into multiple crops and mixed crop–livestock systems, switching from crops to livestock, and switching from dryland to irrigation.

A multinomial discrete choice model was used to analyse the determinants of farm-level adaptation measures. The results show that warming in all seasons promoted adoption of irrigation, multiple cropping and mixed crop–livestock systems. Farmers appear to abandon mono-cropping as temperatures get warmer. With most parts of the region already warm and dry, any further warming will compel farmers to take up various irrigation and multiple and mixed crop–livestock adaptation measures.

On the other hand, more rainfall reduces the probability of choosing irrigation. The influence of changes in the summer-fall precipitation is stronger than winter rainfall effects on the probability of switching away from mono-cropping. As most of the farming systems in Africa rely on rainfall, increased precipitation would be beneficial to dryland crop systems. Alternatively, low rainfall in all seasons induces the need for irrigation to buffer the negative impacts on agricultural production during dry periods. At the same time, limited rainfall also implies reduced availability of water for irrigation; thus it is important for policies to support efficient and effective irrigation systems. Nevertheless, the results suggest that warming influences on the probability of switching to more adapted systems are more powerful compared to the effects of changes in rainfall. That means that the risks of mono-cropping under dryland conditions are higher with warming in general.

More farming experience was found to promote adaptation. Experienced farmers usually have better knowledge and information on climate change and agronomic practices that they can use to cope with changes in climate and other socio-economic conditions. This suggests that farmers' education to improve their awareness of the potential benefits from adaptation is an important policy measure for stimulating farm-level climate adaptation.

Results of the empirical analyses confirm the role of improved access to information (climate and production) and credit in enhancing farmers' awareness, which is crucial for adaptation decision making and planning. Combining access to extension services and credit ensures that farmers have the information for decision making and the means to take up adaptation measures. Policies aimed at promoting farm-level adaptation need to emphasise the critical role of providing information (through extension services) and the means to implement adaptations through affordable credit facilities.

Other enabling factors of significant potential in promoting adaptation, especially the use of irrigation and intensive livestock production systems (which are usually capital intensive), are household access to electricity and ownership of farm capital (such as machinery). Improving access to technology such as electricity and machines increases the chances of farmers taking up adaptation measures.

Better access to markets reduces transport and other market-related transaction costs, and enhances the uptake of farm-level adaptation measures. For instance, better access to markets enables farmers to buy new crop varieties, new irrigation technologies and other important inputs they may need to change their practices in order to cope with predicted changes in climate. This study reveals that market development in Africa tends to concentrate within irrigation agricultural areas, and hence there is a need to improve the relatively poor access of dryland farmers to markets.

Larger farm sizes were found to encourage the use of multiple cropping and integration of a livestock component, especially under dryland conditions. Large farm sizes allow farmers to diversify their crop and livestock options and help to spread the risk of losses associated with changes in climate. This suggests that availability of labour may be a critical factor constraining the switch away from the risky mono-cropping systems.

The above findings illustrate the importance of government policies and strategic investment plans that support improved access to climate forecasting, research in the development of and information about appropriate farm-level climate adaptation technologies, access to credit, farmer education, and market development especially in areas where dryland farming currently dominates.

Chapter 7

Summary, conclusions and implications for policy and research

This study had two main objectives. The first main objective was to measure the aggregate impact of climate change on net revenue from all agricultural production systems (crop, livestock and mixed) in Africa, and to predict future impacts under various climate scenarios. In addition to measuring economic impacts, the second objective of the study was to analyse determinants of farmers' choices between alternative adaptation measures available to African farmers. The empirical estimations were based on a cross-section survey of over 8000 farming households collected by the GEF/WB/CEEPA Africa study on climate change and agriculture. The study covered eleven countries: Burkina Faso, Cameroon, Egypt, Ethiopia, Ghana, Kenya, Niger, Senegal, South Africa, Zambia and Zimbabwe.

Other studies based on the GEF Project estimated the economic impacts of climate change on African agriculture. These studies, however, analysed impacts on dryland crops, irrigated crops and livestock separately. This represents an important limitation, since the choice between crop and livestock production, or their combination (mixed systems), must be considered an endogenous decision made by agricultural producers in response to varying climates and other circumstances. The decision as to what to produce and how to produce it is accordingly an important adaptation mechanism in the face of changing climate and other ecological economic circumstances. This is of special importance for Africa, where the majority of poor small-scale farmers practise mixed crop–livestock agriculture and few depend on crops or livestock only (Dixon et al., 2001).

An important contribution of this study is measuring the aggregate impact of climate change on income from all agricultural production systems (crop, livestock and mixed) in Africa, and predicting future impacts under various climate scenarios. In addition to estimating impacts on mixed crop–livestock farms, the study also measured and compared impacts on specialised crop and livestock farms. The results were contrasted with findings of other regional studies using the same data, but generating different climate response functions for crop and livestock farming separately. Another important contribution of the Ricardian cross-sectional approach used in this study is its ability to incorporate autonomous adaptation mechanisms. Such private adaptation initiatives involve adjustments that have been made by farmers in response to changes in climatic and non-climatic conditions, to increase their profits.

To achieve the first objective, the study adopted the cross-section (Ricardian) approach to measure the impact of change in climate attributes (rainfall and temperature levels) on income from all agricultural production systems (crop, livestock and mixed) in Africa, controlling for other production factors. The analyses controlled for effects of key socio-economic, technology, soil and hydrological factors influencing agricultural production.

The results show that larger farm sizes appear to have a strong positive influence on net farm revenues across all farm types, suggesting that more land allows farmers to produce more crop and livestock enterprises per farm, thus leading to more income. Further, results show that larger families are associated with higher net farm revenues across all farm types. Better access to other farm assets, such as heavy machinery like tractors, appears to strongly and positively influence net farm revenues for all farms, mixed crop–livestock farms and specialised crop farms. These results suggest that capital, land and labour serve as important production factors in African agriculture. National policies need to invest more in improving factor endowments (i.e. family size, land area and capital resources) at the disposal of farming households, in order to enhance farm performances in the face of climate change.

Better access to extension services seems to have strong positive influence on net farm revenue on all farms, mixed crop–livestock farms and specialised crop farms. Improving access to extension ensures that farmers have the information for decision making to improve their production activities. Policies aimed at improving farm-level performance need to emphasise the critical role of providing information (through extension services) to enhance farm-level decision making.

Improving access to technology such as electricity has significant potential in improving farm-level production activities and hence net revenues. For example, the use of irrigation and intensive livestock production systems (which are usually capital intensive), increases when farmers have access to technologies like electricity and other machinery. Improving access to technology such as electricity and machines is therefore important to enhance agricultural production in the face of climate change.

Results from the marginal analysis of the impacts of seasonal climate variables show that net farm revenues are in general negatively affected by warmer and dryer climates. The small-scale mixed crop and livestock system predominant in Africa is the most tolerant system, whereas specialised crop production is the most vulnerable to warming and lower rainfall. For example, a one degree increase in summer temperature resulted in net revenue losses of $98, $189 and $195 per farm for dryland: mixed crop–livestock farms, specialised crop and specialised livestock farms respectively. In all farm types, dryland farms are the worst affected by increases in warming and drying, compared to irrigated farms. Predictions of future climate impacts also indicate that mixed crop–livestock and irrigated farms are less sensitive to climate changes and will experience fewer damages, compared to highly sensitive dryland and specialised crop or livestock farms.

Generally farming systems located in dry semi-arid and arid regions (for example most southern parts of the continent) will suffer most from increases in warming and drying compared to more humid regions. This is likely because of farming systems that are based on natural rainfall (which is unreliable and inadequate) and the prevalence of mono cropping. The results confirm the negative impact of climate change on African agriculture (e.g. Kurukulasuriya & Mendelsohn, 2007a, 2007b; Seo & Mendelsohn, 2007a; Kurukulasuriya et al., 2006) with differing impacts for various systems and scales of farming. It is therefore important for Africa to enhance adaptation efforts both at the micro (farm) and macro (national) levels. Governments need to integrate adaptation strategies into national economic policies, and strengthen micro-level adaptations (such as: diversifying into multiple crops and mixed crop–livestock systems, switching from crops to livestock and from dryland to irrigation), to help farmers reduce potential damage from climate change.

These results have important policy implications, especially regarding the suitability of the increasing tendency toward large-scale mono-cropping strategies for agricultural development in Africa and other parts of the developing world, in the light of expected climate changes. Mixed crop and livestock farming and irrigation offer better adaptation options for farmers against further warming and drying predicted under various future climate scenarios.

For the second objective, the study employed a multinomial choice model to analyse determinants of farm-level climate adaptation measures in Africa. This analysis is different from the analysis carried by Maddison (2007) and all other adaptation studies, in that actual adaptation measures being taken by farmers were considered, using the same sample of African farmers, and based on farmers' perceived adaptations. This study also considered the choice between many adaptation measures simultaneously. This can be compared with studies that analysed such joint endogenous decisions in separate analyses for crop selection (Kurukulasuriya & Mendelsohn, 2007b), irrigation modelling (Kurukulasuriya & Mendelsohn, 2007c), and livestock choice (Seo & Mendelsohn, 2007b). The integrated approach of this study is very important in directing policy to influence the appropriate choice of adaptation mechanisms. Accordingly this study provides an important contribution to knowledge on the economics of climate and adaptation in the agriculture sector in Africa.

The results of the empirical analysis of determinants of adaptation choices indicate that specialised crop cultivation (mono-cropping) is the most vulnerable agricultural practice in Africa in the face of climate change. Based on these findings, there is a trade-off between economies of scale and vulnerability to climate change. Warming, especially in summer, poses the highest climate risk which tends to promote switching away from mono-cropping towards the use of irrigation, multiple cropping and integration of livestock activities. Increased precipitation reduces the probability of irrigation and will be beneficial to most African farming systems, especially in drier areas. Better access to markets, extension and credit services, technology and farm assets (such as labour, land and capital) are critical enabling factors to enhance the capacity of African farmers to adapt to climate change.

An important policy message indicated by the results might be the need for more within-country, region-specific adaptation plans depending on predicted changes in temperature and precipitation. Furthermore, government policies and investment strategies that supports the provision of and access to markets, credit, and information on climate and adaptation measures, including suitable technological and institutional mechanisms that facilitate climate adaptation, are required for coping with climate change, particularly among poor resource farmers in the dry areas of Africa.

As indicated above, the first part of the study assessed the impact of climate change on agricultural systems across Africa, and the second part evaluated the determinants of various adaptation mechanisms used by African farmers. The former applied a (cross-sectional) Ricardian approach, while the later used a multinomial logit model. The study differs from other studies in that the former objective considered the whole agricultural system and measured the impacts on a per farm basis, incorporating crop, livestock and mixed-farming enterprises, and correcting for the endogeneity problems associated with studies that focus on only crop or livestock farming. The results of the first analysis confirm the negative impact of climate change, with differing impacts for different systems and scales of farming. More important is the contribution of the latter analysis, relating to the clear categorisation of six possible adaptations options available to African farmers, and the degree of probability of choice among these options, given changes in precipitation, temperature and other socio-economic variables. These findings are very important in terms of directing policy to influence appropriate choices of adaptation mechanisms.

7.1 Limitations of the study and areas for further research

The study has some limitations that readers should bear in mind. First, combining net revenue from crop and livestock production caused some problems. Crop net revenues could be calculated for each unit of land used. The same was not possible for livestock production, where many smallholder farmers rely on communal grazing lands. This required the analyses to be on a per farm basis, and not per hectare. Furthermore, categorising farms into specialised crop, livestock and mixed crop–livestock enterprises was based on a subjective assessment of the proportion of land under crops and the number of livestock units on a farm. Although this categorisation made it possible to assess the impacts on these different systems, future studies will need to capture the type of farming system at the outset. Despite this limitation, the results of the study generally show that agricultural production, especially dryland systems, will be adversely affected by climate change, which agrees with other studies based on per hectare crop/farm revenue (see Kurukulasuriya et al., 2006; Kurukulasuriya & Mendelsohn, 2007a, 2007b; Seo & Mendelsohn, 2007a).

Another limitation of this study is the restrictive assumptions of the Ricardian cross-sectional method used for the economic analysis. The method assumes that future economic structures and behaviour will replicate the past. However, economic variables such as prices, policy (e.g. trade restrictions, subsidies and taxes) and technology that may influence net revenue vary over time. Predicted impacts based on the Ricardian cross-sectional method reflect current agricultural policies, and fail to account for future policy and other structural economic changes. Further, the model fails to account for spatial and temporal variability in climate variables (temperature and precipitation). Future variations in climate variables may not follow the same past patterns, and variations in climate across space are not necessarily the same as changes over time.

The challenge for future research is to correct for the restrictive assumptions of the cross-sectional method. This analysis was based on cross-sectional data and assumed that prices remain constant. However, welfare calculations based on such an assumption underestimate damages and overestimate benefits as they omit consumer surplus (Cline, 1996). For example, if large and widespread changes in climate result in long-term sustained changes in crop prices, the Ricardian estimates would be inaccurate and the resulting price changes would determine the magnitude and direction of error (Schimmelpfenning et al., 1996). Estimations that fail to take price changes and other factors into account will produce biased estimates of impacts of climate change. Policy recommendations based on such results would be inaccurate and might lead to misdirection and mismanagement of limited resources.

However, Mendelsohn (2000) argues that it is difficult to include the effects of price changes using any method. Given that prices of most crops are determined in the world market, predictions of the likely effects of climate change on each crop would require a global model. However, global crop models are poorly calibrated, making it difficult to predict the likely impacts of the new climate on each crop. In addition, global models predict small aggregate changes on aggregate supply in the 21st century (Reilly, Hohmann & Kane, 1994; Reilly et al., 1996). Furthermore, assuming moderate aggregate changes in supply will have a relatively small bias on estimates of future impacts of climate change. The assumption of constant prices may not be a serious problem for the Ricardian approach, unless there are catastrophic changes in climate (Mendelsohn, 2000).

Furthermore, the Ricardian method fails to account for the effects of variables that do not vary across space, for example, the effects of carbon fertilization. To address this problem, although not done in this study, cross-sectional approaches can be used to provide experimental evidence of the likely impacts of higher carbon dioxide levels in the future.

Another important limitation of this study is the fact that it includes all crops in one category and all livestock types in another category. Different crop types and different animal species among livestock types are impacted differently by climate change and hence there is a need for further disaggregation. While the selection of animal and crop types was beyond the scope of this study, given the broad scale of the analysis conducted, it is recommended, as a second step, to conduct more crop and animal type-specific analyses. This is necessary since farm-level adaptation is conditioned by local circumstances and the specifics of the available options for various agricultural activities.

There are other adaptation options available to farmers that are not considered in the groupings considered in this study. For instance, under the above combinations of adaptation measures farmers may vary planting dates, use different crop varieties, and implement fertilizers, pesticides, soil and water conservation techniques, and insurance measures. Considering all these options however, would lead to a very large number of factorial combinations that would be difficult to analyse within one empirical model. Nevertheless, some of these factors measured by the survey were included as explanatory variables in the empirical analyses that were conducted (e.g. technology factors).

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Appendix 1A: Regression results for dryland farms

Variable name	All farms	Mixed crop-livestock farms	Specialised crop farms
Winter temperature	-0.534	-0.350	-1.514**
Spring temperature	-0.562	-0.527	-0.389
Summer temperature	-0.058	0.350	-0.742
Fall temperature	1.173**	0.436	3.206***
Winter precipitation	0.035***	0.033***	0.045***
Spring precipitation	-0.025***	-0.024***	-0.034**
Summer precipitation	0.013***	0.016***	0.010
Fall precipitation	-0.001	-0.007	0.012
Winter precipitation squared	-0.000***	-0.000**	-0.000*
Spring precipitation squared	0.000***	0.000**	0.000**
Summer precipitation squared	-0.000	-0.000	0.000
Fall precipitation squared	0.000	0.000*	-0.000
Winter temperature squared	0.005	0.001	0.023*
Spring temperature squared	0.009	0.010	0.002
Summer temperature squared	-0.005	-0.011*	0.009
Fall temperature squared	-0.010	0.001	-0.042***
Orthic Ferralsols (foFU)	-0.244	-0.375	-0.056
Fluvisol (jcMFU)	1.096	1.005	-0.087
Ferric Luvisols (lfU)	-0.421**	-0.765***	0.176
Ferric Luvisols (lfCU)	0.383***	0.280*	0.794**
Cambic Arenosols (qc)	0.316	0.312	-0.097
Luvic Arenosol (qlCU)	0.519***	0.458***	1.485***
Chromic luvisols (lCU)	0.605***	0.694***	-3.133***
Farmland (ha)	0.656***	0.689***	0.581***
Mean water flow	0.009***	0.007***	0.019***
Household has tractor	0.431***	0.307*	0.958***
Household access to extension	0.143***	0.150**	0.174*
Household access to electricity (Yes/No)	0.202***	0.236***	0.074
Household size (Num. of people)	0.198***	0.146**	0.324***
Using irrigation (Yes/No)			
Mixed crop-livestock Yes/No)	0.420***		
Specialised crop (Yes/No)	0.566***		
North & East Africa (Yes/No)	-0.252	-0.555*	0.881*
Southern Africa (Yes/No)	-2.100***	-1.879***	-3.108***
Constant	5.021*	8.541***	-9.863*
R Square	0.5087	0.4457	0.6535
N	4303	3237	1010

Appendix 1B: Regression results for irrigated farms

Variable name	All farms	Mixed crop-livestock farms	Specialised crop farms
Winter temperature	-0.993**	-1.106**	-1.056
Spring temperature	1.028**	1.313***	0.626
Summer temperature	0.317	-0.476	-0.108
Fall temperature	-0.531	0.148	0.355
Winter precipitation	0.040***	0.037***	0.031
Spring precipitation	-0.036**	-0.003	0.012
Summer precipitation	0.043***	0.041***	-0.012
Fall precipitation	-0.016*	-0.012	0.022
Winter precipitation squared	-0.000	-0.000	0.000
Spring precipitation squared	0.000***	-0.000	-0.000
Summer precipitation squared	-0.000***	-0.000***	0.000
Fall precipitation squared	0.000***	0.000***	0.000
Winter temperature squared	0.007	0.008	0.002
Spring temperature squared	-0.010	-0.015**	0.003
Summer temperature squared	-0.015	-0.004	-0.006
Fall temperature squared	0.022	0.013	0.005
Orthic Ferralsols (foFU)	-1.185	-2.746	0.977
Fluvisol (jcMFU)	0.354*	0.313	0.988
Ferric Luvisols (lfU)	-4.117	-10.053**	
Ferric Luvisols (lfCU)	1.021***	0.868**	1.656*
Cambic Arenosols (qc)	0.689*	1.160***	-1.221
Luvic Arenosol (qlCU)	0.934***	0.768***	-0.820
Chromic luvisols (lCU)	-0.148	0.026	
Farmland (ha)	0.661***	0.649***	0.753***
Mean water flow	0.008*	0.005	0.035**
Household has tractor (Yes/No)	0.151	0.132	0.068
Household access to extension (Yes/No)	0.148*	0.200**	0.144
household access to electricity (Yes/No)	0.311**	0.307*	0.379
Household size (Num. of people)	0.236***	0.246**	0.195
Using irrigation (Yes/No)		0.000	
mixed crop-livestock (Yes/No)	0.607***		
Specialised crop (Yes/No)	0.873*		
North and East Africa (Yes/No)	0.545	0.521	1.666
Southern Africa (Yes/No)	-0.721	-1.176*	-0.209
Constant	5.461	4.938	4.351
R Square	0.5528	0.5422	0.6843
N	1304	1080	216

Appendix 2: Correlation analysis of continuous explanatory variables

	Winter-spring temp	Summer-fall temp	Winter-spring precip	Summer-fall precip	Head_age	Household_ size	Farming_ experience	Farm_size	Markets_ distance
Winter-spring temp	1								
Summer-fall temp	0.4769	1							
Winter-spring precip	-0.1036	-0.4638	1						
Summer-fall precip	0.2351	-0.2056	0.0809	1					
Head_age	-0.0174	0.0537	-0.0652	-0.0794	1				
Household_size	0.3136	0.3014	-0.199	0.0104	0.2504	1			
Farming_ experience	0.018	0.2114	-0.1975	-0.2294	0.3338	0.2509	1		
Farm_size	-0.0849	-0.0452	-0.0169	-0.0209	0.0033	-0.0007	-0.0087	1	
Markets_distance	0.0541	0.1203	-0.0704	-0.0111	-0.0924	0.0195	-0.0635	0.0016	1

Appendix 3: Variance inflation factor (VIF) test for multicollinearity

Variable	**VIF**
Summer-fall temp	4.92
Winter-spring precip	3.00
Winter-spring temp	2.97
Summer-fall precip	1.61
Farming experience	1.57
Access to electricity	1.52
Household head age	1.44
Distance to market	1.32
Household size	1.28
Own heavy machines	1.24
Access to extension	1.10
Male headed household	1.05
Access to credit	1.02
Farm size	1.02
Mean VIF	**1.79**

Appendix 4: Parameter estimates from the multinomial logit adaptation model

Variable	MLCRIRRIG	MLCRDRY	MOCRLSDR	MOCRLSIR	MLCRLSIR	MLCRLSDR
	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient
Winter-spring temp (°C)	-0.302***	0.142***	0.008	-0.405***	-0.286***	0.110**
Summer-fall temp (°C)	0.375***	-0.006	0.058	0.654***	0.314***	0.008
Winter-spring precip (mm)	-0.007	0.003*	0.013***	0.004	0.017***	0.014***
Summer-fall precip (mm)	0	0.003	0.006***	0.003	0.004*	0.005***
Extension contact (1/0)	1.240***	0.724***	0.056	0.779***	1.169***	0.695***
Access to credit (1/0)	0.792*	0.61**	0.054	0.062	0.867*	0.632*
Distance to market (km)	-0.007*	-0.001	0.003	-0.017***	-0.006**	-0.001
Male headed household (1/0)	1.554***	0.124	0.262	-0.566*	1.564***	0.217
Household head age (years)	-0.008	-0.005	0.001	-0.013	0.002	-0.001
Household size	0.231***	0.161***	0.065*	0.024	0.192***	0.157***
Farming experience (years)	0.024**	0.049***	0.021**	0.010	0.032***	0.046***
Farm size (ha)	-0.003*	0.001	0.001**	0.002	-0.005**	0.003
Own heavy machines (1/0)	1.232***	0.531**	0.193	0.391*	1.570***	0.533**
Access to electricity (1/0)	0.607**	-0.664***	-0.091	1.010***	0.399*	-0.547***
Constant	-6.728***	-4.102***	-2.685**	-6.468***	-5.208***	-3.161***
Number of observations	7327					
Wald $\chi^2(80)$	3975.07					
Prob > χ^2	0.0000					
Log pseudolikelihood	-8541.1862					
Pseudo R2	0.2888					

*; **; *** significant at 10%; 5% and 1% respectively

Note: MLCRIRRG: Multiple crops under irrigation; MLCRDRY: Multiple crops under dryland; MOCRLSDR: Mono crop-livestock under dryland; MOCRLSIR: Mono crop-livestock under irrigation; MLCRLSIR: Multiple crop-livestock under irrigation; MLCRLSDR: Multiple crop-livestock under dryland.