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.

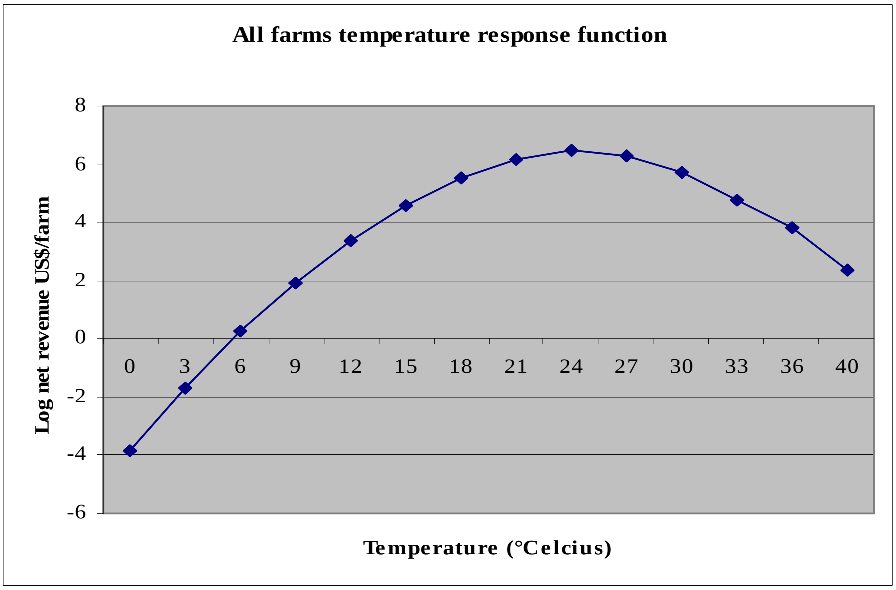

Figure 4.2: Temperature response function – all farms

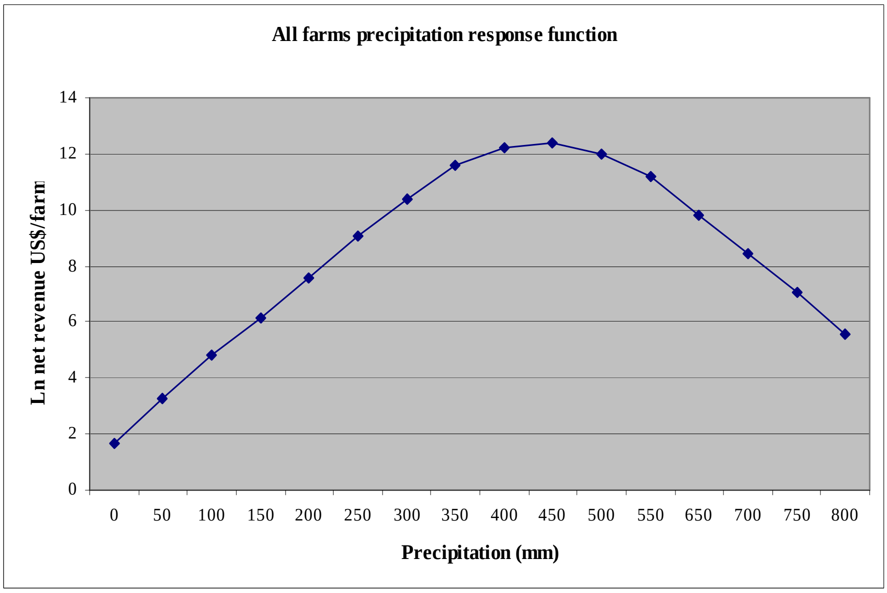

Figure 4.3: Precipitation response function – all farms

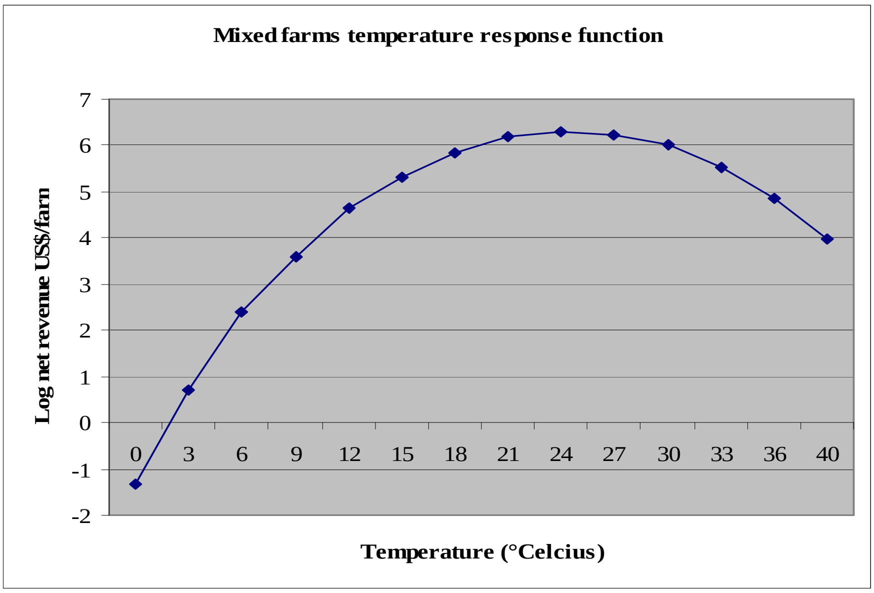

Figure 4.4: Temperature response function – mixed crop–livestock farms

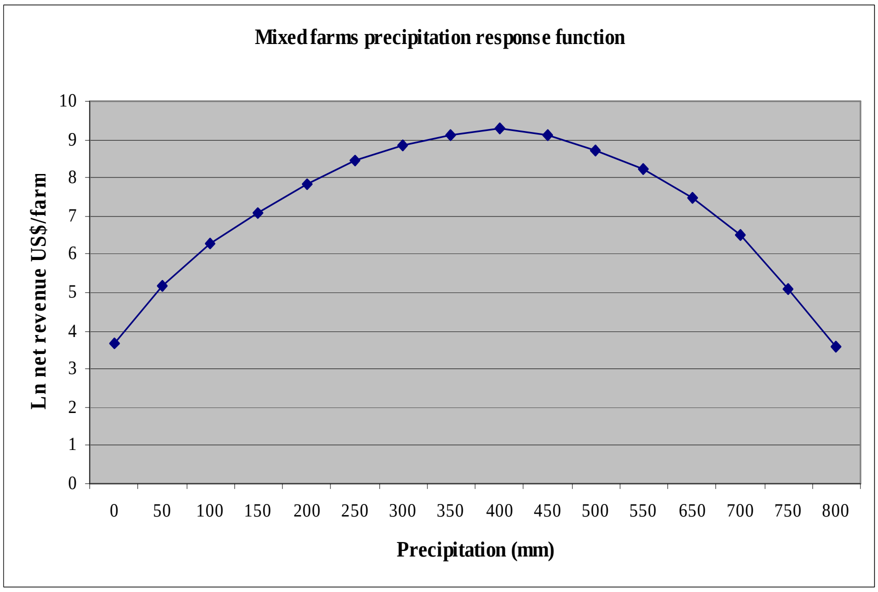

Figure 4.5: Precipitation response function – mixed crop–livestock farms

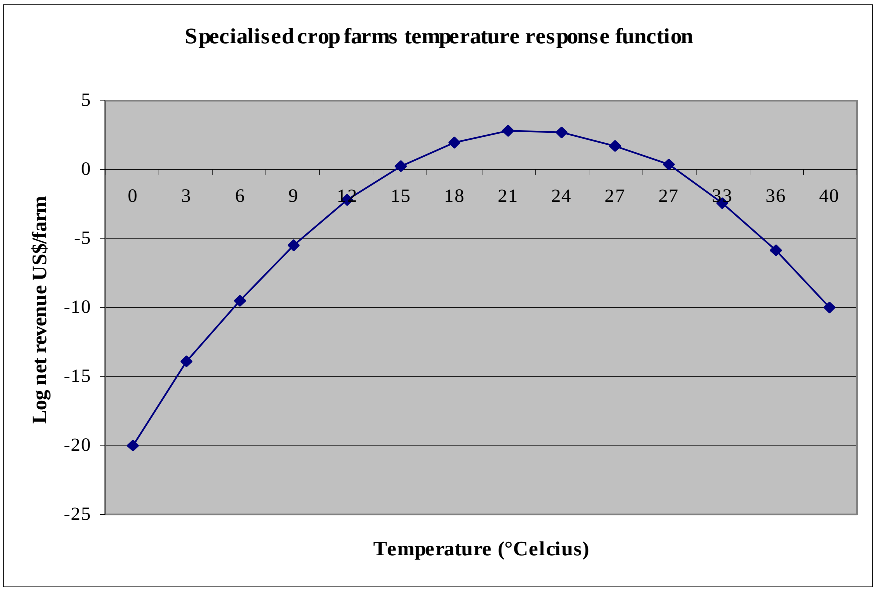

Figure 4.6: Temperature response function – specialised crop farms

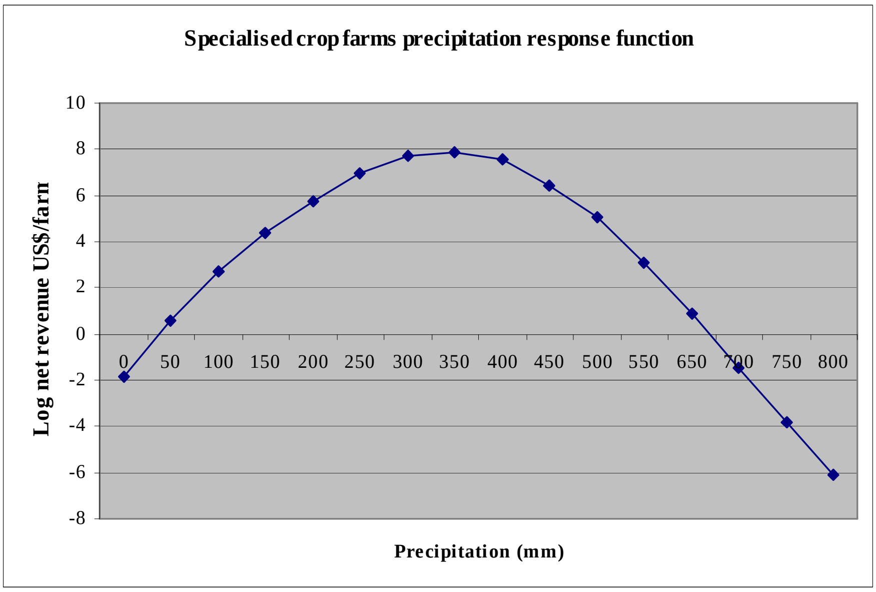

Figure 4.7: Precipitation response function – specialised crop farms

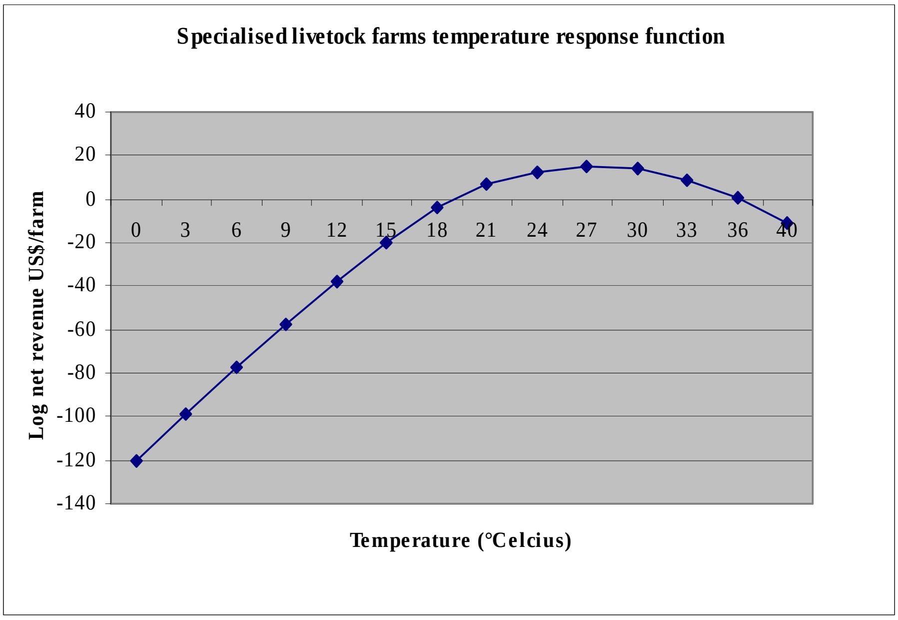

Figure 4.8: Temperature response function – specialised livestock farms

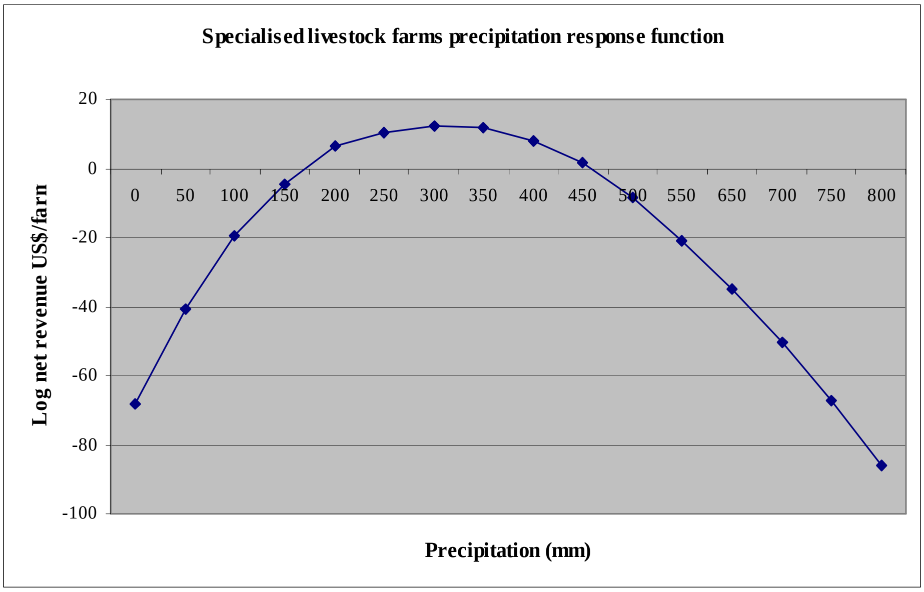

Figure 4.9: Precipitation response function – specialised livestock farms

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.