

The Economic Impact of Climate Change on Kenyan Crop Agriculture: A Ricardian Approach*

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Abstract

This paper measures the economic impact of climate on crops in Kenya. We use cross sectional data on climate, hydrological, soil data and household level data for a sample of 816 households. We estimate a seasonal Ricardian model to assess the impact of climate on net crop revenue per acre. The results show that climate affects crop productivity. There is a non-linear relationship between temperature and revenue on one hand and between precipitation and revenue on the other. Estimated marginal impacts suggest that global warming is harmful for crop productivity. Predictions from global circulation models confirm that global warming will have a substantial impact on net crop revenue in Kenya. The results also show that the temperature component of global warming is much more important than precipitation. Findings call for monitoring of climate change and dissemination of information to farmers to encourage adaptations to climate change. Improved management and conservation of available water resources, water harvesting and recycling of waste water could generate water for irrigation purposes especially in the arid and semi arid areas.

Key words: Climate change, agriculture, crop revenue, adaptations

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Acronyms and Abbreviations

ARTES	Africa Rainfall and Temperature Evaluation System
ASALs	Arid and Semi Arid Lands
CCC	Canadian Climate Model
CEEPA	Centre for Environmental Economics and Policy in Africa
Mm	Millimeters
CO ₂	Carbon Dioxide
FAO	Food and Agriculture Organization
GCM	Global Circulation Models
GEF	Global Environmental Facility
GFDL	Geophysical Fluid Dynamics Laboratory model
IWMI	Integrated Water Management Institute
Km	Kilometer
KSHS	Kenya Shillings
Mm	Millimeters
UOC	University of Colorado
US	United States

1 Introduction

Agriculture continues to be the leading sector in the Kenyan economy in terms of its contribution to real GDP (about 30%). The sector is also the largest contributor to employment (about 82% of the population) and accounts for about 70% of export earnings. Agriculture is also responsible for providing food security for both the rural and urban populations. However, rapidly expanding population, rapid urbanization and the shortage of high potential arable land cause occasional imbalances between the national demand for food and its supply.

The performance of the agricultural sector is determined by crop production, which depends on a large number of factors. Most important is the endowment of the country in terms of soils and climate resources. Kenya has climate and ecological extremes with altitude varying from sea level to over 5000 m in the highlands. The mean annual rainfall ranges from less than 250 mm in semi-arid and arid areas to 2000 mm in high potential areas. Kenya has a total area of 580,367 Km², of which only 12% is considered to be high potential for farming or intensive livestock production. A further 5.5%, which is classified as of medium potential, mainly supports livestock especially sheep and goat. Only 60 % of this high and medium potential land is devoted to crop and rest is used for grazing and forests. The other 82% of the total land in Kenya is classified as arid and semi arid lands (ASALs), which are largely used for extensive livestock production, as well as being the habitat for wildlife both in and outside national parks and game reserves. Due to lack of alternative income earning opportunities, spatial differences in poverty are closely related to and vary with agricultural potential in the country (Republic of Kenya 1999).

The declining agricultural productivity in Kenya is worrisome and a real challenge for a government with a population of approximately 30 million to feed. Worse still is the expected adverse impact of global warming on agriculture in the future. Global circulation models predicted that global warming will lead to increased temperatures of about 4°C and cause variability of rainfall by up to 20% in Kenya by the year 2030. From these predictions, the two extreme climate events that may adversely impact on the agricultural sector are drought (crop water stress leading to declining yields) and flooding (resulting in water logging) in both the ASALs and high potential areas¹. However, even with the predicted climate change scenarios, unpredicted climate events such as high frequency of flooding similar to that observed during the 1997-98 El Nino rains may

¹ Water resources in the country are most vulnerable in the arid and semi-arid areas of the country where severity of drought and floods is expected to increase, while the ground water resources in the coastal regions (currently strained) will be most vulnerable in the future.

still occur, more so in vulnerable areas. The overall adverse impacts of the extreme weather and climate events that may occur because of the projected climate change could have severe socio-economic impacts such as food, water and energy shortages as well as shortage of other essential basic commodities and long term food insecurity.

Against the above background of limited arable land, predicted adverse climate conditions and declining agricultural productivity, the biggest challenge facing the Kenyan government is to intensify food crop production to feed the growing population. However, productivity continues to be undermined by unpredictable weather and climate conditions as well as declining soil fertility. While there is a growing body of literature on the impact of soils on productivity in Kenya, there is a dearth in literature on the impact of climate on agriculture. This paper addresses these research gaps. This paper uses the Ricardian approach to analyze the impact of climate on crop productivity in Kenya. The paper also simulates the impact of long term climate change on agriculture. Understanding the impact of climate on agricultural productivity is crucial for future agricultural policies and interventions in Kenya, more so interventions to mitigate potential adverse impacts of climate change. Such interventions would have important implications for future food security and overall growth of the sector. The impact of this growth would in turn trickle down to the rest of the economy: increase employment and incomes in agriculture and related sectors and therefore boost overall economic growth.

The rest of the paper is organized as follows. The next section presents an analysis of the relationship between climate and agriculture in Kenya. Section three discusses the study site and data. Section four and five present the methods and research findings respectively. Section six concludes.

2. Climate and Agriculture in Kenya

Agro-climate zones and farming systems: Climate, vegetation and land use potential have been used to assess land suitability for different uses. The major elements of climate that affect herbage growth are the intensity and duration of rainfall, the relationship between annual rainfall and potential evapotranspiration and the year-to-year variation in rainfall. Kenya is divided into 7 agro-climate zones using a moisture index based on annual rainfall expressed as a percentage of potential evaporation (Sombroek *et al.*, 1982). Areas with an index greater than 50% have high potential for cropping, and are designated zones I, II, and III (Table 1). These zones account for 12% of Kenya's land area. The semi-humid to arid regions (zones IV,V,VI and VII) have indexes of less than 50% and a mean annual rainfall of less than 1100 mm. These zones are generally referred to as the Kenyan range-lands and account for about 80% of the land area. The seven

agro-climate zones are each sub-divided according to mean annual temperature to identify areas suitable for growing each of Kenya's major food and cash crops. Most of the high potential land areas are located above 1200m altitude and have mean annual temperatures of below 18°C. These areas are mainly suitable for dairy farming (cattle and sheep), cash crops (coffee, tea and pyrethrum), and key food crops (maize, beans and wheat). In the medium potential zones, temperatures are higher, but also favour similar farming systems with high potential areas, though productivity is lower. In these regions barley, cotton, cassava, coconut and cashewnuts are also cultivated. 90% of the semi-arid and arid zones lie below 1260m and have mean annual temperatures ranging from 22° C to 40°C. These areas are less suited for arable agriculture but support sorghum, millet, livestock and wildlife.

Drainage Basins: Kenya is endowed with a large potential of water resources in terms of groundwater, river flows, lakes and oceans. The surface water resources are contained within five main drainage basins whose hydrological characteristics are related to moisture availability, rainfall and climate (Table 2). Except for the water resources in the oceans/lakes, rainfall is a major water resource in Kenya and sustains most of the water resources in the country. Rainfall is also the main driver of the variability in the water balance over space and time, and changes in precipitation have very important implications for hydrology and water resources. Flood frequency and drought flows are affected by changes in the year-to-year variability in precipitation, but also by changes in short-term rainfall properties (such as storm rainfall intensity).

Rainfall and Temperature: The country receives a bimodal type of rainfall where the "long rains" fall between March and May while the "short rains" fall between October and December. The intensity and spread of the rainfall in each region determines the effectiveness of the rainfall. The average annual rainfall ranges from 250mm to 2500mm, the average potential evaporation ranges from less than 1200mm to 2500mm, and the average annual temperature ranges from less than 10° to 30°C. A relatively wet belt extends along the Indian Ocean Coast and another wet area covers western Kenya just east of Lake Victoria. All the mountain ranges have high rainfall while dry tongues are found in the valleys and basins. The annual rainfall generally follows a strong seasonal pattern. The seasonal variations are strongest in the dry low lands of the north and east, but weakest in the humid highlands of the Central and Rift Valley areas.

Mean temperatures in Kenya are closely related to ground elevation. The highest temperatures are recorded in the arid regions of the North-Eastern province along the Somalia coast and to the west of Lake Turkana where the night minimum maybe as high as 29⁰C during the rainy seasons. Coldest areas are the tops of the mountains where night

frost occurs above 10,000 feet and permanent snow or ice cover above 16,000 feet (Mt. Kenya). Annual temperature variations are generally small (less than 5⁰C) throughout the country.

Soils and Topography: Kenya is a country with varying climate, vegetation, topography, and underlying parent rock. Climate is the most important factor influencing soil formation and affects soil type directly through its weathering effects and indirectly as a result of its influence on vegetation. In most parts of Kenya, soils are deficient in nitrogen (N), phosphorous (P) and occasionally potassium (K). In dry areas, the soils have low organic matter mainly because rainfall is low, variable, unreliable and poorly distributed. To understand the distribution of soil in Kenya, the country can be divided into three broad regions: humid, sub-humid and arid. The humid regions (highlands) are areas with an altitude of over 1500m which receive an annual rainfall of over 1000 mm. They have volcanic rocks and the soils are mainly loamy, and include the highlands east and west of the Rift Valley and the Rift Valley floor. Other humid areas with an altitude less than 1500m (humid lowlands) have sandy soils which are well drained and are of loamy, sandy clay texture (e.g. along the Kenyan coast). Other areas of the highlands have fertile loam soils, while alluvial soils (silts) are found along river valleys. Sand dunes and mangrove swamps are found along the coast. The soils covered by mangrove swamps are deep, grey, saline and poorly drained.

The sub-humid regions (Lake Region and Western Kenya) receive slightly less rainfall than the humid areas. They have volcanic and basement rocks and soils are red clay and generally productive. The regions lie between 1000m to 2000m above sea level and rainfall is up to 1,000 mm per year. Dark red clays, sandy loams and alluvial deposits of eroded material from uplands are common along flood plains of big rivers in these regions. In addition, peat swampy soils and black cotton soils dominate the lowlands. The semi-arid regions (northern and north-eastern Kenya) receive on average 300-500 mm of rainfall per year and the soils are shallow and generally infertile, but variable. These soils have developed mainly from sedimentary rocks. Fertile volcanic soils, black cotton soils, dark red soils, lava soils and alluvial soils are scattered across the region depending on distribution of rainfall, altitude and parent rock type.

3 Study site and the Data

3.1 Sampling Procedures

The main data for this study were based on a sample of 816 households from Kenya. The data were collected from 6 out of 8 provinces in Kenya between June and August 2004. Two provinces: Nairobi and North Eastern were excluded from the survey because of

urbanization and aridity respectively. In the later province, farming and pastoral households had to be excluded from the sample because of inaccessibility and other field logistics. From the eight provinces, a sample of 38 out of 46² districts were selected for the field survey. The districts chosen capture variability in a wide range of agro-climate conditions (rainfall, temperatures and soils), market characteristics (market accessibility, infrastructure e.t.c) and agricultural diversity among other factors. Each district was then divided into agro-ecological zones and samples of three different farm types/sizes: large, medium and small chosen from each ecological zone. Detailed information from the ministry of agriculture as well as the “*Farm Management Handbook*” (Jaetzold, R. and Schidt, H., 1982) was used to guide identification of agro-ecological zones and farm types. The sampling procedure was purposely designed to target at least 4 households from each agro-ecological zone, comprising of at least one household from each farm type. The fourth household in each of the agro-climate zones would be of any of the 3 farm types depending on the frequency of the farm types in the district and zone chosen.

3.2 The Data

The key household variables of interest in this study are net crop revenue, wage rates and a few other household variables. We define net revenue as gross revenue less all total variable costs, costs of hired labour, farm tools, machinery, fertilizers and pesticides. Costs of household labour are not netted due to difficulties of accurate measurement. Instead we introduce household wage rates for adults and children as independent variables in the net revenue regression. A summary of the key variables used is presented in table 3.

In addition to the household data, the study also makes use of climate data (temperatures, soil wetness indices and precipitation). For climate data, satellite data were provided by the US Department of Defense. The data values were derived from a set of polar orbiting satellites that are equipped with sensors to detect microwaves through clouds and estimate surface temperature and surface wetness (Basist et al. 1998, 2001; Weng and Grody 1998). The other set of climate data were obtained from Africa Rainfall and Temperature Evaluation System (ARTES). This dataset, created by the National Oceanic and Atmospheric Association’s Climate Prediction Center, is based on ground station measurements of precipitation, minimum and maximum temperature. The data were constructed from a base with data for each month of the survey year and for morning and evening. The monthly means were estimated from approximately 14 years of data (1988-

² Before 1996, Kenya had 46 districts but these were subsequently subdivided to make a total of the current 72 districts. The sampling frame was based on the old district classification, in order to make the data compatible with data on long term climate variables.

2003) to reflect long term climate change. In the final estimating equations, we use seasonal climate variables (see table 3) because we do not uncover any important/significant impact of wet and dry season climate variables on crop revenue.

Hydrological data (run off and flow data), was obtained from the IWMI and the University of Colorado. The run off and flow data estimates are based on monthly values from 1961 to 1990 time series data. The final values are estimated using hydrological models for Africa (IWMI and UOC, 2003). Soil data was obtained from the Food and Agricultural Organization (FAO, 2003). In Kenya, there are at least 28 different types of soil. In this study, we only focus on the key soil types in the 6 sampled provinces, which can be divided into 8 main groups (table 4). Only Andosols are retained in the final estimating model because other soils are unimportant..

4. Conceptual Framework and Methodology

Most studies on the impact of climate change on agriculture employ the Ricardian analysis (Mendelsohn et al.1994) while traditional studies have used the production function approach (Rosenzweig and Iglesias, 1994). The production function approach relies upon empirical or experimental production function to predict environmental damage. As noted in the literature review, the approach has been criticized of having an inherent bias and tending to overestimate the damage of climate change on farming because of failing to take into account the infinite variety of substitutions, adaptations and old and new activities that may displace obsolete activities as climate changes. The Ricardian approach is based on Ricardo’s observation that land rents reflect the net productivity of farmland and examines the impact of climate and other variables on land values and farm revenues. The approach has been found to be attractive because it corrects the bias in the production function approach by using economic data on the value of land. By directly measuring farm prices or revenues, the Ricardian approach accounts for the direct impacts of climate on yields of different crops as well as the indirect substitution of different inputs, introduction of different activities and other potential adaptations to different climates (Mendelsohn et al.1994). The method is also attractive because it not only includes the direct effect of climate on productivity but also the adaptation response by farmers to local climate.

The Ricardian approach is a cross-sectional model applied to agricultural production. It takes into account how variations in climate change affect net revenue or land value. Following Mendelsohn et al.,(1994), the approach involves specifying a net productivity function of the form:

$$R = \sum P_i Q_i (X, F, Z, G) - \sum P_x X \dots\dots\dots(1)$$

where R is net revenue per hectare, P_i is the market price of crop i , Q_i is output of crop i , X is a vector of purchased inputs (other than land), F is a vector of climate variables, Z is a set of soil variables, G is a set of economic variables such as market access and P_x is a vector of input prices. The farmer is assumed to choose X to maximize net revenues given the characteristics of the farm and market prices. The Ricardian model is a reduced form model that examines how a set of exogenous variables F , Z , and G , affect farm value.

The standard Ricardian model relies on a quadratic formulation of climate:

$$R = B_0 + B_1F + B_2 F^2 + B_3 Z + B_4 G + u \dots\dots\dots(2)$$

where u is an error term, F and F^2 capture levels and quadratic terms for temperature and precipitation. The introduction of quadratic terms for temperature and precipitation respectively reflect the nonlinear shape of the response function between net revenues and climate. From available literature, we expect that farm revenues will have a concave relationship with temperature. When the quadratic term is positive, the net revenue function is U-shaped, but when the quadratic term is negative, the function has an inverted U-shape. For each crop, there is a known temperature where that crop grows best across the seasons though the optimal temperature varies by crop (Mendelsohn et al.1994). From equation (2), we can derive the mean marginal impact of a climate variable on farm revenue as well as the mean marginal impact of runoff and flow on farm revenue.

As mentioned in the literature review, the Ricardian analysis has however been criticized on several accounts: One, it does not measure transition costs, where a farmer moves from one crop to another suddenly, yet transition costs are clearly very important in sectors where there is extensive capital that cannot be easily changed. A second drawback of the approach is that it cannot measure the effect of variables that do not vary across space. The approach also fails in that the variation in climate that one could observe across space may not resemble the change in climate that will happen over time. A fourth drawback of the Ricardian model is that it generally assumes prices constant, which introduces bias in the analysis, overestimating benefits and underestimating damages. Five, the approach explicitly includes irrigation, and last the approach reflects current agricultural policies (Kurukulasuriya et al., 2004).

5. Research Findings

5.1 Results of Ricardian Analysis

Our empirical implementation of the Ricardian model is based on equation 2 in the methodology section. We carry out analysis for net crop revenue per acre as the dependent variable, focusing on the impact of seasonal climate factors. Though the relationship of seasonal climate variables can be quite complex, we expect that farm revenues will have a concave relationship with temperature (Kurukulasuriya et al., 2004). Annual climate and wet/dry condition factors are found to be insignificant determinants of crop revenue. In addition to the climate variables, we also model the impact of hydrological, soil and household specific factors.

Estimation Issues

As typical with most cross sectional regressions, four econometric issues are likely to affect the robustness of our results. These include: (i) endogeneity of explanatory variables, (ii) heteroscedasticity in the error terms, (iii) multicollinearity among explanatory variables and (iv) the impact of outliers. The problem of endogeneity of explanatory variables would be solved using an instrumental variable estimator (IV). However, this requires that there are valid instrumental variables that are highly correlated with the explanatory variables concerned but not directly related to revenue. Due to lack of appropriate instruments, we resort to the next best alternative of estimating a reduced form net revenue model rather than a structural model.

The existence of heteroscedasticity in the error terms does not pose a serious problem in terms of obtaining consistent estimates as it only causes a bias in the estimates of standard errors for which we correct using White's general method (White, 1981). However more serious problems are posed by multicollinearity and the influence of outliers. We control for multicollinearity by dropping the most troublesome variables. In the first place, monthly climate variables are highly correlated and were all dropped from the analysis. Other seasonal (3 month average) climate variables were dropped sequentially as we ran the regressions. We however note that multicollinearity is normally an issue of the extent rather than absence and so it cannot be completely eliminated. The idea is to reduce the extent/degree of multicollinearity. We therefore retain variables which seem to have a tolerable degree of multicollinearity. For outliers, we omitted a total of 116 households believed to be outliers for various reasons (see footnote number 5).

Discussion of Results

The Ricardian analysis results are presented in Table 5. The table displays three model results. Column one presents model results with climate variables only. Column two introduces hydrological and soil factors, while the last column introduces household characteristics. For climate variables, we present results for summer and winter temperatures only because fall and spring are collinear with summer and winter temperatures. For precipitation, we retain fall and summer precipitation for the same reason. The results are robust across the three models. High summer temperatures are harmful to crop production while high winter temperatures are beneficial. This is because summer (March-May) is the planting period followed by formative crop growth, while winter (June-August) is the period for ripening and maturity of crops. High summer temperatures would therefore slow down or destroy crop growth, while higher winter temperatures are crucial for ripening and harvesting. In the Kenyan highlands, winters can be quite chilly and excessively low winter temperatures have been associated with crop damage due to frost. The negative coefficient for the quadratic term however suggests that excess winter temperatures would be harmful for crop productivity. Summer temperatures exhibit a U shaped relationship with net crop revenue but winter temperatures portray an inverted U-shaped relationship. Both fall and summer precipitation are however positively correlated with net crop revenue and exhibit a hill (inverted U) shaped relationship with net crop revenue. The results further show that climate exhibits a non linear relationship with net revenue, which is consistent with available literature (Mendelsohn et al.1994, 2003, Kurukulasuriya et al., 2004). The Chow test results show that the overall models are significant at the 1% level of significance, but the R^2 shows that the models explain only between 3 and 13% of the total variation in net revenue³.

Introducing flow and hydrological variables reduces the F statistic marginally from 3.73 to 3.27. However the R-squared increases by almost 100%. The results imply an inverted U-shaped relationship between mean flow and net revenue, and both coefficients are statistically different from zero at the 10% level. All soils except andosols turn out to be insignificant and reduce the significance of other variables considerably and we therefore drop all other soils. The results indicate that andosols have a positive and significant

³ The results presented here omit households suspected to be outliers. Most of the outlying households reported either: zero or very low revenues, very high revenues or very high costs, making net revenues negative. We also exclude 5 households that reported very high crop land (group ranches). In total we exclude a total of 92 households suspected to be outliers. When these variables are included in the regression models, most variables are insignificant but they do not affect the signs of the coefficients. Their impact on the overall explanatory power of the model is also minimal. Median regressions which control for outliers are robust with OLS and so we present and discuss the latter.

impact on net crop revenue, which conforms to apriori expectations because andosols are quite fertile and thus suited for crop production.

Finally we test the impact of some selected household level variables. Introduction of these variables raise the F statistic from 3.27 to 5.30, while the R squared doubles. Most of the household level variables have a significant impact on crop revenue. Livestock ownership dummy, farm size and wage rates are inversely correlated with crop revenue. Farm size exhibits a U shaped relationship with crop revenue implying that large farm size may be associated with higher productivity. Main and secondary occupation of household head, religion of household head and average number of years of education of the household members are positively correlated with net crop revenue. Household size, introduced as a proxy for household labour (or remotely population density) has a positive and significant impact on net crop revenue

Livestock ownership dummy has a negative and significant impact on net revenue. This implies competition rather than complementarity between farming and livestock keeping. We do not uncover any significant effect of education on crop productivity but, the sign of the coefficient implies that education is associated with higher crop revenue. Irrigation has a large positive impact on crop revenue, implying the importance of adaptations to counter the impact of climate change through irrigation.

5.2 Marginal Impacts and Elasticities

In this sub-section, we estimate the marginal impacts of climate on crop agriculture (Table 6). The results are based on the regression results in columns two and four of table 5. The marginal impacts for winter temperatures are positive, but summer temperatures have larger negative impacts on net crop revenue. Using the climate only model, crop revenue is elastic (-1.41) with respect to changes in temperature. The seasonal marginal impacts with respect to summer temperature are statistically significant and thus different from zero, but the impacts for winter are insignificant. Using the model with all variables, the elasticity of crop revenue with respect to changes in temperature more than doubles – (increases from -1.41 to -0.63). These results show that high temperatures are harmful for productivity (elasticity is negative), confirming that global warming is likely to have devastating effects on agriculture unless farmers take adaptation measures to counter the impact of climate change (Kurukulasuriya et al., 2004).

The marginal impacts of precipitation are more modest than for temperatures, but the elasticities are higher. The last row of table 6 shows that crop revenue is highly elastic with respect to changes in precipitation, and that increased precipitation increases

productivity except in the combined climate model (Molua, 2002). Summer precipitation exhibits implausible (though positive) marginal impacts (not presented). The elasticity of revenue with respect to precipitation in the all variable model is much larger (2.71) than in the first model. A 1% increase in rainfall would lead to a 2.71% increase in net crop revenue, though a similar change in temperature would lead to only a 0.63% fall in revenue.

5.3 Predicting Impact of Global Warming on Kenyan Agriculture

Results from the Ricardian analysis show that climate has important effects on agriculture in Kenya. In this sub-section, we use the regression results for the full model to project the impact of global warming on Kenyan agriculture. To simulate the impact of different climate scenarios, two General Circulation Models (GCMs) are used, namely the Canadian Climate Model (CCC) and the Geophysical Fluid Dynamics Laboratory model (GFDL). These models have been found to give reasonable climate forecasts for Kenya. The CCC and GFDL models predict an average increase in temperature of 3.5°C and 4°C respectively with the doubling of CO₂ by the year 2030. For rainfall, evidence from Kenya shows that there have been very large geographical disparities in the trend patterns. Estimates show that there has been a tendency for annual rainfall to decline in the ASALs and increase over the Lake Victoria, the coastal and neighboring regions. This implies that some regions may gain from global warming while others may be adversely affected. Both the CCC and GFDL models however predict that on average, Kenya will experience a 20% fall in rainfall by the year 2030.

Based on the regression results in column 4 of table 5, we simulate the expected impact of climate change on net crop revenue, using the CCC and GFDL models. We add the predicted change in temperature to the benchmark values, and then evaluate the impact on the baseline net crop revenue. We also adjust benchmark precipitation by the predicted percentage to get the new precipitation levels. For the CCC model, we simulate the impact of an increase in temperature by 3.5°C combined with a 20% fall in rainfall and take a similar scenario for GFDL model but a 4°C change in temperature. We apply the scenarios separately for medium and low potential zones on one hand, and high potential zones on the other, then for the country as a whole⁴. This is because it is expected that the effects of climate change on agriculture will not be uniform across continents or even within a country. Some regions may gain while others may experience losses (Gbetibouo and Hassan, 2005; Deressa et al., 2005; Seo et al., 2005).

⁴ The definition of zones is based on figure 2. We define high potential zones to include Central Western and Nyanza provinces (agro-ecological zones I, II and III) and all other provinces in the sample as medium and low potential zones (Zones IV-VII). We combine the latter zones because of the difficulties of accurately separating them into two categories.

The results (Table 7) show that with precipitation remaining the same, changes in temperature predicted by the CCC model would result to a 1% (3.54 US dollars per hectare) gain in high potential zones but a 21.5% (54 US dollars per hectare) loss in medium and low potential zones. The results further suggest that medium and low potential zones will bear the brunt of global warming in Kenya. Using the GFDL model, we estimate losses of up to 178 US dollars per hectare by the year 2030 in these zones compared to a loss of only 32 US dollars in high potential zones and 117 US dollars in the whole country. Though these results may sound surprising, they can be interpreted to mean that a small increase in global warming would have immediate adverse impacts on already dry areas, and this is what is happening to the Kenya at present due to prolonged drought in ASALs, which has already claimed lives of both human beings and livestock, yet the effect is still not yet pronounced in high potential zones. The results confirm that long term climate change has important implications on agriculture. These results support findings in related literature for Africa and beyond (see for instance Gbetibouo and Hassan, 2005; Deressa et al., 2005; Turpie, 2003; Tol, 2002 and Mendelsohn et al., 2000; 2003). Mendelsohn et al.,(2000; 2003) also argue that every region in Africa is expected to experience negative climate change impact by the year 2100.

Our results further show that medium and low potential zones are likely to suffer more from rising temperatures resulting from global warming than from a fall in precipitation. The reverse is however the case for high potential zones and this may be due to the fact that such zones are located in the highlands where temperatures are quite low and so a rise in temperature may have a lower impact than a fall in precipitation. The whole country is also expected to suffer more from declines in rainfall than rising temperatures, just as in medium and low potential zones.

5.4 Perceptions and Adaptations to Climate Change

Economic adaptation has been argued to significantly reduce the vulnerability to anticipated future impacts of climate change. Previous studies have shown that the potential contribution of adaptation to reducing the negative impacts of global warming is large. The basic forms of adaptation identified in the literature including micro level adaptations, market responses, institutional changes and technological developments (Kurukulasuriya and Rosenthal, 2003; Reilly, 1999; Darwin et al. 1995). In our study, we focused on micro level adaptations which include farm production adjustments such as diversification and intensification of crop and livestock production, changing land use and irrigation and altering the timing of operations.

Perceptions of and adaptations to short term climate variations

Analysis of the perceptions and adaptation of farmers to short term climate variations and also constraints to adaptation mechanisms reveal that though households have a range of adaptation measures that they practice, the most popular measure is use of crop diversification/mixed cropping, adopted by 37% of all households and tree planting (16%). A relatively low proportion (6%) adopt adjustments to livestock management probably due to scarcity of land in more arable areas, which may hinder large scale livestock production. Nevertheless, such a measure is expected to reduce soil erosion and improve moisture and nutrient retention (Kurukulasuriya and Rosenthal, 2003). Most other measures were adopted by between 11% and 14% of all households. Though the percentage of households involved is small, results for irrigation, water and soil conservation support the argument that a range of management practices such as water and soil conservation can help reduce vulnerability by reducing run off and erosion and promoting nutrient restocking in soils, while other techniques may improve the soil structure and fertility. 13% of households reported that they did not do anything to counter the impact of short-term variations in weather.

Table 8 tabulates the constraints to adaptations to climate change. The table shows that about 60% of all household are hindered from adaptations by lack of credit and savings (poverty). Another 19% fail to adopt any measure because of lack of knowledge concerning appropriate adaptations. The other constraints are reported by a relatively small proportion of households. Only 8% of households reported that there were no barriers to adaptation. Poverty and lack of knowledge seem to be more critical constraints in medium and low potential zones than in high potential zones.

Perceptions of and Adaptations to Long Term Climate variations

Next we turn to long term climate change adaptation measures. In the first place, the data shows that farmers are aware of increased global warming though a few households are not clear on the direction of change. 47% of all households reported having noticed long term increases in mean temperatures, while only 5% reported decreased temperatures. 18% reported that they had observed climate variations but did not indicate the direction of change. 6% of all households reported having noticed changes in precipitation levels.

Analysis shows that only 60% of all households made any effort to counter long term temperature changes (40% reported no adaptations), compared to 78% in the case of precipitation (table 9). For long term temperature changes, farmers make two main adjustments emerge: crop diversification and shading/sheltering or planting of trees. However, the low of farmers adopting crop diversification (25% and 34% for temperature

and precipitation changes respectively) could be due to lack of knowledge, skills and finances (Kurukulasuriya and Rosenthal, 2003). Shading/sheltering/tree planting is important (taken by 22% of households observing long term temperature increases) because in addition to countering climate change, it is also a form of soil conservation.

Improved water management is adopted by a relatively low proportion of household (16%). These measures include increased water conservation and increased use of irrigation. The low overall adoption rates could be attributed to scarcity of resources including water for irrigation and lack of knowledge on importance of these options. Indeed, only about than 10% of the overall sample of 816 households reported having used any irrigation at all.

6. Conclusions and Implications for Policy.

This paper explores the impact of climate on crop revenue in Kenya. The paper uses primary household level data enriched with secondary climate, hydrological and soil data. We concentrate on a seasonal Ricardian model to assess the impact of climate on net crop revenue per acre. First we assess the impact of climate on agriculture by estimating models with climate factors only, then test the impact of hydrological, soil and household variables.

Our results suggest that climate affects agricultural productivity. Increased winter temperatures increase net crop revenue, while high summer temperatures have a negative impact on crop revenue. Increased precipitation has the impact of increasing net crop revenue. The results further show that there is a non-linear relationship between temperature and crop revenue on one hand and between precipitation and crop revenue on the other. This finding is consistent with studies on the impact of global warming on agriculture (Mendelsohn et al. 1994, 2003; Kurukulasuriya et al., 2004). Another key result is an inverted U-shaped relationship between mean flow and net crop revenue. Further, we also find that andosols, irrigation and household size are positively correlated with crop revenue, while livestock ownership, farm size and wage rates are inversely correlated with revenue.

Estimated marginal impacts further show that crop revenue is elastic with respect to climate change, but is less elastic with respect to temperature than to precipitation. The temperature elasticities suggest that global warming is harmful for agricultural productivity. Though precipitation elasticities are much higher than temperature elasticities, the marginal impacts suggest that the temperature component of global warming may have more serious repercussions than rainfall.

This study further predicts the impact of different climate change scenarios on Kenyan agriculture. We use two Global Circulation Models to do so: the Canadian Climate Model (CCC) and the Geophysical Fluid Dynamics Laboratory model (GFDL), which predict 3.5°C and 4°C changes in temperature by the year 2030 respectively. The models both predict a 20% change in precipitation over the same period. The predictions show that long term changes in temperatures and precipitation will have a substantial impact on net revenue, and that the impact will be more pronounced in medium and low potential zones than in high potential zones. The latter are expected to receive some marginal gains from mild temperature increases, holding precipitation constant.

Our analysis of perceptions and adaptation of farmers to climate change show that farming households in Kenya are aware of both short term and long term climate change and some have implemented various adaptation mechanisms to climate variations. The analysis also shows differences in perceptions and adaptations in medium/low potential zone farmers and their counterparts in high potential zones. Changes in crop mix (diversification) is the most common adaptation measure, more so in high potential zones, while water conservation, irrigation and shading/sheltering of crops are the main adaptation measures in drier regions.

These results imply that adaptation to climate change in Kenya is important if households are to counter the expected impacts of long term climate change. The government should therefore play a more critical role in encouraging adaptations to climate change. Monitoring of climate change and disseminating information to farmers would be a critical intervention, while knowledge on adaptation measures could encourage both short term and long term adaptations to climate change. To gather such knowledge, a multidisciplinary approach involving soils scientists, hydrologists, climate experts and agronomists is required. Using this knowledge, farmers and local leaders should be sensitized, through extension network, on implications of climate change, including the vulnerability of crop production and the necessary adaptation strategies. Management of the scarce water resources in the country could generate more water for irrigation purposes especially in the drier zones. Given dwindling and fluctuating water resources in the country, the government needs to embark on recycling of waste water, which can then be used to save on available water. In addition, water harvesting techniques should be introduced to farmers and adoption encouraged, more so in drier areas to supplement any available water. In addition, protection, conservation and rehabilitation of water catchment areas and river basins is critical to ensure sustainable water supply. Policies that improve household welfare as well as access to credit are also a priority for both short term and long term adaptation measures.

The results in this study are based on general crop agriculture and data was corrected on all crops produced by farmers. Given that different crops have different climate requirements, future studies need to be focused on specific crop responses and adaptations, more-so the staple foods which have long term implications for food security in the country. In addition, this paper does not take into account revenue from livestock production, yet most farmers in Kenya combine livestock and crop production for both subsistence and commercial purposes. Our results show that medium and low potential (mostly semi-arid and arid) zones are expected to be much more adversely affected by global warming. However, these zones are best suited for livestock production by both small scale (pastoralists) and large scale (ranches) producers. Analysis of the impact of climate change on livestock production would give a better picture of the impact in arid and semi-arid lands. There is also need for studies to model the impact of climate change with and without the impact of adaptations that farmers make to counter the impact of climate change. Another shortcoming of this study springs from the nature of household data used. Though there is data on long term climate change, the full impact would be better assessed with time series data on crop production. Long term changes in agricultural production may better reflect the impact of long term climate change than one time estimates of production.

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Appendix

Table 1: Characteristics of Agro-climate Zones and Farming Systems in Kenya

Zone	Moisture Index (%)	Climate Classification	Average annual rainfall (mm)	Average annual potential evaporation (mm)	Vegetation	Farming system
I	>80	Humid	1100-2700	1200-2000	moist forest	dairy, sheep, coffee, tea, Maize, sugarcane
II	65-80	Sub-humid	1000-1600	1300-2100	moist and dry forest	Maize, Pyrethrum, wheat, coffee, sugarcane
III	50-65	semi-humid	800-1400	1450-2200	dry forest and moist woodland	Wheat, maize, barley coffee, cotton, coconut, cassava
IV	40-50	semi- humid to semi-arid	600-1100	1550-2200	dry woodland and bush land	Ranching, cattle sheep, barley, sunflower, maize, cotton, cashewnuts, cassava
V	25-40	semi-arid	450-900	1650-2300	bush land	Ranching, livestock, sorghum, millet
VI	15-25	Arid	300-550	1900-2400	bush land and scrubland	Ranching
VII	<15	very arid	150-350	2100-2500	desert scrub	Nomadism and shifting grazing

Source: Sombroek *et al.* (1982); Jaetzold, R. and Schidt, H. (1982)

Table 2: Characteristics of the Main Drainage Basins in Kenya.

Drainage Basin	Area (Km²)	Mean annual rainfall (mm)	Mean annual runoff (mm)	Climate classification
Lake Victoria	49,210	1000	270	Humid to sub-humid
Rift Valley	126,910	600	120	Arid to semi-arid
Athi River	69,930	650	200	Semi-arid
Tana River	132,090	520	170	Semi-humid (headlands), semi-arid to arid
Ewaso Nyiro	204,610	400	80	Arid to semi arid

Source: Sombroek *et al.* (1982)

Table 3: Distribution of Selected Variables by Agro ecological zone

Variable	Medium & Low Potential		High Potential		All Zones	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Net revenue (US\$)	339.2	376.9	352.38	317.14	344.60	353.44
Temperature Summer	20.2	2.9	17.47	1.46	19.07	2.74
Temperature Winter	19.5	2.4	17.12	1.35	18.50	2.36
Precipitation Fall	101.1	75.4	57.40	24.68	83.20	63.74
Precipitation Summer	97.2	19.3	145.94	24.91	117.18	32.41
Log (mean flow)	5.3	0.3	5.50	0.21	5.40	0.26
Soils (Andosols)	0.1	0.1	0.06	0.09	0.06	0.11
Livestock ownership dummy	0.9	0.3	0.89	0.32	0.88	0.32
Primary occupation of household head is farming	0.8	0.4	0.70	0.46	0.73	0.44
Secondary occupation of household head is farming	0.2	0.4	0.23	0.42	0.21	0.41
Household head is Christian	0.9	0.2	0.98	0.14	0.96	0.20
Average years of education of household members	8.5	3.1	8.46	2.78	8.46	2.99
Farm size	8.5	55.8	2.53	2.81	6.02	42.87
Household size	6.8	2.9	6.26	1.88	6.60	2.53
Male wage rates	115.6	52.7	97.29	34.63	108.11	47.02
Child wage rates	57.4	17.6	51.55	13.25	54.98	16.18
Irrigation dummy	0.2	0.4	0.07	0.26	0.14	0.34
Sample Size	427		297		724	

Table 4: Soil types by characteristics and distribution in study sample

Major soil Classification	Texture subsoil	Texture topsoil	Depth	Organic matter component of topsoil	Drainage	Fertility	% of soil type in survey
Ferrasols	clay	clay	variable	Variable	Good	low	22
Luvisols	clay	variable	variable	Variable	moderate	low to moderate	11
Arenosols	sand	sand	variable	Low	Good	low to very low	1
Nitosols	clay	clay	deep	moderate to high	Good	moderate to high	28
Andosols	clay	clay	deep	moderate to high	Good	high	6
Cambisols	variable	variable	variable	Variable	moderate to good	moderate to high	8
Vertisols	clay	clay	variable	low to moderate	Poor	moderate to high	3
Planosols	clay	variable	variable	low to moderate	Poor	low to moderate	2
Lithosols/ Leptosols	rock	variable	very shallow	Variable	variable	variable	8
All other soils	variable	variable	variable	Variable	variable	variable	11

* Variable means more than 3 classes

Source: Jaetzold, R. and Schidt, H. (1982)

Table 5: Ricardian Regression Estimates of the Net Crop Revenue Model

Variable	Parameter Estimates	Parameter Estimates	Parameter Estimates
Temperature Summer	-542.02 (-2.44)***	-397.71 (-1.85)**	-479.31 (-2.21)**
Temperature Summer squared	11.76 (2.03)**	8.68 (1.58)*	11.03 (1.96)**
Temperature Winter	716.22 (2.55)***	567.73 (2.08)**	702.63 (2.64)***
Temperature Winter squared	-17.09 (-2.30)**	-13.48 (-1.92)**	-17.44 (-2.51)***
Precipitation Fall	13.70 (2.64)***	19.51 (2.98)***	19.79 (2.86)***
Precipitation Fall squared	-0.04 (-2.21)**	-0.06 (-2.82)***	-0.07 (-2.68)***
Precipitation Summer	82.97 (2.49)***	83.00 (2.38)***	76.29 (2.08)**
Precipitation Summer squared	-0.33 (-2.49)***	-0.33 (-2.40)***	-0.31 (-2.11)**
Log (mean flow)		3953.32 (1.86)**	3494.69 (1.64)*
Log (mean flow squared)		-367.62 (-1.88)**	-326.70 (-1.65)*
Soils (Andosols)		602.84 (1.62)**	887.29 (2.34)***
Livestock ownership dummy			-120.25 (-2.58)***
Primary occupation of household head is farming			21.22 (0.51)
Secondary occupation of household head is farming			132.46 (2.62)***
Household head is Christian			154.70 (2.26)**
Average years of education of household members			1.17 (0.31)
Farm size			-3.59 (-3.14)***
Farm size squared			0.01 (2.94)***
Household size			9.15 (1.59)*
Male wage rates			-0.81 (-2.10)**
Child wage rates			-2.57 (-2.41)***
Irrigation dummy			136.43 (2.46)***
Constant	-6567 (-2.33)	-17510 (-2.52)	-16194 (-2.16)
Number of observations	724	724	715
F	3.73***	3.27***	5.30***
R-squared	0.0297	0.0558	0.1291

***, **, * Significant at 1%, 5% and 10% respectively.

Table 6: Impacts on net crop revenue per hectare by Zone (Loss in US\$)

Climate change scenario	Medium & Low potential	High Potential	All Zones
+3.5°C	80.05	-3.54	68.45
+4.0°C	108.79	11.91	93.04
20% reduction in rainfall	69.54	20.14	24.39
+3.5°C+ 20% reduction in rainfall	149.59	16.60	92.84
+4°C+ 20% reduction in rainfall	178.33	32.05	117.43

Table 7: Predicted Marginal Impacts of Different Climate Scenarios

Marginal Impacts	Climate variable model	All variable model
Summer temperature	64.48	57.21
Spring temperature	-105.31***	-83.45**
Overall temperature	-25.78	-11.45
Temperature elasticity	-1.41	-0.63
Winter rainfall	8.04***	11.13***
Precipitation elasticity	1.96	2.71

***, ** Significant at 1% and 5% respectively.

Table 8: Constraints to Short-term Adaptations (% of households)

Constraint faced	% Constrained	Std. Dev.
Lack of information about short term climate variation	8	(0.27)
Lack of knowledge concerning appropriate adaptations	19	(0.39)
Lack of credit or savings	59	(0.49)
No access to water	8	(0.27)
Lack of appropriate Seed	5	(0.21)
Other constraints	13	(0.33)
No barriers to adaptation	8	(0.28)

Table 9: Adaptation to Long-term Climate Change (% of Households)

Variable	Temperature		Precipitation	
	% adopting	Std. Dev.	% adopting	Std. Dev.
Crop diversification / mixed / multi-cropping	25	0.431	37	0.472
Different planting dates	6	0.229	15	0.358
Adjustments to livestock management	4	0.192	6	0.231
Increased use of irrigation / groundwater / watering	6	0.229	16	0.371
Increased water conservation techniques	7	0.247	21	0.406
Decreased water conservation techniques	6	0.236	13	0.342
Shading and shelter / tree planting	22	0.413	9	0.284
No adaptation	40	0.490	22	0.413