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The Impact of Climate Change on Food Calorie Production and Nutritional Poverty

Evidence from Kenya

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The Impact of Climate Change on Food Calorie Production and Nutritional Poverty: Evidence from Kenya

Jane Kabubo-Mariara, Richard M. Mulwa, and Salvatore Di Falco

Abstract

We investigate the effects of climate variables on food and nutrition security and the probability of a household being food and nutrition insecure. Panel data methods from three waves of the Tegemeo Institute Household survey data (2004, 2007, and 2010) are used. Climate change is measured by long-term averages of temperature and rainfall, all measured at the peak precipitation month and extreme values of the Standardised Precipitation-Evapotranspiration Index (SPEI). The results suggest non-linear effects of climate variables on kilocalories produced and on the probability of being food and nutrition insecure. They further suggest that increased moisture is beneficial for kilocalorie production, but excess moisture will be harmful. Overall, the results portray the vulnerability of smallholder farmers to climate change. Technology adoption and adaptation to climate change, as well as household/farm assets, increase kilocalorie production and reduce the probability of being food and nutrition insecure. The findings point at policies related to mitigation and adaptation to climate change, adoption of improved farming technologies, and improved market access.

Key Words: climate change, kilocalories, nutrition, poverty, panel data, Kenya

JEL Codes: Q18, Q54

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The Impact of Climate Change on Food Calorie Production and Nutritional Poverty: Evidence from Kenya

Jane Kabubo-Mariara, Richard M. Mulwa, and Salvatore Di Falco*

1. Introduction

1.1 Motivation and Purpose

Climate change is expected to increase the frequency and intensity of natural disasters and extreme weather events and lead to a reduction in agricultural productivity in sub-Saharan Africa, which is already experiencing declining water quality and quantity (IPCC 2001). IPCC predicts that, by 2050, crop yields in sub-Saharan Africa (SSA) will have declined by 14% (rice), 22% (wheat) and 5% (maize), pushing a vast number of the already poor, who depend on agriculture for their livelihoods, deeper into poverty and vulnerability. It also predicts decreased food availability by 500 calories less per person (a 21% decline) in 2050 and a further increase in the number of malnourished children by over 10 million – a total of 52 million in 2050 in SSA alone. The World Food Programme (2012) further notes that climatic change threatens to significantly increase the number of people at risk of hunger and under-nutrition.

Kenya is one of the countries that have suffered due to global warming. She experienced one of the worst droughts in 2011, where poor rains greatly undermined the food security situation, leaving about 3.5 million people in need of food assistance by August 2011 (World Food Programme 2012). Kenya not only has very high levels of poverty, with about 50% of the population living below the poverty line, but she is also among the poor countries in SSA that are characterized by high levels of the global hunger index (GHI), and is considered to have a serious GHI at 18.6, having dropped from an alarming GHI of 20.6 in 1990 (IFPRI 2011). Close to 70% of Kenyans depend on their natural resource base, depending directly on agriculture, while the remaining 30% still rely on the agriculture sector for food supply. The livelihoods of the majority of Kenyans are therefore at stake due to the threat of climate change.

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There is a growing body of literature on the impact of climate change in Africa. Most studies have concentrated on the impact of climate change on crop and livestock productivity, while other studies have assessed adaptation to climate change.1 This study contributes to the literature by investigating how extreme climate events affect kilocalorie production and thus household food and nutrition security and poverty. While most of the existing studies focus on the effects of climate variables on agricultural production, this study contributes to the limited literature on the effects of climate on food security and the role of climate adaptation in household nutrition in Kenya (Kabubo-Mariara and Kabara 2015; Kabubo-Mariara et al. 2015). This study goes beyond traditional studies of climate change to investigate the effect of climate variables (peak month temperatures and precipitation, as well as extreme climate events measured through very low and very high standardised precipitation evapotranspiration index, SPEI) on kilocalorie production and nutritional poverty. In addition, most studies on the impact of climate change have used cross-sectional data, mainly using Ricardian models. This study uses panel data to estimate the effect of climate change on kilocalories produced and on the probability of being food and nutrition secure. Because smallholder farmers in Kenya rely on their own production for daily consumption, they derive most of their caloric intake from this source. Any shortfall in kilocalorie production therefore has important implications for food and nutritional security.

The rest of the paper is structured as follows: the next section presents the data. This is followed by literature in Section 3 and methods in Section 4. Section 5 presents the results, while Section 6 concludes.

2. Review of Literature

Studies on the impact of climate change on agriculture have increased over the decade, with a more recent focus on Africa. Most of the studies also assess the extent to which adaptation options can lessen the expected impact of climate change. A number of approaches have been used to assess the impact of climate change on agriculture. These include the production function and the hedonic and Ricardian approaches.

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[1] See, for instance, Kabubo-Mariara and Kabara (2015); Kabubo-Mariara et al. (2015); Kabara and Kabubo-Mariara (2011); Herrero et al. (2010); Kabubo-Mariara (2008, 2009); Deressa et al. (2009); Dinar et al. (2008); Hassan and Nhemachena (2008); Kabubo-Mariara and Karanja (2006); Gbetibouo and Hassan (2005).

The production function approach relies on experimental evidence of the effect of temperature and precipitation on agricultural yields (Amthor 2001). Studies using this approach in Africa include a study by Turpie et al. (2002) that analyzed the economic impact of climate change in South Africa. Another study, by Mohamed et al. (2002), argued that climate change factors are significant determinants of millet productivity in Niger and predicted a huge fall in crop productivity by 2025 as a result of global warming. Older studies include Downing (1992) on Zimbabwe and Kenya, Schulze et al. (1993) on South Africa, Lesotho and Swaziland and Sivakumar (1992) on Niger. These studies concur that climate has significant implications for agriculture. The shortcomings of the production function are that the experimental estimates do not account for profit-maximizing farmers' compensatory responses to changes in climate and do not consider the possible implications of farmers' adaptation, thus overstating losses (Kurukulasuriya and Mendelsohn 2008).

Mendelsohn et al. (1994) proposed the hedonic approach as a solution to the production function's shortcomings. The hedonic method measures the impact of climate change by directly estimating the effect of temperature and precipitation on the value of agricultural land with the assumption that, if land markets are operating properly, prices will reflect the present discounted value of land rents into the infinite future. However, further research has shown that cross-sectional hedonic equations appear to be plagued by omitted variables bias in a variety of settings (Black and Kneisner 2003; Greenstone and Gallagher 2005).

To overcome the shortcoming of the hedonic approach, Mendelsohn et al. (1994) introduced the Ricardian approach, which through econometric analysis of cross-sectional data isolates the effects of climate on farm income and land value and incorporates the farmer's possibility of using adaptation strategies, after controlling for some relevant explanatory variables. Most of the studies on the impact of climate change on African agriculture use the Ricardian approach. These include Molua (2002), who, in an analysis of the impact of climate on agriculture in Cameroon, found that increased precipitation is beneficial for crop production and that farm level adaptations are associated with increased farm returns. Deressa et al. (2005), in a study on the impact of climate on South African sugarcane production, show that climate change has significant non-linear impacts on net revenue, with higher sensitivity to future increases in temperature than to precipitation. Gbetibouo and Hassan (2005) found crops to be quite sensitive to marginal changes in temperature compared to changes in precipitation. Contrary to findings by Deressa et al. (2005), Gbetibouo and Hassan argue that irrigation would be an effective adaptation measure for limiting the harmful effects of climate change, and that the impact of climate change is agro-ecological zone specific and therefore that location is important in dealing with climate change issues.

Kabara and Kabubo-Mariara (2011) show that global warming leads to decline in output. Their findings support those for Cameroon by Molua (2008). Kabubo-Mariara (2009), in a study of the economic impact of climate change on livestock production in Kenya, found that, in the long term, climate change is likely to lead to increased poverty, vulnerability and loss of livelihoods. Kabubo-Mariara and Karanja (2007) find that climate affects crop productivity, but show that the temperature component of global warming is much more important than precipitation. Other studies include Schlenker and Lobell (2010) on African agriculture, Davis and Sadiq (2010) on cocoa production yields in Nigeria and Oyekale (2012) on cocoa in South-West Nigeria.

The Ricardian approach has been criticized for failing to identify the key adaptation strategies, among other shortcomings (Kabubo-Mariara and Karanja 2007). Panel data studies have used the Deschenes and Greenstone (2004, 2007) and Massetti and Mendelsohn (2011) approaches to assess the impact of climate change on agricultural production (see, for instance, Bezabih et al. (2014) on Ethiopia and Kabubo-Mariara and Kabara (2015) on Kenya).

Several studies have assessed the impact of climate change on agriculture, agricultural productivity and nutrition outside Africa (Van Passel et al. 2012; Frank et al. 2014; Tirado et al. 2013; Miles et al. 2010; Knox et al. 2012; Iqbal and Siddique 2014). Van Passel et al. (2012) carried out a study of the impact of climate change on European agriculture using a Ricardian model applied to data from 15 Western European countries. The findings of this study showed that climate change has a strong influence on farmland values in Europe and the aggregate impacts predicted a loss of 8% to 44% by 2100, depending on the climate model scenario. The findings of this study support those of Frank et al. (2014), who assessed the impacts of climate change on European agriculture using a joint application of two European-focused global partial equilibrium models. The findings of that study showed that climate change adversely affects agricultural supply and demand quantities as well as producer prices, and that the average calorie consumption per capita decreases in both scenarios by around 3% in Europe and 5-7% globally.

Tirado et al. (2013) further studied climate change and nutrition using a cross-sectoral analysis guided by an analytical framework of the interaction between climate change, vulnerability, adaptation and mitigation and the three main causes of under-nutrition, which include household access to food, childcare and feeding practices, and access to health and environmental health (United Nations Framework Convention on Climate Change). The findings of this study showed that climate change has a direct impact on food and nutrition security. Miles et al. (2010) assessed the regional climate change effects and adaptation strategies for the State of Washington in the U.S., studying the eight climate-sensitive sectors of the state economy, including agriculture, using model simulations of apple, potato and wheat production under different climate change scenarios. The results of this study revealed that agriculture in Washington is highly vulnerable to climate change effects.

Knox et al. (2012) evaluated the impact of climate change on agricultural productivity and yield of eight food and commodity crops in both Africa and South Asia, using a systematic review and meta-analysis of data in 52 original publications. That study projected a mean 8% decrease in yield of all crops by the year 2050 in both regions, indicating decreased crop productivity. The findings of the study were in line with those of Iqbal and Siddique (2014), who estimated the impact of climate change on agricultural productivity in Bangladesh using Ordinary Least Square (OLS) and regional Fixed Effects models on 1975 to 2008 data. The findings revealed that the productivity of rice differs significantly across the regions, and that climate change will have strong negative impacts on agricultural productivity, poverty and food security.

Most of the quantitative assessments on impacts of climate change show that climate change will adversely affect agriculture. Most of the studies specifically focus on impacts of crop productivity or farm revenue. None of the studies have investigated the effect of climate change on nutrition measured through kilocalories produced by a household. Notable relevant studies include Frank et al. (2014), Roberts and Schlenker (2009, 2013) and Tirado et al. (2013), who analyze effects of climate factors on some nutritional aspects. Also related to these is Carlsson-Kanyama (1998), who analyze the effect of climate change on dietary choices, specifically trying to find out how emissions of greenhouse gases from food consumption could be reduced. The present study fills out this scarce literature. The effect of climate change on production of kilocalories has direct impacts on nutrition and food security, thus translating to direct effects on household poverty. The analysis follows the approach by Deschenes and Greenstone (2007), Massetti and Mendelsohn (2011) and Roberts and Schlenker (2009).

3. Data

This paper uses data from the Tegemeo Institute household surveys for 2004, 2007 and 2010. The surveys were conducted by Tegemeo Institute of Agricultural Policy and Development, Egerton University, in collaboration with Michigan State University.[2] The institute collected data from 2,297, 1342 and 1309 households for the three years respectively, spread over 24 districts in Kenya. The three waves of data include the variables required for the analysis in this paper.

The survey data is complemented by data on climate variables, namely the SPEI (Standardised Precipitation-Evapotranspiration Index), rainfall, and temperature. The SPEI is a multi-scaler drought index based on climatic data, which takes into account both precipitation and potential evapotranspiration in determining drought. It captures the main impact of increased temperatures on water demand. The SPEI data was obtained from the Global SPEI database and covers the period between January 1901 and December 2013 (Begueria and Vicente-Serrano 2013). Rainfall data was obtained from CHIRPS (the Climate Hazards Group InfraRed Precipitation with Stations) data archive. CHIRPS is a 30+ year quasi-global rainfall dataset, which incorporates satellite imagery with in-situ station data to create gridded rainfall time series for trend analysis and seasonal drought monitoring (Funk et al. 2015). Temperature data was sourced from the Global Historical Climatology Network Version 2 data set and the Climate Anomaly Monitoring System (GHCN CAMS). GHCN CAMS comprises global land surface temperatures from 1948 to present, analyzed at a high resolution, and captures most common temporal-spatial features in the observed climatology and anomaly fields over both regional and global domains (Fan and van den Dool 2008). The climate data are matched to household level data using sub-location level shapefiles from the 2009 Kenya Housing and Population Census.

4. Methods

Mendelsohn et al. (1994) proposed a hedonic approach to measure the effect of climate change by directly estimating the effect of temperature and precipitation on the value of agricultural land. The appeal of their model, popularly known as the Ricardian

[2] http://www.tegemeo.org/.

approach, is that, if land markets are operating properly, prices will reflect the present discounted value of land rents into the infinite future. This model requires one to obtain consistent estimates of the independent influence of climate on land values, which requires that all unobserved determinants of land values are orthogonal to climate. However, Deschenes and Greenstone (2004; 2007) argue that temperature and precipitation normals covary with soil characteristics, population density, per capita income, latitude, and elevation. This has also been highlighted by Jacoby et al. (2011). What this implies is that unobserved variables are likely to covary with climate, and the cross-sectional hedonic approach confounds the effect of climate with other factors.

To overcome the challenges of the Ricardian approach, Deschenes and Greenstone (2004) advocated for a panel data fixed effects estimator. They used county-level panel data to estimate the effect of weather on agricultural profits, conditional on county- and state-by-year fixed effects. The model takes the form:

$$y_{it} = X_{it}'\beta + \sum_{i=1}^{n} \sigma_i \, f_i(\overline{W}_{ic}) + \varepsilon_{it} \, ; \quad \varepsilon_{it} = \alpha_i + u_{it} \qquad (1)$$

where,

- y_{it} = value of agricultural land in county i in year t;
- X_{it} = vector of observable determinants of farmland values. The t shows that there are time-varying factors that affect land values;
- $\overline{W}_{it}$ = A series of n climatic variables for county c. The bar on $\overline{W}_{it}$ shows that there is no temporal variation in climate factors, hence it is impossible to estimate the effect of the long-run climate averages;
- ε_{it} =stochastic term with permanent county-specific component α_i and an idiosyncratic shock u_{it}; and
- σ_i= is the effect of climate on farmland values. Its estimates are used to calculate the overall effect of climate change.
- The functional form $f_i(\overline{W}_{it})$ could be linear or quadratic

Consistent estimation of each σ_i requires that $E[f_i(\overline{W}_{it})\varepsilon_{it}|X_{it}] = 0$, i.e., we assume a random effects framework. In most cases, however, this assumption will be invalid if there are unmeasured permanent (α_i) and/or transitory (u_{it}) factors that covary with the climate variables, i.e., if $E[f_i(\overline{W}_{it})\varepsilon_{it}|X_{it}] \neq 0$. To estimate this model using the fixed effects framework would entail demeaning the model variables to remove the county-specific effects.

To improve the model, Deschenes and Greenstone (2007) added time-specific heterogeneity to the individual-specific heterogeneity of their 2004 model. They also introduced seasonal weather changes (W_{it}) in any given year to replace the mean annual climate factors ($\bar{W}_{it}$). Their aim was to introduce and estimate the effects of the long-run climate averages. Their improved 2007 model takes the form:

$$y_{it} = \alpha_i + \gamma_t + X_{it}{}'\beta + \sum_{i=1}^{n} \sigma_i f_i(W_{it}) + u_{it} \qquad (2)$$

where:

- $\alpha_i =$ full set of county-fixed effects to absorb all unobserved county-specific time invariant determinants of the dependent variable;
- $\gamma_t =$ year indicators that control for annual differences in the dependent variable that are common across counties;
- $W_{it} =$ indicates that we have replaced the climate variables with annual realizations of weather; and
- $y_{it} =$ the dependent variable, which is now county-level agricultural profits, instead of land values. This is because land values capitalize long-run characteristics of sites, conditional on county fixed effects. Annual realizations of weather should therefore not affect land values. However, weather does affect farm revenues and expenditures, and their difference is profits.

As in the earlier equation, the validity of each estimated σ_i rests on the assumption that $E[f_i(\boldsymbol{W}_{ict})u_{it}|X_{it}\alpha_i\gamma_t] = 0$, which may not be valid, since $E[f_i(\boldsymbol{W}_{ict})u_{it}|\boldsymbol{X}_{it}\alpha_i\gamma_t] \neq 0$. This then requires a two-way within unobserved fixed effects model. This is because we need to account for both time invariant and individual invariant effects in a tractable manner.

This approach differs from the MNS hedonic-cross sectional approach in a few key ways. First, under an additive separability assumption, its estimated parameters are purged of the influence of all unobserved individual and time-invariant factors. Second, land values cannot be used as the dependent variable once the county-fixed effects are included because land values reflect long-run averages of weather, rather than annual deviations from these averages, and there is no time variation in such variables. Third, the approach can be used to approximate the effect of climate change on agricultural land values.

Deschenes and Greenstone (2007) caution that there are two issues that could undermine the validity of using annual variation in weather to infer the impacts of climate change. First, short-run variation in weather may lead to temporary changes in prices that obscure the true long-run impact of climate change. Second, farmers cannot undertake the full range of adaptations in response to a single year's weather realization. These concerns were also raised by Massetti and Mendelsohn (2011). The authors, however, show evidence to discount the possibility of the results obtained being affected by either of these concerns.

In our study, we adapt the approach by Deschenes and Greenstone (2007), who used agricultural profits as their dependent variable. It has been argued that agricultural commodity markets are typical examples of competitive markets, with many price-taking producers and buyers and well-developed spot and futures markets (Roberts and Schlenker, 2009; 2013). This argument is true in developed countries, where markets are a reflection of commodity surpluses and deficits. However, in most developing countries, due to market imperfections, neither agricultural produce markets nor factor markets are reliably representative of the actual market scenarios. Using agricultural farm profits in our estimation would therefore underestimate or overestimate farm returns. For this reason, we choose to use "sum of edible calories" derived from the farmed crops (Roberts and Schlenker, 2009) in the households of our sample as the dependent variable. In addition to overcoming the market imperfection challenge, this caloric summation also presents a simple yet broad-scale analysis of the actual household food situation in the household and can be used as an estimate of the household caloric food security. This transforms Equation (2) into:

$$s_{it} = \alpha_i + \gamma_t + X_{it}'\beta + \sum_{i=1}^{n} \sigma_i f_i(W_{it}) + u_{it} \qquad (3)$$

where s_{it} is the sum of all edible calories from the major farmed crops in county i in year t. The other variables are as defined in Equation (2). We estimate Equation (3) for total kilocalories produced per acre, kilocalories produced for main food crops, and the probability of being kilocalorie poor.

5. Results and Discussion

5.1 Descriptive Statistics

The independent variables used in the model were grouped into household characteristics (gender, age and education of head, household size, and whether any household member participated in off-farm income earning opportunities), assets (total land holding in acres, total livestock units and value of buildings), average seed cost (proxy for cost of inputs), and measures of technology adoption/adaptation to climate change (use of improved seed dummy and average fertilizer use per acre). We also include a dummy to capture whether a farmer received credit, whether the farmer belongs to a cooperative/group, and distance to motorable road (a proxy for market access). Table A1 presents descriptive statistics of the dependent variables of interest. The statistics portray some variations across the three years, most notably fluctuation in assets. The last three rows present summary statistics for the climate variables.

Table A2 presents summary statistics on kilocalories produced for different crops. The survey collected data on production of all crops produced by farming households over the short and long rains growing seasons, totaling about 200 different crops. The quantities of crops harvested were converted into their kilocalorie equivalent per acre, based on the FAO and Tanzanian food composition tables.[3] The kilocalories produced of different crops were then summed up to generate total kilocalories produced.

The results show that the maize crop was the largest source of kilocalories produced, which is important given that maize is the main staple food in Kenya. Other crops with relatively high kilocalorie production are bananas, wheat and beans. The statistics suggest kilocalorie production of all crops increased between 2004 and 2007, but dropped in 2010. The largest decline was observed for bananas and millet. This implies that, on average, households in the sample were worse off in 2010 relative to 2007.

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[3] http://www.fao.org/docrep/003/x6877e/X6877E05.htm#ch5.1. http://www.hsph.harvard.edu/nutritionsource/food-tables/ Accessed, 15th July 2015. For individual crop analysis, we focus on maize (3593 Kcal/kg); beans (3330 Kcal/kg); sorghum (3390 Kcal/kg); millet (3340 Kcal/kg); wheat (3390 Kcal/kg) and bananas (890 Kcal/kg).

5.2 Empirical Results

The effect of climate variables on kilocalories produced was analysed for all farm produce and also for selected crops. The results for the effect of climate variables on total kilocalories produced and the probability of being food and nutrition insecure are presented in Tables 1 and 2. The last column of Table 2 presents the same model but with value of total production as the dependent variable. We further analyze the impact of climate variables on kilocalories produced of the main food crops, namely maize, sorghum, millet, wheat, bananas, beans and indigenous vegetables. Maize, sorghum, millet and bananas are important for food security as they are key staple foods. Beans are an important source of proteins, while indigenous vegetables are important sources of minerals. Table 3 presents the results of the effect of temperature and rainfall on kilocalories produced of the main food crops, while results for SPEI are presented in Table 4.

Table 1 presents results of the effect of climate variables on kilocalories produced and the probability of being food and nutrition insecure while holding other factors constant. A household is defined as food and nutrition insecure if they fall short of a relative poverty line. The literature suggests that relative poverty lines can be set at various percentiles of the welfare measure: 25th, 40th and 60th percentiles (Kabubo-Mariara and Kabara 2015). We therefore construct poverty thresholds based on the three percentiles of kilocalorie production. A household would have experienced nutritional insecurity/poverty if kilocalorie production fell short of any of the percentiles.

In the results, the constant terms show the amount of kilocalories produced under normal climatic conditions. The rest of the coefficients can be used to compute the marginal impacts and elasticity of kilocalorie production with respect to climate variables. Kilocalorie production has lower marginal effects with respect to very wet conditions (high SPEI) than with respect to very dry conditions (very low SPEI), but both effects are statistically significant. A one-unit increase in the likelihood of having very dry conditions would reduce kilocalorie production by 0.243 units, ceteris paribus, while a similar increase in the likelihood of very wet conditions would reduce kilocalorie production by 0.133 units. Thus, very dry conditions are more harmful to production of nutrition than very moist conditions.

The marginal effect of kilocalorie production with respect to temperature is 1.7, suggesting that a 1% rise in temperature increases kilocalorie production by 1.7%. Kilocalorie production is, however, inelastic with respect to temperature (0.661). Both the marginal effect of rainfall and the elasticity of kilocalorie production with respect to rainfall are rather low and insignificant. Based on the 25th percentile of kilocalorie production, the probability of being kilocalorie poor/insecure has a low but significant negative marginal effect (-0.627) with respect to temperature, but a small, positive, marginal effect (0.071) with respect to rainfall. The results for the other percentiles (not presented) point at similar conclusions.

Tables 2 to 4 present results after controlling for other factors. The results in Column 2 of Table 4 show that peak month temperature has large significant effects on the amount of kilocalories produced by a household. The effect of peak month precipitation is lower, but also significant. Further, the results show a U-shaped relationship between kilocalories produced and the peak month temperature, but a hill-shaped relationship with peak month precipitation. The amount of kilocalories produced is also strongly affected by the standardized precipitation and evapotranspiration index, which also portray a hill-shaped relationship. The results for the SPEI suggest that extreme climatic conditions are harmful for kilocalorie production. Specifically, the results suggest a -0.12 very dry conditions sensitivity and a -0.17 very moist condition sensitivity to total kilocalorie production. Further, we observe a -0.4145 very moist condition sensitivity of the probability of being kilocalorie poor, while the sensitivity to very dry conditions is insignificant.

Use of fertilizers and improved seed are measures of adoption of improved technology, but also can be taken as proxies for adaptation to climate change. Use of improved seeds has a large significant effect of increasing the amount of kilocalories produced. The effect of average fertilizer use per acre is also positive and significant, but much lower, with an elasticity of 0.03. The interaction of use of improved seeds and SPEI has a positive significant effect, suggesting that increased moisture will be beneficial if a farmer uses improved seeds. The interaction of the average fertilizer use per acre and the SPEI has a negative significant effect on kilocalories production, suggesting that use of fertilizer during periods of excess wetness will be harmful to kilocalorie production.

We include dummies for year 2007 and 2010 to test whether there are any unobserved characteristics common to households within a particular year, such as higher prices, favourable extension services and markets, prevalence of pests and diseases, etc. The results suggest large and significantly lower kilocalorie production in 2010 compared to 2004, but no significant effect is found for 2007. The interaction between the survey year and the SPEI shows a significant negative effect for 2007, but a larger significant positive effect in 2010. This probably captures differential impacts of other factors affecting kilocalorie production in the two years, holding SPEI constant.

Other factors that are associated with increased kilocalorie production include post-secondary education, assets (livestock and value of buildings), use of fertilizers and improved seeds and distance to extension services; the finding that greater distance to extension services is associated with increased production is an unexpected result. Another surprising finding is that total land holding has a negative effect on kilocalorie production; this probably suggests an inverse correlation between land size and the quality of land.

Columns 4 and 5 of Table 2 present the results for the probability of being food and nutrition insecure. The results corroborate those in Columns 2 and 3 on kilocalorie production and suggest that households with higher levels of kilocalories harvested are less nutritionally poor than their counterparts with low kilocalorie production. Specifically, the results suggest a negative effect of a very moist SPEI on the probability of being poor, as well as an inverted U-shaped relationship with temperature, but a U-shaped relationship with precipitation. Very dry conditions have a positive but insignificant effect. Only total land holding per acre seems to have a negative effect on poverty relative to kilocalorie production. The results for value of production (Columns 5 and 6) also mimic those of kilocalories harvested, with the exception of primary education, total land holdings, log total seed used and the dummy for 2010. All other results imply similar effects, though the magnitudes and level of significance differ.

In Table 3, we present results for individual food crops with temperature and precipitation variables. The results show that all crops except beans and bananas exhibit a large and significant U-shaped relationship with temperature, suggesting that production of calories decreases with the level of temperature. After a given threshold, excessive temperature leads to higher production, probably reflecting the effect of adaptation options to mitigate against rising temperatures. Precipitation exhibits an inverted U-shaped relationship, which is significant only for maize, suggesting that maize production is more sensitive than other crops to climate variables. The results further imply that kilocalorie production of most individual crops was much lower in 2007 and 2010 relative to 2004. Household assets, improved seeds, and fertilizer are clearly important factors for production of kilocalories of different food crops.

Table 4 presents results with extreme climate conditions as the control variables. The results suggest that kilocalorie production of maize, beans and wheat respond significantly to variations in very dry conditions, with the largest impacts on maize and wheat. Only wheat responds significantly to excessive moisture. The results support earlier findings that extreme climatic conditions are harmful to kilocalorie production and that excess drought is more harmful than excess wetness. In this specification, the year 2007 is associated with significantly less kilocalorie production of beans, sorghum, millet, and wheat, while only millet and bananas exhibit the same effect in 2010. The results, however, suggest that there was more kilocalorie production of maize in 2007 and 2010 relative to 2004. As is the case with total kilocalorie production, household assets are clearly important for production of individual crops. Also important and significant are the use of improved seeds and application of fertilizers, while availability of credit and membership in groups are important factors for some crops.

Table 5 presents the results for kilocalorie production of indigenous vegetables. Such vegetables form an important component of nutritional requirements as they are an important source of minerals. The results show that the kilocalorie production of indigenous vegetables is quite sensitive to variations in precipitation (but not to temperature) and an inverted U-shaped relationship with kilocalorie production is observed. Kilocalorie production of indigenous vegetables is also very sensitive to very dry conditions, which are harmful. Other factors which affect production of kilocalorie from indigenous vegetables include female headship, which is important given that most indigenous vegetables are grown by women, and high seed costs, which are associated with significantly lower production of indigenous vegetables.

6. Conclusion

This paper investigates the effects of climate variables and other covariates on kilocalorie production and the probability of a household being kilocalorie poor, using panel data. The analysis is based on three waves of the Tegemeo Institute Household survey covering 2004, 2007 and 2010. Data on climate variables include the Standardised Precipitation-Evapotranspiration Index (SPEI), sourced from the Global SPEI database. Rainfall data was sourced from the Climate Hazards Group InfraRed Precipitation with Stations (CHIRPS) data archive, while temperature data was sourced from the Global Historical Climatology Network Version 2 dataset and the Climate Anomaly Monitoring System (GHCN CAMS). Temperature and precipitation variables are computed at the peak precipitation month. SPEI is used to measure extreme climate conditions (excessive dryness and excessive wetness). The climate data are matched to household level data using sub-location level shapefiles based on the 2009 Kenya Housing and Population Census.

We present results for total kilocalorie production per acre, for the main staple food crops, for beans and for indigenous vegetables. Kilocalorie production captures farm productivity and is also a proxy for production of household nutrition. Beans and indigenous vegetables have important implications for nutritional security, as they are sources of protein and minerals respectively. We further present results for the household being kilocalorie poor, which assess the impact of climate variables on the likelihood of a household falling within the 25th percentile of kilocalorie production.

The results show a significant U-shaped relationship between kilocalories produced and peak month temperature, but an inverted-U shaped relationship with peak month precipitation. The results suggest a non-linear relationship between climate variables and the amount of kilocalories produced. The amount of kilocalories produced is also strongly and adversely affected by extreme climatic conditions, namely excess dryness and excess moisture. The results suggest a -0.12 (-0.17) excess dryness (moisture) sensitivity of total kilocalorie production, and a -0.415 excess moisture sensitivity of the probability of being kilocalorie poor. The marginal effect of temperature on kilocalorie production suggests that a 1% rise in temperature increases kilocalorie production by 1.7%. Kilocalorie production is, however, inelastic with respect to temperature and precipitation. Overall, the results illustrate the vulnerability of smallholder farmers to climate change. The results for the probability of being kilocalorie poor also portray vulnerability of households to climate change.

All crops except beans and bananas exhibit a large, significant U-shaped relationship with temperature, but only maize responds significantly to variations in precipitation. The results seem to suggest that maize and wheat production are more sensitive to climate variables than are other crops. The results further suggest that extreme climatic conditions are harmful to kilocalorie production and that excess drought is more harmful than excess wetness. Technology adoption and adaptation to climate change increase kilocalorie production and reduce the probability of being kilocalorie poor. Other important factors include education, household size and assets (livestock and value of buildings). Distance to extension services and total land holding have unexpected reverse effects. Kilocalorie production of indigenous vegetables is quite sensitive to precipitation and very dry conditions. Female headship is also found to be an important factor for production of indigenous vegetables, while high seed costs adversely affect kilocalorie production.

The results suggest the need for policies that cushion households, especially poor households, against adverse climate change effects. Such polices should include mitigation and adaptation measures. In addition, adoption of improved technologies should be encouraged in order to boost kilocalorie production and reduce the probability of households falling into poverty. Other policies should focus on boosting household assets and improvement of infrastructure/market access.

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Tables

Table 1. Effects of Climate Variables on Kilocalories Produced and Probability of Being Kilocalorie Poor

Variables	Kcal produced (1)	Kcal produced (2)	Poor (1)	Poor (1)
Log peak month temperature	-82.4875***		29.4368*	
	[17.889]		[15.023]	
Log peak month temperature squared	13.8906***		-4.9612**	
	[2.945]		[2.471]	
Log peak precipitation	2.4274***		-7.5463***	
	[0.645]		[1.134]	
Log peak precipitation squared	-0.2311***		0.7270***	
	[0.063]		[0.110]	
Very dry conditions (low SPEI)		-0.243***		0.3921***
		[0.033]		[0.062]
Very moist conditions (high SPEI)		-0.133***		-0.084
		[0.060]		[0.114]
Constant	123.6241***	7.804***	-25.07	-0.4470***
	[26.860]	[0.014]	[21.887]	[0.042]
Observations	3,922	3,922	3,933	3,933
R-squared	0.014	0.021		
Wald chi2 (4/2)			44.99	47.77
Number of Obs.	1,311	1,311	1,311	1,311

***, **, * denotes significant at 1%, 5% and 10% respectively.

Table 2. Effects of Climate Change Variables on Kilocalories Produced per acre, Probability of Being Kcal Poor and Value of Production

VARIABLES	Kcal produced (1)	Kcal produced (2)	Poor (1)	Poor (2)	Value of output (1)	Value of output (2)
Female head	-0.1098	-0.0909	0.1478*	0.1573*	-0.0877	-0.0831
	[0.078]	[0.078]	[0.081]	[0.083]	[0.078]	[0.078]
Log age of head	-0.0345	-0.0503	-0.1701	-0.1336	0.3770**	0.3591**
	[0.169]	[0.168]	[0.156]	[0.160]	[0.168]	[0.168]
Primary education	-0.0578	-0.0675	-0.2100**	-0.1428	0.1296**	0.1189*
	[0.062]	[0.061]	[0.088]	[0.089]	[0.061]	[0.061]
Secondary education	0.0222	-0.0063	-0.4593***	-0.3778***	0.1673*	0.1454
	[0.094]	[0.094]	[0.120]	[0.122]	[0.094]	[0.094]
Post-secondary educ.	0.2465**	0.1981*	-0.2908*	-0.2222	0.4293***	0.4094***
	[0.120]	[0.119]	[0.169]	[0.172]	[0.119]	[0.119]
Log household size	0.063	0.0637	-0.3091***	-0.3840***	0.1546**	0.1582***
	[0.061]	[0.060]	[0.066]	[0.067]	[0.060]	[0.060]
Off-farm income dummy	-0.0344	-0.0595	0.1867**	0.1652*	-0.1130**	-0.1288***
	[0.047]	[0.047]	[0.095]	[0.096]	[0.047]	[0.047]
Log total land holding (acres)	-0.0077***	-0.0071***	-0.0370***	-0.0355***	0.0111***	0.0115***
	[0.002]	[0.002]	[0.007]	[0.007]	[0.002]	[0.002]
Log total livestock units	0.0666	0.0920**	-0.3300***	-0.2866***	0.2729***	0.2850***
	[0.041]	[0.040]	[0.060]	[0.060]	[0.040]	[0.040]
Log value of buildings	0.0132**	0.0175***	-0.0297***	-0.0180*	0.0192***	0.0221***
	[0.005]	[0.005]	[0.011]	[0.011]	[0.005]	[0.005]
Log total seed cost	0.0184*	0.014	0.0149	0.0513***	-0.0368***	-0.0412***
	[0.011]	[0.011]	[0.020]	[0.020]	[0.011]	[0.011]

Used improved seeds	0.3095***	0.3638***	-0.8627***	-0.7323***	0.4660***	0.5233***
	[0.053]	[0.053]	[0.095]	[0.098]	[0.052]	[0.053]
Log average fertilizer per acre	0.0289***	0.0228***	-0.1029***	-0.0884***	0.0598***	0.0611***
	[0.008]	[0.009]	[0.014]	[0.015]	[0.008]	[0.009]
Log distanced to extension services	0.0474*	0.0334	0.0345	0.0115	0.0766***	0.0625**
	[0.025]	[0.025]	[0.045]	[0.045]	[0.025]	[0.025]
Farmer received credit	-0.015	-0.0168	0.0029	-0.01	0.0645*	0.0655*
	[0.035]	[0.035]	[0.066]	[0.067]	[0.035]	[0.035]
Member belongs to a cooperative/group	0.0508	0.0666*	-0.2284***	-0.2414***	0.1323***	0.1420***
	[0.039]	[0.039]	[0.071]	[0.071]	[0.039]	[0.039]
Log distance to motorable road	-0.0207	-0.012	-0.0743	-0.0531	-0.0166	-0.0034
	[0.040]	[0.040]	[0.074]	[0.075]	[0.040]	[0.040]
Log peak month temperature	-55.0332***		28.6227*		-35.4564**	
	[17.988]		[14.800]		[17.902]	
Log peak month temperature squared	10.1049***		-5.2220**		6.7161**	
	[2.949]		[2.436]		[2.935]	
Log peak precipitation	2.0631***		-4.5115***		1.6997**	
	[0.687]		[1.162]		[0.684]	
Log peak precipitation squared	-0.1881***		0.4314***		-0.1486**	
	[0.067]		[0.113]		[0.066]	
Very dry conditions (low SPEI)		-0.1166*		0.1624		0.0487
		[0.062]		[0.116]		[0.062]
Very moist conditions (high SPEI)		-0.1677**		-0.4145**		-0.3386***
		[0.076]		[0.176]		[0.076]
Fertilizer*SPEI		-0.00001***		0		0.0001
		[0.000]		[0.000]		[0.000]

Improved seeds* SPEI		0.1420***		-0.0091		0.1378***
		[0.042]		[0.088]		[0.042]
2007	0.0141	0.0786	-0.2801***	-0.3264***	0.1020**	0.0603
	[0.049]	[0.053]	[0.102]	[0.115]	[0.049]	[0.053]
2010	-0.3704***	-0.2114***	0.3410***	-0.3883***	0.042	0.4467***
	[0.057]	[0.076]	[0.098]	[0.149]	[0.057]	[0.076]
2007*SPEI		-0.1596**		-0.0973		0.0672
		[0.066]		[0.137]		[0.066]
2010*SPEI		0.3370***		-0.3405**		0.1738**
		[0.077]		[0.148]		[0.076]
Constant	75.4529***	7.2047***	-24.6219	1.9903***	48.5717*	7.6851***
	[27.247]	[0.722]	[21.655]	[0.727]	[27.117]	[0.721]
Observations	3,916	3,916	3,916	3,916	3,916	3,916
R-squared/Wald Chi2(23/25)	0.079	0.089	418.75**	371.88**	0.187	0.191
Number of Obs.	1,310	1,310	1,310	1,310	1,310	1,310

Standard errors in brackets; *** p<0.01, ** p<0.05, * p<0.1

Table 3. Effects of Temperature and Precipitation on Kilocalories Produced of Individual Food Crops

Variables	Maize	Beans	Sorghum	Millet	Wheat	Bananas
Female head	-0.2466*	-0.0541	-0.3570*	0.0824	-0.1401	0.0255
	[0.146]	[0.177]	[0.188]	[0.175]	[0.151]	[0.217]
Log age of head	0.279	0.4872	-0.1643	0.41	-0.1309	-0.0596
	[0.315]	[0.382]	[0.406]	[0.376]	[0.325]	[0.467]
Primary education	0.0836	0.2262	-0.0121	-0.1532	-0.0731	0.1802
	[0.115]	[0.139]	[0.148]	[0.137]	[0.119]	[0.170]
Secondary education	0.2101	0.5053**	-0.2453	0.3368	-0.2026	0.3389
	[0.175]	[0.213]	[0.226]	[0.210]	[0.181]	[0.260]
Post-secondary educ.	0.4020*	0.5654**	-0.4126	0.2471	-0.2761	0.3915
	[0.223]	[0.271]	[0.288]	[0.267]	[0.231]	[0.331]
Log household size	0.3298***	0.3332**	0.0994	0.0534	0.1493	-0.0894
	[0.113]	[0.137]	[0.146]	[0.135]	[0.117]	[0.168]
Off-farm income dummy	-0.1798**	-0.0918	0.0687	-0.1661	-0.1378	0.0876
	[0.088]	[0.107]	[0.114]	[0.105]	[0.091]	[0.131]
Log total land holding (acres)	0.0079*	0.0012	0.0022	0.0153***	0.0124***	-0.0027
	[0.004]	[0.005]	[0.006]	[0.005]	[0.005]	[0.006]
Log total livestock units	0.3271***	0.2624***	0.1904*	0.1145	0.1218	0.3844***
	[0.076]	[0.092]	[0.097]	[0.090]	[0.078]	[0.112]
Log value of buildings	0.0380***	0.0335***	0.0307**	0.0109	0.0247**	0.0062
	[0.010]	[0.012]	[0.013]	[0.012]	[0.011]	[0.015]
Log total seed cost	-0.0109	0.0235	-0.0289	-0.0463*	0.021	-0.0655**
	[0.020]	[0.024]	[0.026]	[0.024]	[0.021]	[0.030]
Used improved seeds	0.6681***	0.4879***	0.1528	0.3591***	0.1878*	-0.0121
	[0.098]	[0.119]	[0.127]	[0.117]	[0.102]	[0.146]
Log average fertilizer per acre	0.0828***	0.0386**	-0.0330*	0	-0.0096	0.0121

	[0.015]	[0.019]	[0.020]	[0.019]	[0.016]	[0.023]
Log distanced to extension services	0.0599	0.0328	0.0175	-0.0221	0.0004	0.0911
	[0.047]	[0.058]	[0.061]	[0.057]	[0.049]	[0.070]
Farmer received credit	0.0289	0.1764**	0.0281	0.0649	0.0274	-0.0699
	[0.066]	[0.080]	[0.085]	[0.079]	[0.068]	[0.098]
Member belongs to a cooperative/group	0.0698	0.2079**	-0.0641	0.0769	0.0627	0.2446**
	[0.072]	[0.088]	[0.093]	[0.086]	[0.075]	[0.107]
Log distance to motorable road	-0.0047	0.1345	0.2343**	-0.088	-0.0917	0.0112
	[0.075]	[0.091]	[0.097]	[0.090]	[0.078]	[0.112]
Log peak month temperature	-105.5958***	1.5414	-87.9881**	-112.1208***	-109.9513***	25.1522
	[33.516]	[40.653]	[43.238]	[40.058]	[34.651]	[49.719]
Log peak month temperature squared	19.4003***	1.8041	14.8680**	18.5529***	19.1089***	-3.8843
	[5.496]	[6.666]	[7.090]	[6.568]	[5.682]	[8.152]
Log peak precipitation	6.1852***	2.2913	1.6367	1.4931	2.1407	-2.9508
	[1.280]	[1.553]	[1.651]	[1.530]	[1.323]	[1.899]
Log peak precipitation squared	-0.5849***	-0.2036	-0.1621	-0.1315	-0.1853	0.2664
	[0.124]	[0.151]	[0.160]	[0.148]	[0.128]	[0.184]
2007	-0.0648	-0.3190***	-0.6252***	-0.7327***	-0.4376***	-0.12
	[0.092]	[0.111]	[0.118]	[0.109]	[0.095]	[0.136]
2010	-0.8308***	-0.7660***	-0.4508***	-0.7910***	-0.7589***	-0.2917*
	[0.106]	[0.129]	[0.137]	[0.127]	[0.110]	[0.157]
Constant	129.8150**	-26.5595	127.6697*	164.3988***	152.1110***	-28.6755
	[50.768]	[61.578]	[65.494]	[60.677]	[52.487]	[75.312]
Observations	3,916	3,916	3,916	3,916	3,916	3,916
R-squared	0.111	0.047	0.028	0.075	0.049	0.021
Number of obs.	1,310	1,310	1,310	1,310	1,310	1,310

Standard errors in brackets; *** p<0.01, ** p<0.05, * p<0.1

Table 4. Effects of Extreme Climate Events on Kilocalories Produced of Individual Food Crops

Variables	Maize	Beans	Sorghum	Millet	Wheat	Bananas
Female head	-0.2277	-0.0428	-0.3340*	0.1051	-0.1204	0.0397
	[0.146]	[0.178]	[0.188]	[0.175]	[0.151]	[0.217]
Log age of head	0.1783	0.4297	-0.1752	0.3987	-0.1523	0.0056
	[0.314]	[0.382]	[0.405]	[0.375]	[0.324]	[0.466]
Primary education	0.0708	0.2132	-0.0237	-0.1633	-0.0916	0.1842
	[0.115]	[0.139]	[0.148]	[0.137]	[0.118]	[0.170]
Secondary education	0.1524	0.4794**	-0.2791	0.3187	-0.2324	0.3467
	[0.175]	[0.213]	[0.226]	[0.209]	[0.181]	[0.260]
Post-secondary educ.	0.2883	0.5183*	-0.4507	0.2005	-0.3246	0.4019
	[0.223]	[0.271]	[0.288]	[0.267]	[0.230]	[0.331]
Log household size	0.2889**	0.3084**	0.0848	0.0582	0.1505	-0.088
	[0.113]	[0.137]	[0.146]	[0.135]	[0.116]	[0.168]
Off-farm income dummy	-0.2188**	-0.095	0.0403	-0.1738*	-0.1577*	0.0562
	[0.088]	[0.107]	[0.113]	[0.105]	[0.091]	[0.130]
Log total land holding (acres)	0.0085*	0.0012	0.0027	0.0156***	0.0128***	-0.0023
	[0.004]	[0.005]	[0.006]	[0.005]	[0.005]	[0.006]
Log total livestock units	0.3843***	0.2897***	0.2074**	0.126	0.1419*	0.3934***
	[0.075]	[0.092]	[0.097]	[0.090]	[0.078]	[0.112]
Log value of buildings	0.0506***	0.0379***	0.0352***	0.0145	0.0299***	0.0043
	[0.010]	[0.012]	[0.013]	[0.012]	[0.010]	[0.015]
Log total seed cost	-0.0219	0.0107	-0.0344	-0.0469**	0.0176	-0.0633**
	[0.020]	[0.024]	[0.026]	[0.024]	[0.021]	[0.030]
Used improved seeds	0.7086***	0.5028***	0.1382	0.4166***	0.2936***	-0.0535
	[0.100]	[0.121]	[0.129]	[0.119]	[0.103]	[0.148]
Log average fertilizer per acre	0.0800***	0.0450**	-0.0298	-0.0056	-0.0129	0.0038

	[0.016]	[0.020]	[0.021]	[0.019]	[0.017]	[0.024]
Log distanced to extension services	0.0515	0.0237	0.0067	-0.0395	-0.02	0.093
	[0.047]	[0.057]	[0.060]	[0.056]	[0.048]	[0.069]
Farmer received credit	0.0197	0.1686**	0.0151	0.0526	0.0237	-0.0583
	[0.066]	[0.080]	[0.085]	[0.079]	[0.068]	[0.098]
Member belongs to a cooperative/group	0.1113	0.2313***	-0.0595	0.0879	0.0812	0.2376**
	[0.072]	[0.088]	[0.093]	[0.086]	[0.074]	[0.107]
Log distance to motorable road	0.0241	0.1626*	0.2455**	-0.0852	-0.0913	-0.0259
	[0.075]	[0.091]	[0.097]	[0.090]	[0.077]	[0.111]
Very dry conditions (low SPEI)	-0.4928***	-0.3018**	-0.2007	0.1917	-0.3250***	-0.184
	[0.116]	[0.141]	[0.150]	[0.139]	[0.120]	[0.172]
Very moist conditions (high SPEI)	0.0426	-0.0242	-0.2592	0.0108	-0.2649*	0.0293
	[0.142]	[0.172]	[0.183]	[0.169]	[0.146]	[0.210]
Fertilizer*SPEI	0.00002	0.00001	0.00001	0.00001	0.00001	0.00001
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
Improved seeds* SPEI	0.0602	0.1017	-0.0209	0.1471	0.3080***	0.0014
	[0.079]	[0.096]	[0.101]	[0.094]	[0.081]	[0.117]
2007	0.1665*	-0.2775**	-0.6372***	-0.8106***	-0.5012***	0.0903
	[0.100]	[0.121]	[0.128]	[0.119]	[0.103]	[0.148]
2010	0.3574**	0.1723	-0.0928	-0.3206*	-0.0492	-0.4876**
	[0.142]	[0.173]	[0.183]	[0.170]	[0.146]	[0.211]
2007*SPEI	-0.1834	0.1724	0.1349	-0.0558	-0.1139	-0.4534**
	[0.124]	[0.151]	[0.160]	[0.148]	[0.128]	[0.184]
2010*SPEI	0.9398***	0.5757***	0.2259	0.4324**	0.4573***	-0.3001
	[0.143]	[0.174]	[0.185]	[0.171]	[0.148]	[0.213]
Constant	4.6554***	1.1274	1.9543	-0.5271	0.7405	3.5582*
	[1.354]	[1.645]	[1.743]	[1.615]	[1.394]	[2.006]
Observations	3,916	3,916	3,916	3,916	3,916	3,916

R-squared	0.111	0.044	0.031	0.078	0.056	0.022
Number of obs.	1,310	1,310	1,310	1,310	1,310	1,310

Standard errors in brackets; *** p<0.01, ** p<0.05, * p<0.1

Table 5. Effects of Climate Change Variables on Kilocalories Produced of Indigenous Vegetables

Variables	Temperature & Precipitation	Extreme Events
Female head	0.3135**	0.3269**
	[0.139]	[0.138]
Log age of head	0.0296	0.0033
	[0.299]	[0.298]
Primary education	0.1536	0.1403
	[0.109]	[0.109]
Secondary education	0.0295	0.0012
	[0.167]	[0.166]
Post-secondary educ.	-0.1516	-0.1957
	[0.212]	[0.211]
Log household size	-0.0873	-0.0819
	[0.107]	[0.107]
Off-farm income dummy	0.1279	0.1076
	[0.084]	[0.083]
Log total land holding (acres)	0.0007	0.0014
	[0.004]	[0.004]
Log total livestock units	0.0537	0.0806
	[0.072]	[0.071]
Log value of buildings	0.0124	0.0139
	[0.010]	[0.010]
Log total seed cost	-0.0429**	-0.0345*
	[0.019]	[0.019]
Used improved seeds	0.0056	0.0195
	[0.093]	[0.092]
Log average fertilizer per acre	0.006	0.0079

	[0.015]	[0.015]
Log distanced to extension services	0.0064	-0.0006
	[0.045]	[0.044]
Farmer received credit	0.0472	0.0335
	[0.063]	[0.063]
Member belongs to a cooperative/group	0.0991	0.1078
	[0.069]	[0.068]
Log distance to motorable road	-0.1224*	-0.0869
	[0.072]	[0.071]
Log peak month temperature	-0.3163	
	[31.814]	
Log peak month temperature squared	0.9637	
	[5.216]	
Log peak precipitation	2.9015**	
	[1.215]	
Log peak precipitation squared	-0.2826**	
	[0.118]	
2007	-0.3403***	-0.2606***
	[0.087]	[0.082]
2010	-0.5767***	-0.1998**
	[0.101]	[0.093]
Very dry conditions (low SPEI)		-0.3426***
		[0.078]
Very moist conditions (high SPEI)		0.0516
		[0.107]
Constant	-14.4105	0.9297
	[48.190]	[1.282]
Observations	3,916	3,916

R-squared	0.022	0.024
Number of Obs.	1,310	1,310

Standard errors in brackets; *** p<0.01, ** p<0.05, * p<0.1

Appendix

Table A1. Descriptive Statistics

	Full sample		2004		2007		2010	
Variable	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Female head	0.24	0.43	0.21	0.40	0.24	0.43	0.27	0.45
Age of head	59.57	13.36	59.57	13.42	58.71	13.36	60.43	13.24
Primary education	0.53	0.50	0.52	0.50	0.53	0.50	0.53	0.50
Secondary education	0.21	0.41	0.21	0.41	0.22	0.41	0.21	0.41
Post-secondary educ.	0.06	0.23	0.05	0.22	0.05	0.23	0.06	0.24
Household size	7.97	3.62	8.37	3.60	8.00	3.62	7.53	3.58
Off farm income dummy	0.89	0.32	0.85	0.36	0.91	0.29	0.90	0.30
Total land holding (acres)	5.88	11.32	6.32	12.58	6.05	12.03	5.28	8.99
Total livestock units	2.70	6.30	3.05	7.98	2.66	5.79	2.40	4.64
Value of buildings (kshs* '000)	131.01	309.00	30.79	144.51	164.41	314.70	197.81	388.63
Average seed cost per acre (kshs)	309.68	488.82	234.92	330.62	271.18	332.80	423.18	691.05
Used improved seeds	0.86	0.35	0.77	0.42	0.91	0.29	0.91	0.29
Average fertilizer use (kg/ acre)	652.98	2095.83	1069.32	3261.46	101.43	432.46	788.39	1363.79
Distanced to extension services (kms)	5.09	5.36	5.29	5.79	4.57	5.09	5.40	5.13
Farmer received credit	0.46	0.50	0.32	0.47	0.52	0.50	0.54	0.50
Member belongs to a cooperative/group	0.74	0.44	0.76	0.43	0.75	0.43	0.70	0.46
Distance to motorable road (kms)	0.68	1.08	1.06	1.33	0.53	0.84	0.46	0.91
Peak month temperature (^{0}C)	20.85	2.49	20.55	2.49	20.83	2.50	21.17	2.45
Peak month precipitation (mm)	205.53	86.07	219.17	84.21	187.10	97.06	210.31	71.93
Peak month SPEI	-0.30	0.82	-0.30	0.55	0.49	0.49	-1.09	0.49
No. of obs.	3931		1311		1311		1311	

*Kenyan shillings

Table A2. Summary Statistics- Kilocalories Produced (‘000)

	Full sample		2004		2007		2010	
Variable	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Total	12654.51	32549.56	13455.2	27227.97	13550.68	41747.56	10956.58	26334.63
Maize	5530.08	17221.84	5574.04	13209.53	6558.61	23541.36	4459.04	12653.20
Beans	531.88	951.27	597.70	951.56	515.48	1034.62	482.24	856.38
Sorghum	96.11	321.73	94.60	285.55	101.24	341.72	92.51	335.28
Millet	61.98	280.64	96.30	403.63	50.06	195.31	39.46	182.17
Wheat	664.26	2658.83	792.28	3981.27	561.10	1305.27	638.85	1897.89
Bananas	967.78	14943.15	1432.07	17436.36	1192.22	18900.64	277.96	2861.61
No. of obs.	3923		1311		1305		1307	