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Abstract

Agriculture is the mainstay of the Kenyan economy with an estimated GDP share of 26 percent in 2012, and thus remains an important contributor to employment and food security of rural populations. Climate variability and change have adversely affected this sector. This situation is expected to worsen in the future if the latest findings of Intergovernmental Panel on Climate Change (IPCC) are anything to go by. We estimate the effect of climate variability and change on crop revenue and on maize and tea revenue separately using household panel data collected between 2000 and 2010 in rural Kenya. Effect of climate variability and change is estimated using a fixed effects estimator. Findings show that climate variability and change affect agricultural production but differs across different crops. Temperature has negative effect on crop and maize revenues but positive one on tea while rainfall has negative effect on tea incomes. Long-term effects of climate change on crop production are larger than short-term effects, requiring farmers to adapt effectively and build their resilience. We find that tea relies on stable temperatures and consistent rainfall patterns and any excess would negatively affect the production. Climate change will adversely affect agriculture in 2020, 2030 and 2040 with greater effects in tea sector if nothing is done. Therefore, rethinking about the likely harmful effects of rising temperature and increasing rainfall uncertainty should be a priority in Kenya. It is important to invest in adaptation measures at national, county and farm level as well as implementing policies that prevent destruction of the natural environment in order to address the challenges posed by climate variability and change.

Keywords**:** agricultural incomes, food security, fixed effects model, adaptation, panel data

JEL Classification*:* C31, Q24, Q12, Q54

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Acronyms

ASAL	-	Arid and Semi-arid Lands
CCC	-	Canadian Climate Model
CIAT	-	International Center for Tropical Agriculture
GDP	-	Gross Domestic Product
GFDL	-	Geophysical Fluid Dynamics Laboratory model
GPS	-	Global Positioning System
IPCC	-	Intergovernmental Panel on Climate Change
KMS	-	Kenya Meteorological Service
KNBS	-	Kenya National Bureau of Statistics
NCCRS	-	National Climate Change Response Strategy
NIB	-	National Irrigation Board
RoK	-	Republic of Kenya
SSA	-	Sub-Saharan Africa
TAPRA	-	Tegemeo Agricultural Policy Research and Analysis

1. Introduction

1.1 Background information

Agriculture continues to be the mainstay of the Kenyan economy with an estimated GDP share of 25.9% (ROK, 2013) making it an important contributor to employment and food security of rural households. Climate change has significantly affected global agriculture in the 21^{st} century and the Intergovernmental Panel on Climate Change (IPCC) assessment report indicates that most countries will experience an increase in average temperature, more frequent heat waves, more stressed water resources, desertification, and periods of heavy precipitation (IPCC, 2007a; IPCC, 2014). The current IPCC report (AR5) indicates that the past three decades have been warmest in the history of instrumental records, with each decade being warmer than the preceding period (IPCC, 2014). Further, the reports indicate that the African continent is warmer than it was 100 years ago (Osman-Elasha, 2008). Future impacts are projected to worsen as the temperature continues to rise and precipitation becomes more unreliable and the consequences could be dire.

Currently, a rise of two degrees centigrade in global temperatures is considered to be the threshold for catastrophic climate change (IPCC, 2007a). This type of rise in temperature would expose millions of people to drought, hunger and flooding. Climatic variability and change has always presented a threat to food security in Kenya through its effect on rainfall, soil moisture and productivity. Since early 1990s, Kenya has been affected by the droughts of 1991-2, 1992-3, 1995-6, 1998-2000 and 2004, the *El-Niño* rains that resulted in the floods of 1997-1998 (Orindi and Ochieng, 2005) and the drought of 2008-9. Climatic variability and change directly affect agricultural production and food security given that most of the population in Kenya lives in the rural areas and relies on agriculture for its livelihoods. This is exacerbated by the fact that agriculture predominantly depends on rainfall. Osman-Elasha (2008) suggests that it is the poor in Africa who are highly vulnerable to climatic and environmental hazards as their options for diversifying their resources and income sources are limited.

As a strategy to feed the growing population, Kenya has planned to roll out an irrigation flagship project in the ASAL regions as outlined in the Vision 2030, the country's development blueprint covering the period 2008 to 2030 (RoK, 2007). Notably, irrigation agriculture has been identified by Kenyan government as one of the ways for moderating the effects of climate change. Following this recognition, a flagship project, Galana Kulalu irrigation scheme in Tana River area in the coastal region was launched in January, 2014. The vulnerability of poor populations in the region to climate change and extreme weather events is worsened by the spread of HIV/AIDS, lack of access to land due to the traditional land tenure systems and adequate water, low levels of technology and education and institutional mismanagement (Nhemachana *et al*., 2010). This calls for clear mitigation and adaptation strategies in order to deal with the threats posed by climate change, which is also stipulated in Kenya's National Climate Change Response Strategy (NCCRS) (2010) as well as in the National Climate Change Action Plan (NCCAP) (2013-2017).

In addition, the stock of greenhouse gases which contributes to warming of the planet is expected to grow substantially from the burning of fossil fuels and land use changes if no action is taken to reduce their emissions. A study by Mariara and Karanja (2007) showed that adaptation measures can reduce negative impacts of global warming and climate change. The adaptation measures comprise alternative crops, intercropping different varieties, use of drought tolerant seed varieties, employing irrigation and water harvesting techniques, crop insurance, early warning and monitoring systems, construction of dykes, human migration, changing planting dates, diversifying in and out of agriculture, reliance on safety nets and social networks and sale of assets. One constraint to adaptation has been that some of the adaptation technologies such as irrigation systems and dykes require huge capital outlays.

In view of these, the Kenyan government has put in place a NCCRS whose aim is to respond to the challenges and opportunities posed by climate change (RoK, 2010). The mission of NCCRS is to strengthen nationwide focused actions towards adapting and mitigating against a changing climate, by ensuring commitment and engagement of the whole nation in combating the impacts of climate change, while taking into account the vulnerable nature of the natural and ecological resources, and society as a whole. Environmental Protection and Climate Change has been put in place as one of the important national priorities in the context of Kenya Vision 2030, under its NCCAP (2013-2017). It recognizes the need to safeguard natural resources, such as the Mau Forest and other water towers, since ecology brings the country prosperity through tourism and other economic activities.

With changes in precipitation and temperatures patterns in the country taking place, there is need to increase the area under irrigation given that 80% of land in Kenya is arid and semi-arid land (ASAL), hence making its population highly vulnerable to climate change. Against this background, our study fills the literature gap by investigating the effects of climatic variability and change on the agricultural production by estimating panel econometric models for Kenya.

1.2 Review of related literature on climate variability and change and agriculture in Kenya

Climate change is arguably the most important challenge facing African countries, largely due to their geographic exposure (the geographical location of most African countries on the lower latitudes), low income, greater reliance on climate-sensitive sectors such as agriculture and weak capacity to adapt to the changing climate (Belloumi, 2014). However, there are limited studies that have documented adverse socio-economic impacts of extreme weather events specifically in Kenya. The effects have been felt on almost all sectors such as health, agriculture, livestock, environment, hydropower generation and tourism (SEI, 2009). Kenya is adversely affected by climatic variability and change because of her dependency on rain fed agriculture, with variability in rainfall and temperature directly affecting crop and livestock yields.

Empirical results show that existing climate variability has significant economic costs as a result of periodic floods and droughts, which lead to major macro-economic costs and reductions in economic growth (SEI, 2009). Downing (1992) explored the impact of climate change in Kenya and found that higher temperatures would have a positive impact in highland areas but a negative effect in lowland areas and especially in the semi-arid areas. Therefore, potential food production would increase with rising temperature and rainfall, but in the semi-arid areas, yields would decline as a result of insufficient precipitation. Fischer and Van Velthuizen (1996) indicated that the overall impact of climate change on food production in Kenya would be positive but results would vary by region. They also asserted that the increase in production would arise from an increase in carbon dioxide and temperature, provided that there would be an increase in precipitation as well.

Adger (1999) argued that social vulnerability to climate change is a key dimension in the constitution of vulnerability, and that it shifts emphasis onto the underlying, rather than the proximate causes of vulnerability. In Kenya, smallholder farmers have been found to respond to drought through diversification into off-farm employment activities (Downing *et al*, 1997). Mariara and Karanja (2007) also showed that adaptation measures in terms of micro-level farm adaptations, market responses, technological developments and institutional changes have a large potential in reducing negative impacts of global warming and climate change.

Farmers in Kenya are aware of short-term climate changes; most of them have noticed an increase in temperatures with some taking adaptive measures and that perceptions and adaptations varied across agro-climatic zones (Ndukhu *et al*, 2012). The medium and low potential areas would be more adversely affected by global warming (Mariara and Karanja, 2007). Besides, farmers' perceptions that Kitui County is getting drier and that rainfall decreases by 34mm per year are consistent with the rainfall data (Oremo, 2013). Using cross sectional data for the region, Oremo's study evaluated the relationship between rainfall and maize yields without considering temperature changes which equally influence maize productivity. We therefore, extend this study by using interaction between long term rainfall and temperature to extend knowledge on the impact of climate variability and change on crop revenue and also on maize and tea revenues.

While the study by Kabubo-Mariara and Karanja, (2007) provides the most detailed and more recent account of the impacts of climate change in Kenya, a few critical gaps do, however, exist and which we seek to address in the current study. First, the Ricardian analysis estimates the effect of climate on net crop revenue across space without incorporating a time dimension. We further contribute to the discussion by using the Tegemeo Agricultural Policy Research and Analysis (TAPRA) panel data set which takes account of changes in household incomes, rainfall and temperature across both space and time, and thus enabling the assessment of any variability across these key indicators over time. Secondly, while most studies model effect of climate on crop revenue only, we go further and assess the effects on selected key crops in Kenya, maize and tea. Disaggregation of revenue by crop types sheds more light on the effects of climate variability and change on maize which is an important staple crop and tea, the leading foreign exchange earner that contributes about 20% of the total foreign exchange earnings in Kenya.

2. Materials and Methods

2.1 Data description

2.1.1 Farm household data

We use a balanced four rounds household data (2000, 2004, 2007 and 2010) comprising of 1,243 households across eight agro-regional zones in Kenya, namely Coastal lowlands, Eastern lowlands, Western low lands, Western transitional, high potential maize zone, Western and Central highlands, and Marginal rain shadow. Agro-regional zones are a hybrid of broad agro- ecological zones and administrative boundaries (Argwings-Kodhek *et al*., 1999). The panel data is of high quality with the necessary quality control ensured in all the data collection waves by proper training and supervision of the enumerators.

The panel data collected through rural household surveys covered 24 administrative districts, 39 divisions and 120 villages using structured questionnaires. Detailed description of sampling design and collection procedure is found in Argwings-Kodhek (1999). The sample excluded large farms with over 50 acres while Nairobi and Northern regions were excluded because of urbanization, and aridity and migration nature of pastoralists, respectively. The data collected over the years is quite broad, covering several aspects of household livelihoods including crop yields and revenues.

2.1.2 Climate data

This study relies on the climate data (rainfall and temperature) from Kenya Metrological Services (KMS) weather stations across the country. The data obtained from KMS include temperature (0C) and rainfall (mm) from 1980 to 2010 for different regions in Kenya. These two parameters (rainfall and temperature) have the longest and widest data coverage in the country and are the most common climatic variables considered by many studies in Sub-Saharan Africa. We use temperature and rainfall for respective data collection years and their long term values as have been applied in previous studies such as Sarkeret al., (2012), Fezzi, (2014) and Kabubo-Mariara and Karanja (2007) to assess effects of climate change on agricultural production. We have included long term climate variables (moving average for 30 years) because past climate shocks may still influence future agricultural revenues. We match climate variables for 107 villages across Kenya from 1980. In this process, the households in different sub-locations are linked with climate data from the nearest weather stations in order to carryout econometric analysis. Descriptive statistics of the climate and socio-economic data used in the econometric model are presented in Table 1.

Table 1: Descriptive statistics of the data included in the econometric model

Variable	Description	Mean	Std. Dev.
Dependent variables			
Crop revenue	Gross revenue in Ksh/acre/year	23046.36	23581.39
Tea revenue	Gross tea revenue in Ksh/acre/year	103806.7	180888.7
Maize revenue	Gross maize revenue in Ksh/acre/year	23145.55	58237.26
Climate variables			
Rainfall	Mean monthly rainfall (mm/mo) in the respective data collection year	126.331	61.229
Long term mean rainfall	Long term moving mean rainfall (mm/mo) 1980-2010	100.436	28.532
Temperature average (°C)	Mean annual air temperature (°C) in data collection year	20.775	2.860
Long term mean temperature (°C)	Long term moving mean of air temperature (°C) 1980-2010	20.806	3.014
Rainfall * temperature	Interaction term of long term rainfall and temperature	2119.146	669.778
Other variables			
Gender	1 if household head is male	0.794	0.405
Education	Years of schooling of household head	7.043	4.603
Household size	Number of household members	5.999	3.023
Fertilizer used in all crops	Inorganic fertilizer in kgs per acre[2]	59.847	120.963
Fertilizer used in maize	Inorganic fertilizer in kgs per acre	42.406	95.883
Fertilizer used in tea	Inorganic fertilizer in kgs per acre	336.277	307.708
Farm size	Size of land in acres	5.802	9.032
Crop diversification	1-Herfidhal index[3]	0.728	0.191
Assets	Value of total assets in Ksh	247166.7	434666.7

Notes: Ksh-Kenya shillings

2.2 Estimation strategy

The impacts of climate change on agriculture have been mainly studied using the Ricardian approach, which involves regressing the value of land against climate variables and other control variables (Mendelsohn *et al*. 1994). This approach assumes that land markets are functioning properly but existence of ill-defined property rights and tenure insecurity in several regions in Kenya makes its application less feasible. Besides, a major drawback of the method is that it

[2] Inorganic fertilizer in Kgs is the sum of all types of fertilizers used by a given household.
[3] The crop diversification index (CDI) is then calculated by subtracting Herfindahl index (HI) from one ($CDI = 1 - \sum_{i=1} P_i^2 = 1 - HI$), where Pi is the proportion of value of *ith* crop relative to the overall area of land cultivated.

The index ranges from zero, reflecting complete specialization (for example just one crop), to one, reflecting complete diversification (i.e, an infinite number of crops) does not account for price changes and also fails to fully control for the impact of other variables that affect agricultural farm incomes (Mendelsohn and Dinar, 1999).

Based on this argument, we adopt augmented production function as a general framework to model the effects of climate change on crop revenue and also separately on maize and tea revenues. Production function framework allows for control of economic variables (Deschenes and Greenstone, 2004), whereas the disadvantage is that it does not take farmers' responses to climate change into account. We specify production function where crop, maize and tea revenue is a function of factors of production, farmer personal attributes and climate variability and change factors (Equation 1):

$$Y_t = [illegible], \forall_{it}, \emptyset_{it}) \qquad (1)$$

Where [illegible] represent factors of production such as land, labour (captured as household members), assets, $\forall_{it}$ farmer personal attributes (gender and education of the household head, household size) and $\emptyset_{it}$ climate variability and change factors (temperature, long term temperature, rainfall and long term rainfall). In the estimation of effects of climate variables, we control for agricultural inputs, such as farm land, livestock, labour, agricultural assets and fertilizers. This study also differs from many studies because we control for the socio-economic information such as household size, gender and education of the farmers. This is also echoed by De Salvo Maria *et al*, (2013) who did not include structural and economic characteristics of the investigated farms. The production function where crop revenue, tea and maize revenue obtained by farmer i at time [illegible] is a function of production factors, socio-economic and climate factors (Equation 2).

$$\ln Y[illegible] = \alpha_1 + \alpha_2[illegible] + \alpha_3[illegible] + \alpha_4[illegible] + \alpha_5[illegible] + \alpha_6[illegible] + \alpha_7[illegible] + \alpha_8[illegible] + \alpha_9[illegible] +$$
$$[illegible]_{10}[illegible]^2 + [illegible]_{11}[illegible] + [illegible]_{12}[illegible]^2 [illegible]_{13}[illegible] + [illegible]_{14}[illegible] + [illegible]_{15}[illegible]^2 + [illegible]_{16}[illegible] + ^2$$
$$[illegible]_{17}[illegible] * [illegible] + \emptyset_t + [illegible] \qquad (2)$$

Where, $lnNR_i$ represent the natural logarithms of crop revenue[4], maize and tea revenue for farmer [illegible]. The variables [illegible], [illegible] and [illegible] represent the natural logarithms of farm size, total value of agricultural assets and fertilizer used, respectively, while [illegible] is the crop diversification index. Socio-economic variables include education ([illegible]) and gender ([illegible]) of the household head and household size ([illegible]). For climate variables, [illegible] and Rai[illegible] denote the mean annual temperature and mean monthly rainfall in the respective data collection years, while [illegible] and Rai[illegible] represent long term temperature and rainfall (from 1980 to 2010), respectively. The study considers different agro-regional zones across many years (2000-2010) and so the analysis captures regional and temporal scale variations. Equation 2 is estimated using fixed effects estimator. The fixed effects model captures the time varying effects $\emptyset_t$ which are time dummies associated with each year while α are the coefficients to be estimated.

Since the input variables in the model are expressed in natural logarithms, their coefficients are interpreted as elasticities of agricultural incomes with respect to each input. The squared variables have been included to take into account the non-linear relationship between agricultural income and climate factors. The results from crop research show that yield response to weather and climate is highly non-linear and there are significant interaction effects between temperature and rainfall (Welch *et al.*, 2010). We have, therefore, included interaction terms between annual temperature and rainfall as independent variable in the production function model. As observed by Fezzi, (2014), most Ricardian studies in Kenya (e.g Mariara and Karanja, 2008) do not account for such interaction between temperature and rainfall. We use future rainfall predictions from Kenya Meteorological Service (KMS) while for temperature we rely on predictions from the literature obtained using different climate models. The climate change scenarios were employed to project the changes in farm incomes due to changes in temperature and rainfall in Kenya.

Simulations of the effects of climate change are done based on elasticities computed from equation 2. The average elasticities of climate variables on crop, maize and tea revenues are evaluated at the mean. Elasticity is the partial derivatives of agricultural revenues with respect to

[4] The crops include maize, coffee cherries ,beans, sorghum, millet, bananas, tea, wheat ,cotton, sugarcane, pyrethrum, cowpeas, coconuts, cashew nuts, french beans, irish potatoes, cassava tobacco, sunflower, rice, groundnuts, green grams, simsim, sweet potatoes, arrow roots, passion, irish potatoes, tomatoes, sukuma wiki, cabbage , spinach, watermelon, pumpkin, yams, snow peas.

factors of production, farmer specific characteristics and climate variables shown in Equation 2. Elasticities are derived from marginal effects (equation 3) using chain rule.

$$? \frac{??}{??x_i} = \alpha_i ?(x_i) * ?(x_i) \qquad (3)$$

Both sides of equation 3 are multiplied by $\frac{x}{y}$ to obtain the elasticity as shown in equation 4.

$$? \frac{??/??}{??x_i/x_i} = \alpha_i ?(x_i) * ?(x_i) \qquad (4).$$

Where α_i is a linear term coefficient for independent variables (??) including the quadratic coefficients for long term rainfall and temperature variables. We use the predicted climate change values compared with 1980-2010 base average to simulate the effect of rainfall and temperature on revenue from all crops as well as that from maize and tea.

3. Results and Discussion

3.1 Effects of climate variability and change on agriculture production

Econometric results presented in Table 2 show that rainfall has a positive effect on revenues from all crops grown and maize but has a negative effect on tea revenue. Temperature has a negative effect on crop revenue but a positive effect on tea revenue. The negative coefficient and significant quadratic terms suggests that excess temperature beyond maximum threshold of 23.5 ºC (FAO, 2014) would be detrimental to tea production. Similarly, rainfall exhibits negative relationship with tea and positive quadratic term which indicates that very little rainfall is not useful for tea production[5]. In tea production, severe frost due to lower temperatures mainly at night leads to scorching of plants. The low temperatures cause water in the cell sap to expand and rapture the cell wall resulting into chemical reactions normally associated with green leaf fermentation and leaves turn brown (Cheserek, 2012). The findings point out that long-term effects of climate change (in relation to temperature) on crop production are larger than short- term effects, an indication that farmers need to adapt effectively to reduce extreme effects of climate variability. This is because as farmers adapt to deal with effects of climate variability that affects their production year after year, they will be effectively slowing down the potential effects of climate change. Our results clearly indicate that climate has a non-linear relationship with revenue from all crops, maize and tea, which is consistent with other findings (Kabubo- Mariara and Karanja, 2007; Fezzi and Bateman, 2013; Belloumi, 2014). Also the findings show that the coefficients associated with temperature are much larger than those for rainfall, confirming the findings of Kabubo-Mariara and Karanja (2007) and Dinar Ariel *et al.,* (2008) that temperature as a contributor to global warming is much more important than rainfall. The interaction term (long term rainfall and temperature) has a negative and significant correlation with crop and maize revenues but positive with tea revenue. Previous studies by Monteith (1977) and Morison (1996) clearly indicate that the amount of water required for plant development increases with temperature implying a positive rather than negative interaction. With this kind of scenario, we conclude that with smallholder farm level data, there is an additive
climate change effect without a strong interaction between rainfall and temperature.

[5] The tea producing counties sampled in our study include Kisii, Vihiga, Muranga, Nyeri and Bomet

Table 2: Effect of climate variability and change parameter estimates

Variables	Crop revenue		Tea Revenue		Maize revenue	
Rainfall	0.007***	(0.001)	-0.0223***	(0.005)	0.0043***	(0.001)
Rainfall sq.	-0.000***	(0.000)	0.0001***	(0.000)	-0.000***	(0.000)
Long term rainfall	0.033	(0.085)	-0.1277	(0.290)	0.0905	(0.098)
Long term rainfall sq.	0.0002	(0.000)	0.0006	(0.001)	0.0000	(0.000)
Mean temperatures	-0.5740***	(0.160)	1.0372**	(0.505)	0.0411	(0.208)
Mean temperatures sq.	0.0164***	(0.004)	-0.0249*	(0.015)	0.0031	(0.005)
Long term mean temperature	-8.2395***	(2.493)	8.8997*	(4.730)	-9.800***	(3.232)
Long term mean temperature sq.	0.1525**	(0.062)	-0.1536	(0.124)	0.2858***	(0.078)
Rainfall*temperature	-0.0055	(0.003)	0.0008	(0.011)	-0.0060	(0.004)
Gender of household head(1 if male)	-0.0775	(0.077)	-0.3155	(0.204)	0.0648	(0.115)
Lneducation (years)	0.0633	(0.048)	0.1083	(0.092)	0.0626	(0.056)
Lnhousehold size	0.0171	(0.047)	-0.1852*	(0.101)	0.0252	(0.059)
Crop diversification index	-1.3214***	(0.154)				
Lnland size (acres)	-0.0899***	(0.027)	0.2806***	(0.080)	0.2573***	(0.042)
Lnfertilizer used on crop(kg/acre)	0.1175***	(0.025)				
Ln total value of asset (ksh)	0.0680***	(0.020)	0.0826*	(0.049)	0.1608***	(0.024)
Ln fertilizer used in tea (kg/acre)			0.0380	(0.051)		
Ln fertilizer used in maize (kg/acre)					-0.0099	(0.025)
Yearly FE	Yes		Yes		Yes	
Constant	-82.647***	(25.80)	-104.630*	(53.832)	88.830***	(33.988)
Observations	2,662		587		2,430	
R-squared	0.228		0.331		0.128	
Chi^2 of Hausman test	97.34	p=0.000	99.14	p =0.000	193.74	p =0.000
Wald test for heteroskedasticity	χ^2= 5.4e+06	p=0.000	χ^2= 3.3e+05	p =0.000	χ^2 =1.5e+29	p =0.000
Wooldridge test for autocorrelation	F=14.817	p=0.000	F= 0.207	p =0.650	F= 14.309	p =0.000

Notes: Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1
The Hausman test rejects the null hypothesis, indicating that using fixed effects over random effects model is appropriate for all the equations.
The Wald test indicates presence of heteroscedasticity in the error terms which we have partly addressed by obtaining the transformations of independent variables and reporting robust standard errors.

However, tea exhibits a strong positive interaction between rainfall and temperature because tea production significantly depends on stable temperatures and consistent rainfall patterns. High temperature causes drying of the soils resulting to limited water content available for tea, decreases yields and negatively impacts on quality. Dry soils increase soil erosion, emergence of new pests and diseases, sun scorch damage and biodiversity loss including tree loss (ITC, 2014). Therefore, as temperature and rainfall rise, the cold and water stress is reduced, thus increasing tea yields subject to sufficient carbon-dioxide for fertilization.

Crop diversification has a negative and significant effect on crop revenue meaning that farmers earn less income from cropping activities as they move towards specialization. This means that for small-scale farmers, crop diversification contributes to improved crop revenue and helps to prevent revenue from falling below a given threshold even when they are faced with climate variability and change as well as several institutional and marketing constraints.

We also estimate the effects of socio economic factors which show that size of land owned, use of chemical fertilizers and agricultural assets has a significant role in improving agricultural revenues. Although, unexpected, size of land owned negatively and significantly influences crop revenue. This finding indicates that large land size has a negative effect on revenues from all crops grown by household. This could be consistent with the finding in literature of an inverse relationship between farm size and productivity. Three main explanations have been advanced for this scenario. First, the inverse relationship could be due to market failures, which imply that due to high unemployment, smaller farms which may have more labor per acre of land than larger farms may be forced to use more labor than is optimal on their farms, resulting in higher yields for smaller farms. Secondly, this scenario could be due to omitted variables, such as soil quality in the econometric analysis (Matchaya, 2009). It is likely that most households will choose to cultivate better quality land first and choose land of relatively lower quality as they increase the size of their farms, implying that larger farms will have lower soil quality on average. Third, the inverse relationship could be due to measurement error. This may occur when small-scale farmers over-report land size while relatively larger farmers under-estimate their land holdings, thus leading to a spurious inverse relationship between farm size and productivity. As a way to address this problem, Savastano *et al.*, (2010), proposes that taking land size using global positioning system (GPS) is more appropriate. However, land size positively and significantly influences maize and tea revenues.

Fertilizer intensification is a major determinant of crop revenue but low application per acre has not really spurred growth in tea and maize sectors in Kenya. Although, chemical fertilizer enhance crop productivity it also releases greenhouse gases into the atmosphere contributing to global warming. Studies by Sarker *et al* (2012) conclude that in order to reduce climate change challenges, it is important to reduce chemical fertilizer use and increase usage of organic materials in crop production. The value of assets owned by the household is significantly important for attaining higher crop incomes. The yearly fixed effects are significant which implies that differences in the agricultural revenues exist over the years probably due to varying market conditions such as prices, policy and technology over the period.

3.2 Predicted future effect of climate change on agricultural production

Belloumi, (2014) predicted that the future climate of Southern and Eastern Africa (including Kenya) will be hotter and drier. Overall, our analysis shows that rainfall will increase between 2020 and 2040. This confirms findings reported by CIAT (2011) that rainfall is likely to increase in Kenya by 2020 and 2050. Projections from KMS data indicate that annual rainfall will increase by 11.2%, 26.3% and 29.8% in 2020, 2030 and 2040, respectively (Table 3). Recent predictions such as by CIAT (2011) and KMS show that rainfall in Kenya will increase in the future but those from Canadian Climate Model (CCC) and Geophysical Fluid Dynamics Laboratory model (GFDL) models reported by Kabubo-Mariara and Karanja (2007) predict a 20% fall in rainfall by 2030. Their study used climate data from 1988-2003 while recent studies use data from 1980-2010, thus we think that the type of data as well as the characteristics of model used might have led to the observed differences.

Table 3: Predicted values of mean monthly rainfall and annual temperature by 2020-2040 compared to base year

Climate variables	1980-2010	2020	2030	2040
Mean monthly rainfall (mm)	100.4	111.6	126.8	130.3
Mean annual temperature (0C)	20.8	21.8	22.8	23.3
% change in mean monthly rainfall	-	11.2	26.3	29.8

Notes: Temperature values have been calculated based on previous literature

Due to inability to obtain predicted temperature from KMS we adopted predictions from previous studies in Kenya (CIAT, 2011) and in Southern and Eastern Africa (Belloumi, 2014). Following CIAT and KMS predictions that the temperature in Kenya is likely to increase between 1^0C to 2.5^0C on average, we assume that the annual temperature will increase by 1^0C in 2020 and 2^0C and 2.5^0C in 2030 and 2040, respectively.

Simulation results show that change in the temperature component of global warming is much more important than change in rainfall in Kenya which is consistent with the regression results and confirms findings reported by Kabubo-Mariara and Karanja (2007). Increasing rainfall will have positive significant effect on crop and maize revenue but negatively affect tea revenue by

2020, 2030 and 2040. Holding all other factors constant, 1^0C increase in temperature would reduce crop revenue by 14% but increases tea revenue by 2.3% by 2020. In addition, 30% increase in rainfall in 2040 would reduce tea revenue by 9%. Tea as a crop is very sensitive to both rainfall and temperature and any excess would negatively affect production patterns. A study by FAO (2014) has also predicted that the tea production in Kenya would decrease because of rainfall distribution and rise in air temperatures beyond the maximum threshold of 23.5 ºC, thus temperature is a key weather parameter, likely to influence tea production patterns.

Table 4: Predicted effect of climate change on agricultural production

Year	Increase level (%/ ^{0}C)	Climate variable	Rainfall and temperature increase effect (in %)		
			Crop revenue	Maize revenue	Tea revenue
2020	11%	Rainfall	0.8	0.6	-2.5
	1^0C	Temperature	-14.2	1.1	2.3
2030	26%	Rainfall	0.9	1.2	-5.5
	2 ^{0}C	Temperature	-14.8	2.2	2.4
2040	30%	Rainfall	1.0	1.9	-8.8
	2.5^0C	Temperature	-15.2	3.3	2.5

4. Conclusions and Policy Implications

This paper presents the effects of climate variability and change on total crop revenue as well as on maize and tea revenues among small-scale farmers in Kenya. We focus on maize and tea production because they play an important role as food staple and foreign exchange earner, respectively. We have used household fixed effects model on household panel data from eight agro-regional zones in Kenya. Based on the analysis, we find that climate change has potential to significantly affect small-scale farmers' livelihoods.

Findings indicate that temperature has negative effect on crop and maize revenues but positive effect on tea revenue. Rainfall has a positive effect on crop and maize revenues and a negative effect on tea incomes. Long-term effects of climate change on crop production are larger than short-term effects, thus farmers need to adapt effectively to reduce effects of climate variability and building their resilience. Climate change effect on tea production exhibit strong interaction between rainfall and temperature but does not for all crops and maize. Small-scale farmers are still motivated to diversify cropping activities in order to reduce the downside risk (e.g by spreading the risk across available crops) caused by persistent climatic variability and change. Small-scale farmers are affected by several market failures including underdeveloped input and output markets as well as poor or expensive crop insurance, and thus they rely on crop diversification as an alternative risk-coping mechanism.

Predictions for the future effect of climate change show that agriculture will be adversely affected by 2020, 2030 and 2040 but much effect will be felt in the Kenyan tea sector. Results further indicate that temperature as an indicator of global warming is much more important than rainfall in Kenya which confirms the findings reported by Kabubo-Mariara and Karanja (2007) and Dinar Ariel *et al.*, (2008). Tea as the main foreign exchange earner in Kenya will be adversely affected by climate variability and change if nothing is done. Thus, there is need to rethink about the likely harmful effect of climate variability and change in the future and integrate this into agricultural and environmental policy formulation processes.

Much effort should be made in consolidating and implementing policies particularly those that prevent destruction of natural environment and ensure that crop insurance as a risk coping mechanism has a solid framework that can help to enhance its uptake by farmers in different agro-regional zones. Given that human activities are the major drivers of climate variability and change, it is necessary to invest in adaptation measures at national, county and farm level especially in the tea growing regions, as a way of building farmers' resilience. In this regard, farmers would need to adopt an integrated approach comprising of adaptation measures including growing drought tolerant crop varieties, increasing investment in agriculture and using sustainable farm management practices.

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