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Managing climate risk through crop diversification in rural Kenya

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Abstract

Crop diversification is a viable climate risk management strategy to increase crop production and productivity among farm households. We use a panel of farm household and meteorological data collected over ten years to analyze crop diversification trends and the impacts of climate change and variability on crop diversification in small-scale farms in Kenya. Previous studies are inconclusive on what context(s) crop diversification is beneficial to farmers and the influence of climate change and variability on the decision to diversify crop production. Using panel data models, we find small-scale farmers in regions with low rainfall and high temperatures are more likely to diversify crop production. Further findings show that farm size, inorganic fertilizer use, household incomes and access to off-farm livelihood options are predictors of crop diversification. Crop diversification is not a one-size-fits-all strategy and should be adopted in situations where it gives maximum benefits, consistent to existing land use policies and well-known benefits of a specified crop portfolio. A win-win situation will involve land sparing, a balance between specialized and diversified cropping systems and scaling up adoption of the improved technologies among vulnerable farmers in drought risk areas.

Key words: Climate change, crop diversification, panel data, small-scale farms, Kenya

1. Introduction

Climate change and variability significantly influence agricultural production, biophysical, political and social systems that affect the availability of food in many developing countries. Existing studies suggest that climate change, water scarcity and land-use change jeopardise continued efforts to increase agricultural productivity and ensure food security at different levels (Sasson 2012). Climate change and variability are projected to have adverse impacts on agriculture in Kenya for the next two decades (Ochieng *et al.* 2016). This may hamper food security and increase incidences of rural poverty, given that majority of the population reside in rural areas and are primarily dependent on agriculture as the main source of livelihood. A study by Kimenju *et al.* (2008) shows a decline in the share of crop income to the overall farm household income from 50 percent in 2000 to 44 percent in 2007, largely due to reduced production from climate change and variability such as El Nino rains/floods experienced in the preceding years, drought of 2008-2009 (Rok 2012).

The challenges of climate change and variability are amplified in scenarios of rain-fed agriculture that is widespread among small-scale farmers in developing countries like Kenya. Various measures have been adopted by farmers to mitigate against adverse effects of climate change and to increase agricultural productivity. One of the measures is crop diversification, defined as an increase in the number of crops or the varieties and hybrids of a particular crop on the farm (Bradshaw *et al.* 2004). However, in addition to technical fixes such as introducing new crop varieties, irrigation etc., interventions to address climate change should also aim at understanding how different factors interact in a complex manner to reduce specific risks (Denis *et al.* 2016).

Due to population expansion and pressure on land in countries such as Kenya, arable land is dwindling, and this presents a dilemma on whether to adopt land sharing or sparing strategies to increase food production (Fischer *et al.* 2008). Sustainable agricultural systems in the face of climate change and variability will involve land sparing and crop diversification. This is particularly, relevant in many non-mechanized and rain-fed production systems, on fragmented parcels of land that characterize the farming landscapes of most developing countries. It will not only improve resilience to climate change and variability, but also increase soil fertility, household level food security and nutrition. Crop diversification provide insurance against the production risk of crop failure, is a useful strategy to cope with the income problems of farm households (Meert *et al.* 2013), and improves natural resources, soil fertility and environmental sustainability by controlling parasites and diseases (Lin 2011).

Research show that when smallholder's farmers are exposed to drought, its effect to a household's livelihood would vary depending on cropping strategies. For example, soil moisture within monoculture fields has been shown to be lower compared to diversified fields (Lin, 2007), leading to a relatively larger crop harvest. This means that crop diversification stabilizes yield, improves nutrition diversity and health (Lin 2011). Moreover, diversified systems are believed to perform better and are more resilient since they are associated with reduced pest pressures; lower use of nitrogen fertilisers particularly when leguminous crops are included; reduced soil erosion due to cover crops; and increased yield (Krupinsky *et al.* 2002; Lin 2011). Recent studies indicate that crop diversification could potentially reverse the likely negative impacts of climate change and

variability among small-scale farmers in developing countries (Bradshaw 2004; Lin 2011; Makate *et al.* 2016).

With the continued changes in rainfall patterns and depletion of water resources, less diversified cropping patterns are bound to become less productive particularly in the context of rain-fed agriculture. In addition to the ever-increasing demand for food and raw materials for agribusiness industries, agricultural intensification is believed to be the main course of future growth of small-scale farming. This could be through climate change adaptation strategies such as mixed cropping and production of high-value crops (Ngigi 2009) but there is need to critically redesign alternative cropping patterns based on agro-climatic zones and demonstrate them to farmers. Seo (2010) forecast that the number of diversified farms across Africa would increase, while the specialised ones will decrease under climate predictions by 2060¹.

There are many initiatives to intensify production in monoculture systems in many developing countries. However, the belief that intensive systems are more productive than diversified systems is not always true particularly in the case of predominantly subsistence production with limited marketable surpluses. Empirical studies (mainly using cross-sectional data) on the potential of crop diversification as one of the viable strategies to mitigate against the adverse effects of climate change and variability has yielded mixed results. It is not clear in what context(s) crop diversification is beneficial to small farms (i.e. Bradshaw 2004). Further, the influence of climate change and variability on the decision to diversify crop production is not conclusive. In this article, we analyze the trends in crop diversification, rainfall and temperature by agro-ecological zones using a four-wave panel of farm households and meteorological data collected over 30 years in rural Kenya. The influence of climate change and variability on the decision to adopt crop diversification strategy is tested and discusses viability of crop diversification to small-scale farmers in different regions. In the process, the paper contributes to the growing body of literature on social and ecological vulnerability of rural households in the face of global climate change and change.

The remainder of the paper is organised as follows. The next section introduces the data sources, measurement of crop diversification and the empirical approach. Section three discusses the results of the estimated model on adoption of crop diversification as a migration strategy for climate change and variability. Conclusions and policy implications section concludes with a summary of key findings and a discussion of policy options.

2. Data and Methods

2.1 Data description

We use panel data collected by Tegemeo Institute of Agricultural Policy and Development, Egerton University in collaboration with Michigan State University. The balanced panel comprises four periods of survey data (2000, 2004, 2007, and 2010) collected from farm households across different regions of rural Kenya. The sampling frame for the panel survey was prepared in 1997 in consultation with the Kenya National Bureau of Statistics (KNBS). A detailed description of the sampling design and collection procedure is found in Argwings-Kodhek *et al* (1999). The study covers eight old agro-regional zones in Kenya namely coastal lowlands, eastern lowlands, western

¹ Kenya is one of the countries studied by Seo (2010).

lowlands, western transitional zone, high potential maize zone, western highlands and marginal rain shadow. The agro-regional zones are a hybrid of broad agroecological zones, administrative and political boundaries (Argwings-Kodhek *et al.* 1999). The households were interviewed using semi-structured questionnaire. The analysis in this study is based on a balanced panel of 1243 farm households. The survey covered 22 administrative districts, 37 divisions and 107 villages. Nairobi and North Eastern regions were excluded from the sample because of urbanisation and aridity, respectively. This also means that our sample excludes pastoral households who are likely to be most vulnerable to climate and weather shocks.² In this paper, we consider three major agro-ecological regions³: lowlands (coastal and inner lowlands), midlands (lower midland, lower highland/upper midland, and upper midland), and highlands (lower highland, upper highland/ lower highland, and upper highland) (Figure 1).

Figure 1: Tegemeo survey villages and agroecological zones (AEZ).

Source: Ochieng *et al.* 2016

² About 10% of Kenya's population reside in ASALs – arid and semi-arid lands (as cited in Kirbride & Grahn 2008), thus Tegemeo data set represents a large majority of the population of rural Kenya.

³ Classification of agro-ecological zones are based on the maximum temperature thresholds within which the most common crops of Kenya can be grown. The annual mean temperature for each major zone (for which such information is available) is as follows: Coastal lowland (> 24°C, with maximum <31°C), inner lowland (> 24°C, with maximum >31°C), lower midland (21–24°C), upper midland (18–21°C), and lower highland (15–18 °C), and upper highland (10–15°C) (KMS data base).

The data covered household, farm and other socio-economic characteristics. In our analytical framework, household data is combined with climate data (rainfall and temperatures) obtained from the Kenya Meteorological Service (KMS). The climate data used in this study is obtained from 29 weather stations near the surveyed households and comprised average monthly rainfall and temperatures in all the panel years, as well as their longer term averages from 1980 to 2010. Other studies have also used similar climate data from KMS to investigate the effect of climate change on small-scale agriculture in Kenya (Kabubo-Mariara & Karanja 2007; Ochieng *et al.* 2016).

2.2 Measurement of crop diversification

Crop diversification is useful in two ways: first, it expands the production possibility set or area allocation frontier for a farmer, thereby increasing opportunities for income generation and employment creation. Second, it reduces the risk of having all “eggs in one basket”- growing only one crop or a few crops with potentially high covariance risk (Samuelson 1967). It is also a strategy for maximising the use of land, water, and other resources with the aim of increasing agricultural productivity. There are several ways of measuring crop diversification ranging from simple methods such as the number of crops grown to other complex ones such as Shannon index, Simpson diversity index and Herfindahl index. Major crops grown by sampled farmers are presented in Table 1A in the appendix. To provide a more precise measure of crop diversity based on proportions rather than absolute counts, we use crop diversification index is calculated for each farmer per panel year based on the relative composition of crops within the area of land cultivated. We adopted Simpson’s crop diversification index (CDI) which ranges from zero, reflecting complete specialisation (for example just one crop), to one, reflecting full diversification (i.e., an infinite number of crops). CDI is calculated as one minus Herfindahl index:

$$CDI = 1 - \sum_{n=1}^i P_i^2 = 1 - HI \quad (1)$$

where P_i is the area under i th crop and HI is the Herfindahl index computed as:

$$HI = \sum_{n=1}^i P_i^2 \quad (2)$$

We calculated the average score for the CDI for the period 2000–2010 for all the farmers and farm classes based on the farm size. The farms are arbitrarily classified based on the total land owned by the farmers as follows: small farms (≤ 5 acres), medium farms (5-10 acres) and large farms (> 10 acres). Based on this criterion, the majority of farmers in our sample have small farms (66%) followed by medium (20%) and relatively large (14%) farms. The CDI is used as dependent variable in the model which analyses factors influencing adoption of crop diversification as a climate change adaptation strategy.

2.3 Modelling the effect of climate change on crop diversification

Fixed Effects (FE) and Random Effects (RE) estimators are the workhorse of panel data analysis. However, we use RE since it allows for estimation of the effects of time-invariant variables and it's more efficient in estimating variables that have minimal longitudinal variance. FE model is often preferred for controlling the time invariant heterogeneity. As a robustness check for consistency and unbiasedness of the estimates, we additionally employ Mundlak-Chamberlain procedure (MC), which is a hybrid of RE and FE estimators (Mundlak 1978; Chamberlain 1984) and extends the RE analysis by modelling unobserved heterogeneity using the household means of time-varying variables. Notably, MC yields the same estimates for time varying variables as FE, while at the same time models heterogeneity to explain differences across farm households based on other factors that cannot be observed or that data cannot be obtained. The model(s) are then estimated using Tobit since crop diversification index is censored at zero. The model is represented as below:

$$y_{it}^* = X_{it}\beta + \mu_i, \mu_i | \chi \sim \text{Normal}(0, \sigma^2) \quad (3)$$

$$Y_i = 0 \text{ if } y_i^* \leq 0$$

$$Y_i = y_i^* \text{ if } y_i^* > 0$$

In data censoring cases, the latent variable y^* should have homoscedastic normal distribution with linear conditional mean; X_i is a vector of known exogenous variables in the model while β is a vector of unknown parameters and μ_i is the error term assumed to be independent and normally distributed as $\mu_i \sim N(0, \sigma^2)$. The outcome variable Y_{it} is the crop diversification index. The exogenous variables (X_i) including climate data (rainfall and temperature). The crop diversity function that we estimate is as follows:

$$Y_{it} = \beta_0 + \beta_1 \times R_{it} + \beta_2 \times T_{it} + \beta_2 \times RC_{it} + \beta_2 \times TC_{it} + \beta_3 \times HC_{it} + \beta_4 \times FC_{it} + \beta_5 \times AEZ_{ii} + \beta_6 \times Year_{it} + \varepsilon_{it} \quad (4)$$

where Y_{it} = crop diversity index for household i at time t . R_{it} and T_{it} respectively represents the rainfall and temperature for the respective data collection years. RC_{it} and TC_{it} represent long term temperature and rainfall (from 1980 to 2010), respectively. HC_{it} denotes the household head characteristics (age measured in years, sex which equals one if head is male and years of education). While FC_{it} represents the farm characteristics which include farm size, inorganic fertilizer use, household access to off-farm income, distance to input seller and to the motorable road in kilometers and total household income).

We consider changes of the adoption of crop diversification strategy over the years ($Year_{it}$) as well agro-ecological zones (AEZ_{ii}) to capture regional and temporal scale variations within the country. Farmers' decision to opt for more diversified systems would be highly influenced by the ability of the diversification to support household's resilience by accessing food and incomes during times of extreme climate risks. Thus, we hypothesise that declining rainfall and increasing temperatures lead to greater crop diversification among small-scale farmers. The declining rainfall

patterns often force farmers to shield themselves against potential crop failure by diversifying crop production. Detailed measurements of these variables are presented in Table 1.

We consider three agro-ecological zones (lowlands, midlands and highlands) across four years (2000, 2004, 2007 and 2010). This has been done to capture households residing in the lowlands (coastal and inner lowlands), midlands (lower midland and upper midland), and highlands (lower highland, upper highland/ lower highland, and upper highland) who experience different or similar challenges from a given climate event (see Figure 1). This is important because households across these three agro-ecological regions do exhibit varying livelihood strategies and face different climatic conditions. The highlands are more densely-populated, cooler, with more rainfall on average and well-integrated into markets compared to other zones (Table 1). Some parts of the highlands have cash crops such as coffee and tea which constitute a major source of income. Households in highlands also have the largest average farm size and household size, have easier access to fertiliser sellers and have a better road network. Lowlands are drier with an average temperature of 26°C and households in these areas mainly derive their livelihood from tourism, fishing and farming (crop and livestock) while in the midlands, households are more geographically dispersed, experience temperatures that are relatively lower than in the lowlands and households rely on food crop production, particularly maize as the main source of income. Regarding crop diversification, households in lowlands exhibit the highest diversification index (0.77) followed by midlands (0.76) (Table 1).

Table 1. Basic household characteristics

Variable	Description	All households		Lowlands (1)		Midlands (2)		Highlands (3)		Tests		
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	1=2	1=3	2=3
<i>Dependent variable</i>												
Simpsons' crop diversity index (CDI)	1-Herfindhal index	0.73	0.19	0.77	0.19	0.76	0.17	0.59	0.20	ns	***	***
<i>Climate variables</i>												
Rainfall	Mean monthly rainfall (total yearly/12(mm/mo) in a year	126.30	61.20	87.78	73.37	131.046	62.59	128.027	41.78	***	***	ns
Long term rainfall	Long term mean monthly rainfall (total yearly/12(mm/mo),1980-2010	100.40	28.50	81.55	13.36	106.65	31.06	101.78	21.64	***	***	***
Temperature average (°C)	Mean annual air temperature (°C) in a year	20.70	2.90	26.23	0.78	20.94	2.18	17.83	0.89	***	***	***
Long term temperature (°C)	Long term mean air temperature (°C) 1980-2010	20.80	3.00	24.14	4.049	21.12	2.28	18.11	0.74	***	***	***
<i>Household head and farm characteristics</i>												
Age	Years of the head	57.389	13.52	56.33	13.68	57.75	13.40	56.68	13.82	ns	ns	*
Gender	1 if male head	0.79	0.41	0.83	0.38	0.77	0.42	0.85	0.36	***	ns	***
Education	Education of the head in years	7.04	4.60	5.87	4.52	7.15	4.62	7.16	4.52	***	***	ns
Household size	Number of members of the household	6.00	3.02	7.49	4.27	5.78	2.84	6.06	2.75	***	***	**
Farm size	Total land owned in acres	5.80	9.03	5.53	7.08	4.54	6.99	10.13	13.36	ns	***	***
Inorganic Fertilizer use	Quantity of fertilizer in kilograms per acre	59.85	120.96	4.72	21.13	57.69	134.85	91.32	83.52	***	***	***
Off-farm income	1 if access to off-farm income such as employment or remittances	0.74	0.44	0.79	0.41	0.76	0.43	0.66	0.47	ns	***	***
Distance to input seller	Distance from homestead in kilometers	4.24	6.34	11.57	14.30	3.39	4.17	3.70	3.91	***	***	ns
Distance to motorable road	Distance from homestead in kilometers	0.83	1.47	1.46	2.58	0.74	1.15	0.84	1.63	***	***	ns
Net household income per adult equivalent (AE)	Net household income in Ksh per AE	62834	84375	43772	63955	57848	73083	87561	115882	ns	***	***
Number of observations		4,972		468		3,448		1,056				

Notes: Asterisks denote the level of significance of difference in means, *** p<0.01, ** p<0.05, * p<0.1 and ns =not significant; Ksh= Kenyan Shilling

3. Results and discussion

3.1. Crop diversification, rainfall and temperature trends by agro-regional zones in Kenya.

Crop diversification has been increasing over the years from 2000-2010 in lowland areas (Figure 2). Lowlands are relatively drier and households in these areas tend to grow several crops to reduce risk from weather and climate (see Table 1A in the appendix). As expected most farmers in highlands are more specialized in growing fewer crops (less diversified) with diversification index of 0.59. The trend shows that households in the highlands reached their maximum diversification in 2004 and reduced number of crops from this point forward. The highlands have relatively fertile soils and receive higher rainfall (mainly between 1,400 and 1,800 millimeters) compared to other agro-ecological zones. This amount of rainfall can accommodate two cropping seasons (long rain season starting from mid-March-July and short rain season from mid-October-December). Thus households in this region get better harvest.

A similar trend is observed in midlands with a slight decline of diversity index in 2007 onwards. Overall, these results suggest that areas of greater population density and agro-ecological potential and closer to urban centres would have seen more specialization than other areas. These results indicate that small-scale farmers still have the incentive to diversify their crops to prevent a decline in production level below their requirement for subsistence and market (income) needs. The crop diversity index is higher in lowlands (drier areas) given that the adaptation opportunities available to small-scale farmers are limited and often water harvesting strategies and irrigation infrastructure do not provide sufficient water to continue cultivation during dry periods (McCord *et al.* 2015). This leaves them with crop diversification as the cheapest livelihood strategy.

Figure 2: Crop diversification indices by zone in Kenya, 2000-2010

Overall, the level of crop diversity increased from cultivating about 10 crops per household in 2000 to 15 crops in 2004 but then sharply declined to 10 in 2010. Over the years, larger farms increased crop diversity to 13 crops in 2004 but this dropped in later years, showing that farmers moved towards specialisation as time progressed. A similar trend is observed among farmers with

medium and small land holding (Figure 1a-b in the Appendix). Using a more precise measure of crop diversity based on the proportions of land devoted to crops rather than an absolute count of crops grown show a similar trend that crop diversity as a strategy is more pronounced among farmers with small and medium landholdings.

Previous research shows that Kenya has been experiencing relatively constant average temperatures of about 20.8°C (minimal variations) from 2000-2010 with the highest temperatures in the lowlands (Ochieng *et al.* 2017). Rainfall has been increasing across the agro-ecological zones followed by a sharp decline in 2008-2009 (Ochieng *et al.* 2017) attributed to the prolonged drought in 2008-09 (Rok 2012,). This adversely affected farm household food security, agricultural livelihoods in general and wildlife particularly in the lowlands. Bradshaw *et al.* (2004) argue that given the changing climatic conditions in the future, particularly increase in extreme climate events, farmers may be forced to revisit the practice of crop specialisation. Crop diversification acts as a risk reduction strategy given a mixture of crops with minimal yield and price covariance (Bradshaw *et al.* 2004, Makate *et al.* 2016). However, its benefit may be outweighed by limitations such as start-up costs and their implications for achieving economies of scale. We argue that such contemplation must consider many factors of production and marketing beyond climatic ones.

Using the CDI, we identified two groups of farmers as ‘more diversified’ and ‘less diversified’. In low lands, more diversified farms have higher crop incomes compared to more specialized or less diversified farms (Table 2). On the other hand, in the midlands and highlands, specialized farms have higher crop incomes while livestock incomes are derived from more diversified farms in the highlands. These findings show that crop diversity as risk management strategy may work in some agro-ecological zones and fail work in others. This is in line with the argument that climate change adaptation strategy should be context specific and consider nature of climate related risks, outcomes, and adaptation options available to the affected population (Denis *et al.* 2016). Therefore, it is important to consider the role of external factors (e.g. physical resources such land, access to productive resources, incomes etc.) play in influencing the success of any adaptation or mitigation strategy such as crop diversification. In this paper, we discuss these multiple factors in section 3.2.

Table 2. Farm incomes and use of improved maize varieties by crop diversification

Agro-ecological zone (AEZ)	Crop diversity categories ¹	Using improved maize varieties (%)	Crop income per year (Ksh)	Livestock income per year (Ksh)	Number of observations
Low land (n=468)	Less diversified	47.31	48,333	24,668	167
	More diversified	48.84	56,623	19,386	301
	t-test	ns	*	ns	
Midlands (3448)	Less diversified	77.60	133,189	43,855	1,411
	More diversified	66.67	79,464	34,846	2,037
	t-test	***	***	***	
Highlands (1056)	Less diversified	88.12	176,008	93,465	908
	More diversified	95.27	116,120	135,626	148
	t-test	**	**	**	
All zones (4972)	Less diversified	79.41	143,128	60,686	2,486
	More diversified	66.21	78,881	38,974	2,486
	t-test	***	***	***	

Notes: ¹Quantile (median) was used to generate two categories. Asterisks denote the level of significance of difference in means, *** p<0.01, ** p<0.05, * p<0.1.

3.2. Factors influencing adoption of crop diversification as a strategy to climate change and variability in rural Kenya

The results of the econometric estimation of equation (4) are shown in Table 3. In general, most of the regression results are consistent with the descriptive analysis presented above. The estimated coefficients of the independent variables have expected signs and are statistically significant in both Mundlak-Chamberlain (MC) and standard RE models. Crop diversity has a significant negative relationship with long-term rainfall but a positive one with temperature. The results are similar in both the RE and MC models (row 5 and 7). These results imply that as precipitation increases, farmers become more specialised, while they become more diversified as temperature rises. Research has shown that temperature changes have been found to having higher negative impacts on crop yields than changes in rainfall (Kabubo-Mariara & Karanja, 2007; Ochieng *et al.* 2016). Small-scale farmers tend to seek alternative crops that may be more profitable and reliable in the context of changing weather patterns. Hence, diversification provides an opportunity for the farming households to smooth consumption throughout the year. Crop diversification is chosen over specialization in warmer climate scenarios as also observed in other studies across Africa (Seo 2010). These results demonstrate that climate change and variability directly alter crop production and management decisions encouraging adoption of crop diversification as a coping strategy. Frequent occurrences of climate extremes in Kenya have led to the introduction of mitigating programs such as weather index-based crop insurance schemes to indemnify farmers in cases of losses⁴. Weather index-based crop insurance has been implemented

⁴ The Kenya index-based weather insurance is a pilot project supported by Financial Sector Deepening (FSD) Kenya, the Rockefeller Foundation and the World Bank. The pilot trials have been done by Syngenta Foundation and International Livestock Research Institute (ILRI).

in the pilot program dubbed “Kilimo Salama” in collaboration with insurance companies to protect small-scale farmers in Kenya. However, studies have shown that it has limited success among small-scale farmers in Kenya due to several challenges such as lack of awareness of the insurance products, complexity and poor design of the insurance concept, higher premiums and basis risk which affect uptake of crop insurance (FSD 2013; Kirimi *et al.* 2016).

Crop diversification is influenced by the size of the farm owned, off-farm income and amount of fertiliser used. Land is a valuable resource that influences the number of crops and our findings show that farmers become more diversified in their cropping activities as the size of their farm's decreases. These results are consistent with the findings in Africa and Asia that farms specialize as they grow larger and diversify into off farm employment activities (Kimenju & Tschirley, 2008⁵; Kasem, & Thapa 2011; Pope & Prescott 1980). This could be because large farms often demand more management skills, inputs and finance and households may not be able to produce multiple crops. The households may opt to grow cash crops such as tea and coffee, particularly in highlands where households have large farms. However, findings in some regions in Pakistan and Zimbabwe indicates that farmer's ability to engage in crop diversification increases with farm size (Ashfaq *et al.* (2008) and Makate *et al.* (2016) and results from semi-arid areas in Kenya (McCord *et al.* 2015). These results are from households in semi-arid areas who are more likely to diversify as landholding increases since they are more vulnerable to drought risks.

The average farm size per household declined from 6.1 acres in 2000 to 5.2 acres per household. The decline also varies by AEZ (Figure 1(c) in the appendix). While our results are intuitive and consistent with the expectations, it is noteworthy that most land use policies may support specialization which comes with larger farm sizes. This generally allows farmers to benefit from modern machinery and expert advice, among others. Resource constrained farmers with only larger farm sizes may not be motivated to adopt diversification strategy because of limitations such as high investment costs, and difficulty to achieve economies of scale (Bradshaw *et al.* 2004). It may thus be necessary to define an optimal level of diversification that is consistent with the declining land sizes and takes account of well-known advantages of a specified crop portfolio. Nevertheless, it is expected that with the continued declining land sizes, the outcome may be more a matter of destiny as opposed to choice.

It is observed that households with higher net incomes per adult equivalent and access off-farm sources of incomes are less likely to diversify into producing multiple crops. They instead decide to specialize by focusing on a few cash crops that give them higher returns and satisfy their livelihood requirements. However, low-income households often face constraints that prevent them from expanding their income-generating activities. The households with the highest off-farm earnings tend also to have highest investment in agriculture and incomes (Mathenge *et al.* 2015) while poor households with less incomes adopt crop diversification as a survival and risk management strategy (Meert *et al.* 2013).

⁵ Kimenju & Tschirley (2008) used Tegemeo panel data set for 2000-2007.

Table 3. Effect of climate change and variability on crop diversification

Dependent variable: Crop diversification index (CDI)	Random Effects model (RE)			Mundlak model (MC)		
	Coef.	Std. Err.	t statistic	Coef.	Std. Err.	z
Monthly rainfall	0.0002	0.0002	1.54	0.0001	0.0002	0.68
Monthly rainfall sq.	-0.0000	0.0000	-2.16**	-0.0000	0.0000	-1.52
Monthly temperatures	-0.0421	0.0314	-1.34	-0.0564	0.0333	-1.69*
Monthly temperature sq.	0.0008	0.0007	1.15	0.0012	0.0008	1.57
Long term rainfall	-0.0040	0.0008	-4.98***	-0.0037	0.0009	-4.21***
Long term rainfall sq.	0.0000	0.0000	4.86***	0.0000	0.0000	4.11***
Long term temperature	0.0429	0.0360	1.19	0.0123	0.0575	0.21
Long term temperature sq.	0.0011	0.0008	1.35	0.0002	0.0014	0.12
Age of household head	-0.0004	0.0003	-1.53	-0.0009	0.0004	-2.12**
Gender of the head	0.0022	0.0079	0.28	0.0107	0.0115	0.93
Education of the head	-0.0006	0.0007	-0.87	-0.0000	0.0011	-0.03
Household size	-0.0017	0.0010	-1.67*	0.0020	0.0013	1.49
Land size	-0.0007	0.0003	-2.01**	0.0006	0.0005	1.29
Fertilizer quantity	-0.0001	0.0000	-4.41***	-0.0001	-0.0000	-2.67***
Off-farm income	-0.0097	0.0055	-1.75*	-0.0061	0.0060	-1.02
Distance to input sellers	0.0001	0.0004	0.22	0.0006	0.0005	1.34
Distance to motorable road	-0.0025	0.0016	-1.51	-0.0023	0.0018	-1.31
Net household income/AE	-0.0002	0.0000	-4.96***	-0.0000	0.0000	-4.25***
Midlands zone ^a	0.1759	0.0127	13.83***	0.1573	0.0146	10.8***
Lowland zone	0.1426	0.0231	6.18***	0.2058	0.0284	7.25***
2004 year dummy ^b	0.0631	0.0063	10.02***	0.0670	0.0073	9.16***
2007 year dummy	0.0536	0.0070	7.71***	0.0588	0.0084	6.99***
2010 year dummy	0.0268	0.0068	3.97***	0.0320	0.0100	3.19***
Constant	1.7166	0.2317	7.41***	1.9880	0.2807	7.08***
sigma_u	0.1004			0.1004		
sigma_e	0.1420			0.1420		
rho	0.3333			0.3333		
Number of observations	4,972			4,972		
Number of households	1243			1243		

Notes: Asterisks denote the level of significance: *** p<0.01, ** p<0.05, * p<0.1. ^aHighlands is excluded from the AEZ dummy to use as a control; ^bYear 2000 is the base year for comparison.

Results further indicate that farmers use less fertiliser per acre as their farms become more diversified. Farmers grow multiple crops and may not be able to purchase the fertiliser required, or they deliberately reduce amounts applied to take advantage of benefits associated with intercropping (e.g., legume-cereal intercrops). This could mean that crop diversification is often taken up by households with limited investment in complementary inputs (e.g inorganic fertilizers) required to increase crop yields. Previous findings show that farmers reduce the amount of inorganic fertilizer used when they anticipate depressed rainfall (Fufa & Hassan 2006).

AEZ dummies capture characteristics not considered in the independent variables and show the differences in crop diversification across the three agroecological zones. This means that farm households in lowlands and midlands are significantly adopting crop diversification as a strategy than those in the highlands. Farmers located in lowlands with unfavourable warmer climate, diversify more and use less purchased inputs such as fertilisers, pesticides and improved seeds. The year dummies are also significant and reflect the differences in crop diversification over the four-wave period.

4. Conclusion and policy discussions

Small-scale farmers are diversifying their crop production as a risk management strategy to counter adversities of climate change and variability. Crop diversification strategy has been viewed as a potential risk management strategy and an option to enhance crop production and productivity. This paper examines (1) trends in rainfall, temperature and crop diversification from the year 2000 to 2010 (2) how climate change and variability affect crop diversification as a strategy to reduce production risk (3) explore what contexts crop diversification is more beneficial to small-scale farmers.

Climate change and variability significantly affect farmers' decisions to adopt diversified cropping activities. Increases in rainfall and temperature have different effects on crop diversification. Farmers tend to diversify more as temperature rises but less as rainfall increases. Farmers in the lowlands which experience frequent droughts and warmer climate are likely to diversify crop production as a livelihood strategy. In areas experiencing unfavourable weather conditions, farms are more diversified and with less inorganic fertilizer use. Such a scenario is correlated with diversification rather than specialisation which demands more intensive practices such as high use of fertiliser and improved crop varieties.

Overall, the findings indicate that crop productivity is likely to dwindle further with the changing climate and weather patterns. Hence, farmers need to adopt crop diversification alongside other farm management practices and crop insurance to ensure resilience to climate change and variability. The results show that farmers are constrained in terms of declining farm size, limited access to farm inputs (e.g., inorganic fertilizers) and lack of enough income to invest in intensive agriculture, thus the diversified production system is likely to persist among small-scale farmers who are more vulnerable. Crop diversification, as risk management strategy, may work in some agro-ecological zones and not in others.

Crop diversification is not a one-size-fits-all strategy and should be adopted in regions (e.g in lowlands) where it gives maximum benefits, consistent to existing land use policies and known benefits of a specified crop portfolio. Crop diversification efforts should not crowd-out specialized production among resource endowed farmers. A win-win situation will involve land sparing, a balance between specialized and diversified cropping systems, investments in research and development of drought resistant crop varieties, and increased farmer awareness to scale up adoption of the new technologies among vulnerable farmers in drought risk areas. Poverty reduction is also crucial in any strategy to build resilience in the small-scale farm sector in the developing countries.

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Appendix

Figure 1(a) Average number of crops per farm (for all farms and by farm size) for small-scale farmers in Kenya for the years 2000, 2004, 2007 and 2010.

Figure 1(b): Average CDI per farmer (0= fully specialised; 1=fully diversified) (for all farmers and by land size) for the years 2000, 2004, 2007 and 2010.

Figure 1(c). Average farm size by agro-ecological zones and year

Table 1A. Percentage of small-scale farmers growing different crops in 2010 by zone (top 20 crops listed)

	Lowlands	Midlands	Highlands	Overall
Maize	95.31	99.45	99.29	99.01
Beans	69.53	95.12	91.07	91.75
Bananas	25.00	77.80	52.86	67.30
Avocado	10.16	70.26	46.07	59.21
Kales (Sukuma wiki)	25.00	59.82	72.50	59.13
Nappier, elephant grass	10.16	54.27	47.86	48.59
Cowpeas	56.25	56.71	3.21	45.23
Sweet potatoes	32.81	51.72	22.50	43.62
Amaranths	27.34	38.62	42.86	38.43
Mangoes	44.53	45.50	5.00	36.75
Cassava	38.28	39.84	2.50	31.70
Irish potatoes	28.91	24.08	56.07	31.40
Sorghum	14.84	33.07	9.64	26.28
Guava	14.06	26.97	16.07	23.38
Coffee	0.00	23.20	5.71	17.19
Pumpkins	11.72	17.54	17.14	16.88
Pawpaws	17.19	20.53	4.29	16.73
Lugard	3.91	17.09	20.00	16.42
Millet	1.56	17.31	17.86	15.89
Tea	0.00	11.54	33.93	15.20