SOCIO-ECONOMICS
Working Paper 11

November 2014

Climate shocks and choice of adaptation strategy for Kenyan maize-legume farmers: Insights from poverty, food security and gender perspectives

Songporne Tongruksawattana

CIMMYT
International Maize and Wheat Improvement Center

CGIAR
RESEARCH PROGRAM ON
Climate Change, Agriculture and Food Security
CCAFS

SOCIOECONOMICS

Working Paper 11

Climate shocks and choice of adaptation strategy for Kenyan maize-legume farmers:

Insights from poverty, food security and gender perspectives

Songporne Tongruksawattana

Address: International Maize and Wheat Improvement Center (CIMMYT)
ICRAF House, United Nations Avenue, Gigiri – P.O. Box 1041-00621, Nairobi, Kenya.
Ph. +254 (20)-722-4600; E_mail: s.tongruksawattana@cgiar.org

CIMMYT International Maize and Wheat Improvement Center

CGIAR Research Program on Climate Change, Agriculture and Food Security CCAFS

Headquartered in Mexico, the International Maize and Wheat Improvement Center (known by its Spanish acronym, CIMMYT) is a not-for-profit agriculture research and training organization. The Center works to reduce poverty and hunger by sustainably increasing the productivity of maize and wheat in the developing world. CIMMYT maintains the world's largest maize and wheat seed bank and is best known for initiating the Green Revolution, which saved millions of lives across Asia and for which CIMMYT's Dr. Norman Borlaug was awarded the Nobel Peace Prize. CIMMYT is a member of the CGIAR Consortium and receives support from national governments, foundations, development banks, and other public and private agencies.

The CIMMYT Socioeconomics Program (SEP) Working Papers series contain preliminary material and research results from CIMMYT social scientists and its partners. The papers are subject to an internal peer review. They are circulated in order to stimulate discussion and critical comment. The opinions are those of the authors and do not necessarily reflect those of their home institutions or supporting organizations. For more information on this series contact the CIMMYT website.

Correct Citation: S Tongruksawattana. 2014. *Climate shocks and choice of adaptation strategy for Kenyan maize-legume farmers: Insights from poverty, food security and gender perspectives.* Socioeconomics Program Working Paper 11. Mexico, D.F.: CIMMYT.

ISBN	978-607-8263-46-2 (On-line)
AGROVOC Descriptors	Maize; Zea mays; Farmers; Food security; Households; Gender; Kenya; Climatic change; Adaptation; Poverty; Western Kenya; Eastern Kenya
Keywords	Climate change, Adaptation, Poverty, Food security, Gender, Kenya
AGRIS Category Codes	E10 Agricultural Economics and Policies P40 Meteorology and Climatology
Dewey Decimal Classif.	633.15

Contents

Tables

Figures

Acknowledgements and disclaimer

The study was conducted under the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), which is a strategic partnership of CGIAR and Future Earth. This research was carried out as part of the Project titled "Sustainable Intensification of Maize-Legume Farming Systems for Food Security in Eastern and Southern Africa" (SIMLESA). I acknowledge additional funding support from the Australian Centre for International Agricultural Research (ACIAR).

My sincere thanks are due to scientists and colleagues from the lead centre of the SIMLESA project (CIMMYT), Mulugetta Mekuria, Menale Kassie and Geoffrey Muricho, for having helped to carry out the field activities. I also thank Bekele Shiferaw for his encouragement and support for the conceptual framework. I am grateful to the comments and suggestions on the draft version, provided by Hugo de Groote, Melinda Smale, Paswel Marenya and Ali Akhter, which have greatly helped to refine the document.

Acronyms

ACIAR	Australian Centre for International Agricultural Research
CCAFS	Climate Change, Agriculture and Food Security
CGIAR	Consultative Group on International Agricultural Development
CIMMYT	International Maize and Wheat Improvement Center
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Products
GHG	Greenhouse Gases
GOK	Government of Kenya
Ha	Hectares
IPCC	Intergovernmental Panel on Climate Change
Ksh	Kenyan Shillings
MOA	Ministry of Agriculture, Kenya
MLN	Maize Lethal Necrosis
MVP	Multivariate Probit
NGO	Non-governmental Organization
SIMLESA	Sustainable Intensification of Maize-Legume Farming Systems for Food Security in Eastern and Southern Africa
TLU	Tropical Livestock Unit
USD	United States Dollar
UNFCCC	United Nations Framework Convention on Climate Change

Executive summary

Climate change is a serious threat for agriculture, food security and the fight against poverty, especially in sub-Saharan Africa. With the IPCC climate outlook for the 21^{st} century, the future of maize production in Kenya remains under threat of more intense and frequent droughts, fluctuations in temperature and more erratic rainfall patterns. Effective adaptation to these progressive changes in climatic condition is the key to securing food production and livelihoods for millions of poor people. This study was conducted to provide a comprehensive understanding of the adaptation behaviour of maize-legume farm households in response to climate shocks, with emphasis on poverty, food security and gender perspectives. The research was conducted in rural Eastern and Western Kenya for the "Sustainable Intensification of Maize-Legume Farming Systems for Food Security in Eastern and Southern Africa (SIMLESA)" project.

Data for this study are drawn from a SIMLESA baseline survey conducted in 2011. A total of 613 households were sampled by proportionate random sampling in two districts from the western region (Bungoma and Siaya) and three districts from the eastern region (Embu, Meru and Imenti South). Despite the area's high potential for agricultural productivity, half of the surveyed households are living in poverty, with expenditure below 1 USD per capita per day. 70% of surveyed households in the western region compared to 30% in the eastern region identified themselves as food-insecure and almost 20% of households are female-headed in both regions. Between 1961 and 2012 the trend has been for annual rainfall to decrease in Siaya and Embu, to remain constant in Meru, and to increase in Bungoma. While Embu, Bungoma and Meru have experienced an increase of 1°C in the average daily temperature, in Siaya the temperature has decreased by 2°C. These observed changes in patterns of precipitation and temperature have put small-scale farm households in all districts under more pressure as regards production risks, as some crops, especially maize, are sensitive to certain temperature ranges.

Between 2000 and 2010, almost all of the surveyed maize-legume farm households reported drought as the most frequent and severe climate shock on farm production, followed by crop pests and excessive rainfall. Drought, which on average occurred almost three times during the 10-year period, had the most severe effect on food-crop production and income when compared to crop pests and excessive rainfall. Based on farmers' assessments, poor households with per capita expenditure in the lowest tertile were affected by drought, crop pests and excessive rainfall less frequently than households in the upper tertiles. With regard to food security, the effect of drought as measured by reduction in food production and income is more severe for food-secure households than for food-insecure households, although the effect of crop pests on income is more severe for food-insecure households. Concerning gender, the adverse effect of crop pests on food production and income is found to be more severe for male-headed than for female-headed households. These results are contrary to what might be expected and should be treated with caution. One possible explanation may be related to the potential effect of having a large asset endowment and large-scale farm

production, which makes the upper tertiles and food-secure households especially susceptible to climate shocks.

A farm household's adaptation to climate shocks follows a two-step process. As a response to the reduction in food production and income, a shock-affected household will first decide whether or not to undertake any action, before choosing a particular adaptation strategy from the available options. Almost 90% of shock-affected farmers applied at least one adaptation strategy, and most households reported that they had adapted to drought, with fewer reporting having adapted to crop pests and excessive rainfall. In the first step, results of probit regression show that the influence of previous frequent experience of drought significantly reduces the likelihood of adapting to drought and to excessive rainfall, while previous frequent experience of crop pests significantly increases the probability of adapting to all three types of shock. Although poverty and food insecurity are not found to have a significant influence on the adaptation decision for any shock, female-headed households are statistically 15% more inclined to adapt to excessive rainfall than male-headed households. The role of information through extension and membership of associations is found to support the decision to adapt to drought and excessive rainfall. The decision to adapt to drought and crop pests is found to increase with a proportion of steep farm land, but to decrease with farm size. Exposure to new technology is also found to influence the adaptation decision, as the adoption of improved maize varieties discourages crop pests, and maize-legume intercropping supports adaptation to excessive rainfall. However, education is shown to reduce the probability of adaptation to drought, while household size and credit access are found to reduce the probability of adaptation to crop pests. Distance to the main market and high rainfall variation show a significant positive effect on the probability of adapting to crop pests. High temperatures, on the other hand, tend to reduce the probability of adapting to drought and crop pests.

Results from multivariate probit regression identify complementarity and substitutability between adaptation strategies. Among four common adaptation strategies for coping with drought, farm adjustment (e.g. use of improved seed varieties with early maturity and tolerance to stress, replanting, use of external inputs, conservation agricultural practices and crop diversification) is found to be a substitution strategy for selling assets and borrowing. Reducing consumption is found to be a substitution strategy for selling assets, but is complementary to borrowing for adapting to drought. To adapt to crop pests, results show farm adjustment to be a substitution strategy for selling assets and reducing consumption. However, selling assets is a complementary strategy for borrowing, but is a substitution strategy for seeking treatment for crop pests, which in turn, is a substitution strategy for borrowing. On the other hand, farm adjustment appears to be the single dominant adaptation strategy for coping with excessive rainfall. Regression results for all three types of shock further highlight the reinforcing influence between different types of shocks for households that have not only experienced one type of shock several times, but have also experienced multiple types of shock during the same period. The impact of a current shock may be aggravated by the impact of previous experience of shocks. As shown from adaptation to drought, for example, frequent experience of crop pests is found to support reducing consumption while discouraging farm adjustment and

borrowing, while frequent experience of excessive rainfall is found to support farm adjustment but to discourage reducing consumption. Frequent experience of drought, on the other hand, encourages farm adjustment as an adaptation strategy for crop pests, while frequent experience of excessive rainfall reduces the likelihood of sales of assets and borrowing, but increases the probability of seeking treatment to cope with crop pests.

Sampled households in the lowest tertile are less likely to reduce consumption and to borrow to adapt to drought, but they are more likely to adjust farm management to adapt to excessive rainfall. When faced with a reduction in food and income, food-insecure households are more inclined to eat less to adapt to drought, and to borrow to adapt to crop pests, but they are less likely to adjust farm management to adapt to excessive rainfall. Although there is no significant influence of gender on the choice of adaptation strategy for drought and excessive rainfall, female-headed households are found to be 15% more likely to sell assets than their male-headed counterparts to adapt to crop pests. Other socioeconomic variables, particularly household size, assets, off-farm income, membership of associations, contact with extension, and credit access, show diverse influence on choice of adaptation strategies. In terms of farm and farm-management variables, a small farm size encourages farm adjustment for adapting to drought, and seeking treatment for dealing with crop pests. A large area of steep slope on the farm is found to support adjustment in farm management for adapting to drought, but selling assets, reducing consumption and borrowing are more favoured by households with a large area of flat land. Cultivation of improved maize varieties and a small holding of livestock further encourage farm adjustment for adapting to drought, while households with a large livestock holding are more likely to sell the animals. Households living in an area with high variations in rainfall and temperature are more likely to adjust their farm management as an adaptation strategy for drought. On the other hand, households living in low-temperature areas are more likely to sell assets to cope with drought and crop pests, whereas seeking treatment to cure crop pests is more likely for farm households in dry and cold areas.

This study highlights the significant interdependency and reinforcing influence of frequency of other shock types on coping with and choosing an adaptation strategy for a particular shock. Therefore an effective policy scheme to support adaptation should not take any one shock in isolation, but should incorporate the context and composite implication of other shocks. Research into adapting to climate change and policy discussion should also recognize that a certain adaptation strategy can be applied for different types of shocks. For example, adjustment of farm technology and practices can be promoted to combat drought, crop pests and excessive rainfall. However, as farmers may choose to apply multiple adaptation strategies, it is important to take into account the complementarity and substitutability between different types of adaptation strategies, which is context-specific for each type of shock. Moreover, assistance should target food-insecure households belonging to the lower expenditure group and those led by female heads, as these are often disadvantaged in terms of asset ownership and access to the technology and information necessary for adaptation to shocks.

1. Introduction

Climate change is a serious threat for agriculture, food security and the fight against poverty, especially in sub-Saharan Africa where every second person is struggling to live with less than 1 USD per day (Thornton et al. 2008). Crop failure due to unexpected climate shocks such as drought, crop pests and excessive rainfall increases the risk of a longer period of hunger and hardship for the many rural poor who rely on small-scale farming for food and income. Farming systems in this part of the world remain primarily traditional and geared toward semi-subsistence, with low utilization of external inputs and technologies, so that yields of food crops depend on favourable climatic and biophysical conditions. To respond to increasing unprecedented incidents of rising temperatures and shifting in precipitation patterns, some farm households undertake various adaptation strategies. The inadequate ability of households to adapt to progressive climate change is seen as an important driving force that makes households vulnerable to poverty, especially those living in rural areas with few social, technical and financial resources (World Bank 2010, UNFCCC 2007). Hence an understanding based on empirical evidence of the factors influencing adaptation behaviour is urgent and essential to target rural development and formulate agricultural policies that increase the resilience of rural farm households in vulnerable environments.

Despite Kenya being the largest and fastest-growing economy in East Africa, more than 67% of its 43 million people are fighting poverty (World Development Indicators 2012). Agriculture employs 75% of the workforce and contributes the largest share of GDP growth (24%) but grew by only 1.5% in 2011 (KNBS 2013). In Kenya, maize is the most important staple food and a traditional favourite component of meals, with an average annual consumption of 125 kilograms per capita accounting for roughly one third of daily caloric intake (Pingali 2001). Maize is also a major crop in Kenyan agriculture, being grown on half of cultivated land in almost all agroecological zones by 98% of 3.5 million smallholder farmers, who contribute at least 75% of national production (Kirimi et al. 2011). However, Kenya has been relying on imports and food aid for maize since 2000 (USAID KMDP 2011).

Drought, excessive rainfall, and crop pests, as well as declining soil fertility, deteriorating soil structure and lack of production-enhancing technology have all been attributed for successive crop failures and decreasing production, which is thus unable to meet the challenge of satisfying domestic consumption (Nyoro et al. 2007). To address low soil fertility and soil moisture-retention problems, maize and legume intercropping under conservation agricultural practices has been proposed as a sustainable intensification of food-crop production that aims to increase the resilience of maize-based farming systems to progressive climate change. The "Sustainable Intensification of Maize-Legume Farming Systems for Food Security in Eastern and Southern Africa (SIMLESA)" is an example of the effort in 2009 led by the International Maize and Wheat Improvement Center (CIMMYT) and its partners in Eastern and Southern Africa, with support from the Australian Centre for International Agricultural Research (ACIAR). The project is currently on-going in Kenya,

Tanzania, Ethiopia, Malawi and Mozambique, and is targeting maize and five main legumes grown in the region (beans, pigeon peas, groundnuts, cowpeas and soybeans).

Given that almost all agriculture in Kenya is rain-fed with low fertilizer application, the impact of drought on maize production is substantial in a country where over 80% of land area is arid or semi-arid, and where most of this area has a low and uncertain rainfall distribution pattern averaging 500 – 800 mm per annum (WEMA 2012). With the IPCC climate outlook for the 21st century, the future of maize production in Kenya remains under threat of more intense and frequent droughts, fluctuations in temperatures and more erratic rainfall patterns. Effective adaptation to these progressive changes in climatic conditions is the key to securing food production and safeguarding the livelihoods of millions of poor people. However, up to date there is no empirical evidence on common adaptation strategies and individual adaptation decisions of maize-legume farmers in Kenya for coping with agricultural production shocks due to increasing climatic variability. Available studies usually look at adaptation to climate shocks for an individual shock type in isolation, and do not take into account the interdependence and reinforcing influence of experiences of different shock types.

The objective of this study is therefore to provide a comprehensive understanding of maize-legume farm-household adaptation behaviour when faced with climate shocks, from the perspectives of poverty, food security and gender in rural Eastern and Western Kenya. The paper aims to (1) identify major climate shocks on farm production and common adaptation strategies during 2000 – 2010, (2) define farm household-level socioeconomic factors that explain farmers' adaptation decisions and choices of adaptation strategies, (3) assess interrelationships between different shock types on adaptation decision and strategies, and (4) examine complementarity and substitutability between adaptation strategies. More importantly, this study provides an empirical insight into formulating development policy with regard to adaptation to climate change, which will enhance the adaptive capacity of poor, food-insecure and female farmers in rural areas.

2. Farmers' adaptation to climate shocks on farm production

The Intergovernmental Panel on Climate Change (IPCC) defines climate change as a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties, and that persists for an extended period beyond that of individual weather events (IPCC 2007). The main process driver of climate change is a result of increasing anthropogenic emissions and concentrations of primary greenhouse gases (GHG)—carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4) — above the natural level in the atmosphere (IPCC 2007, UNFCC 2007). The thermal infrared radiation emitted by the Earth's surface is absorbed by greenhouse gases, leading to an increased infrared opacity of the atmosphere and radiative forcing. The heat and evaporation developed in this process cause the temperature to rise and the precipitation pattern to change. Farming depends essentially on temperature and rainfall, and prolonged periods of drought, erratic rainfall patterns (e.g. late rain onset, early rain termination, and sporadic rainfall distribution), flooding, and periods of unusual heat and cold, are direct consequences of precipitation and temperature fluctuation (IPCC 2007). In addition, crop pests in a warmer climate may become more active than at the present time, and may expand their geographical range because temperature, light and water are major factors controlling their growth and development (Bebber et al. 2013, Rosenzweig et al. 2001).

The process of climate change can have both positive and negative unexpected impacts on different land users and farming systems, but it increases farmers' exposure to new and unfamiliar conditions, especially the shifting of mean values and an increasing variation in climate patterns (Osbahr et al. 2008). Farm production, income and food security of rural households depend therefore on the ability to adapt farm planning and cultivation patterns to progressive climate change, in order to reduce damage from negative impacts, and to capture benefits from positive impacts. Although adaptation does not directly prevent climate change, it reduces the damage caused and allows beneficial opportunities to be explored (Stern 2007).

To address the negative impact of climate change on farm production, adaptation in this study is defined as any adjustment in natural or human systems, whether reactive *(ex-post)* or anticipatory *(ex-ante)*, that alleviates the decrease in yield and increase in yield variability brought about by climate change (Smit and Skinner, 2002). While some adaptations can be undertaken after the shocks have manifested themselves, other adaptations can be undertaken in anticipation to reduce the likelihood of the shock occurrence (Fankhauser et al. 1999; Smith and Lenhart 1996; Tol et al. 1998). Adaptation may involve building capacity (i.e. increasing the ability to adapt to changes), and implementing adaptation decisions (i.e. transforming the capacity into action) although individual adaptation actions are influenced and constrained by institutional, economic and social conditions (Adger et al. 2005; Smithers and Smit 1997). Adaptation may be classified as coping action when

undertaken in response to short-term weather variability as opposed to long-term climate change (Ziervogel et al. 2008).

In terms of adaptation in agriculture, Cooper et al. (2008) differentiated adaptation strategies into three categories: (a) risk-management options prior to the start of the planting season; (b) in-season adjustment of crop and resource management; and (c) after-season risk management that minimizes impacts on livelihood. Mendelsohn (2000) and Stern (2007) further distinguish between private and public adaptations. Private adaptations are behavioural responses driven by an individual's self-interest, i.e. when only the decision-maker implementing and paying for the adaptation profits from the adaptation benefit accrued. Public adaptations (e.g. joint adaptation by a community) share the benefit among many beneficiaries, including those who do not partake in the implementation or cost payment.

In this paper the focus of attention is placed on the private adaptation strategies implemented by individual farm households in response to climate shocks prior to, during, and after the planting season. Specifically, the farm household's adaptation to shock is depicted in a sequential decision-making framework (Figure 1). The exposure to shocks on agricultural production caused by climate change affects a household's crop yield, reducing food production and income. In the first stage, a shock-affected farm household decides whether or not to undertake any adaptive action to cope with the reduction in food production and income. In the second stage, having decided to adapt, the household will choose a particular adaptation strategy from among the available options. Central to adaptation is the trade-off between present and future consumption-smoothing at the expense of productive capacity and asset liquidation.

In this second stage, two main aspects of adaptation to climate shock are considered. **On-farm adaptation strategy** refers to the household's on-farm production practices and technology management in response to and/or in anticipation of lower yields and increasing yield variability (Smit and Skinner 2002). On-farm adaptation strategy involves adjustment of farming practices and often encompasses the adoption of new technology in breeding and agronomy (Bryan et al. 2009). This strategy includes the use of one of more of the following practices: planting improved varieties with early maturity and tolerance to stress; replanting; application of external inputs such as fertilizer; early or relay planting; conservation agricultural practices; crop diversification; crop intensification; and treatment of crop pests and diseases (e.g. Claessens et al. 2012, Kristjanson et al. 2012, Mercer et al. 2012, Cavatassi et al. 2011, Thompson et al. 2010). **Off-farm adaptation strategy** refers to the ways in which a household prepares for and copes with a reduction in food and income through managing their consumption and capital. Farm households can reduce their consumption of food and restrict other expenses as their food and income decline (e.g. Cooper et al. 2008, Dercon 2007, Jalan and Ravallion 1999); they can sell assets such as livestock, land, saved agricultural products and other assets in exchange for cash and other consumables (e.g. Cooper et al. 2008, Kochar 1999, Newhouse 2005); or they can borrow from formal and informal sources (e.g. Tadesse and Brans 2012, Cooper et al. 2008, Newhouse 2005, Kochar 1999).

Other studies in literature show additional options for adaptation. To cope with increasing climatic variability, poor farmers in Mozambique, for example, relied on reciprocity and exchange of resources across different network levels as well as on income diversification and collective land-use management (Osbahr et al. 2008). To cope with severe drought, farmers in Burkina Faso changed their lifestyle in different ways to earn a living, for example by migration, off-farm employment, social support networking and livestock production (Roncoli et al. 2001).

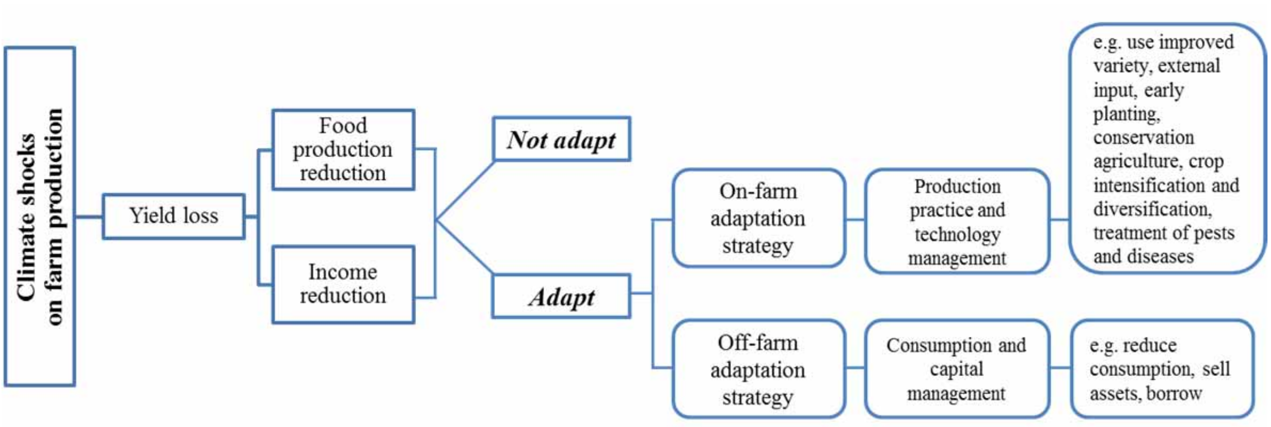

Figure 1: Climate shocks on farm production and farm households' adaptation strategies

Source: Own illustration

3. Empirical framework

3.1 Modelling adaptation decision: a two-step approach

To understand the adaptation behaviour of farm households, an empirical model is needed to explain (1) what factors influence a farmer's decision as to whether or not to adapt when a shock occurs, (2) what factors determine a choice of a particular adaptation strategy, (3) whether adaptation to one type of shock is influenced by experiences of other types of shock, and (4) which adaptation strategies are complements and which are substitutes to one another. Facing climate-induced agricultural production shocks that affect food production and income, a farm household can either undertake any adaptation strategy to reduce the loss from the shock and to prepare itself for a possible recurrence, or else not adapt. Non-adaptation can be interpreted as a result of lack of adaptive capacity, or of the shock being inconsequential to the household. Each of the alternatives brings a different stream of utilities — U_1 from adaptation and U_0 from non-adaptation – which are index functions of a set of deterministic and stochastic variables.

Utility from adaptation: $U_1 = f(\boldsymbol{S}, \boldsymbol{X}, \boldsymbol{L}, \varepsilon_1)$

Utility from non-adaptation: $U_0 = f(\boldsymbol{S}, \boldsymbol{X}, \boldsymbol{L}, \varepsilon_0)$

The deterministic vectors to adaptation are the nature of the climate shock incidents that enforce change (***S***), properties of the farm household defined as socio-demographic characteristics and farm management (***X***), and specific characteristics of the location (***L***) (Smithers and Smit 1997). ε_1 and ε_0 are stochastic variables for adaptation and non-adaptation, respectively. For an individual household in a given period, the utility from taking an adaptation action can be interpreted as the benefit from undertaking measures that compensate for losses in food production and income caused by shocks. The choice of efficient adaptation, or non-adaptation, is the one that makes a household better-off through an increase in utility, and a household will only adapt if the stream of utility derived from adaptation is greater than from non-adaptation (Mendelsohn 2012). Although utility is unobservable, the observed binary choice of adaptation action ($Y = 1$) or non-adaptation ($Y = 0$) provides a proxy for such utility comparison with a certain probability.

Probability of adapting: $Pr(Y = 1|S, X, L) = Pr(U_1 > U_0)$

Probability of not adapting: $Pr(Y = 0|S, X, L) = Pr(U_1 \leq U_0)$

Based on maximization of utility and probability of adaptation, the key questions in this paper essentially address two steps of decision-making. In the first step, a shock-affected household decides whether or not to take any action to adapt to the climate shock. The adaptation decision at this initial step for each type of shock can be solved by standard probit regression estimating the relationship between a latent discrete binary decision variable Y_i^* as dependant variable (adapt:

$Y_i = 1$; not-adapt: $Y_i = 0$) and a set of explanatory variables (S_i, X_i, L_i) and an error term (ρ_i) for all households i up to n (Step 1).

Step 1: Adaptation decision

$$Y_i^* = \alpha_i S_i + \beta_i X_i + \delta_i L_i + \rho_i$$
$$Y_i = 1 \quad \text{if} \quad Y_i^* > 0$$
$$Y_i = 0 \quad \text{otherwise}$$

The probability that a household chooses to adapt to each type of shock depends on the values of S_i, X_i, L_i and the parameters $\alpha_i, \beta_i, \delta_i$ which describe their influences. The functional form of a probit model assumes a normal distribution of the error terms, and the estimation is based on the maximum likelihood method.

In the second step, after the decision to adapt an adapting household will select a particular adaptation strategy from among the available options that may be used simultaneously as complements or substitutes (Step 2). For this purpose, the standard binary (univariate) probit model in Step 1 can be expanded to multivariate probit regression (MVP) with a standard normal distribution to assess factors influencing the selection of various adaptation strategies. As opposed to other modelling approaches such as multinomial logit regression and separate binary response (univariate) probit equations, multivariate probit is more suitable because it estimates the influence of explanatory variables on each of the different adaptation strategies $\mathrm{j} = 1, \ldots, \mathrm{J}$, while accounting for systematic correlations of unobserved and unmeasured factors across strategies but not across observations within a given strategy (Young et al. 2009, Greene 2011, MacFaddden 1981). Correlations may be due to complementarity (positive correlation) or substitutability (negative correlation) between different strategies. Therefore the estimates of multinomial logit or separate univariate probit equations are biased and inefficient when such correlations exist (Greene 2011, Wooldridge 2010). Specifically, MVP regression extends the error terms ε_i which have a multivariate normal distribution, each with zero mean and variance-covariance matrix V, where variance $\rho_{\mathrm{jk}} = 1$ for $\mathrm{j} = \mathrm{k}$ and covariances $\rho_{\mathrm{jk}} = \rho_{\mathrm{kj}}$ to allow for such correlation (Cappellari and Jenkins 2003). Step 2 uses the same set of explanatory variables as step 1 and can be specified as following:

Step 2: Choice of adaptation strategy

$$Y_{i1} = \begin{cases} 1 \text{ (Strategy 1)} & \text{if } Y_{i1}^* = \alpha_1 S_{i1} + \beta_1 X_{i1} + \delta_1 L_{i1} + \rho_{i1} > 0 \\ 0 \text{ (Otherwise)} & \text{if } Y_{i1}^* \leq 0 \end{cases}$$

$$Y_{i2} = \begin{cases} 1 \text{ (Strategy 2)} & \text{if } Y_{i2}^* = \alpha_2 S_{i2} + \beta_2 X_{i2} + \delta_2 L_{i2} + \rho_{i2} > 0 \\ 0 \text{ (Otherwise)} & \text{if } Y_{i2}^* \leq 0 \end{cases}$$

$$\vdots$$

$$Y_{iJ} = \begin{cases} 1 \text{ (Strategy J)} & \text{if } Y_{iJ}^* = \alpha_J S_{iJ} + \beta_J X_{iJ} + \delta_J L_{iJ} + \rho_{iJ} > 0 \\ 0 \text{ (Otherwise)} & \text{if } Y_{iJ}^* \leq 0 \end{cases}$$

Based on the simulated maximum-likelihood method, estimation of the MVP models applies the Geweke-Hajivassilion-Keane smooth recursive conditioning simulator which draws upon the product of sequentially conditioned univariate normal distribution functions with joint probability (Geweke et al. 1997; Hajivassiliou et al. 1996). Joint decision-making by farmers is tested using the Wald test (Cappellari and Jenkins 2003). MVP is widely applied in literature which explores the correlation between shocks and binary choices of adaptation strategies (e.g. Tongruksawattana et al. 2013, Waibel et al. 2013, Nhemachena and Hassan 2007, Rashid et al. 2006, Takasaki et al. 2002).

3.2 Model specification and variables hypothesized to influence a farm household's adaptation

Since decision on adaptation and choice of adaptation strategy vary depending on type of shock, it is appropriate to specify a separate model consisting of two decision-making steps for each shock type. In step 1, all shock types are specified to the same dependent variable which is a binary response to adaptation when at least one adaptation strategy was used. In step 2, each shock type may have its own set of specific adaptation strategies as binary response dependent variables subject to common strategies found in the sample. For all shock types, however, adaptation behavior may be explained by the same set of explanatory variables, although with different directions and degrees of influence. A detailed description of the dependent and explanatory variables, including their expected influence on a farm household's adaptation, is provided in Table 1.

Table 1: Variables hypothesized to influence a farm household's adaptation to climate shocks on farm production

Explanatory variable	Description of explanatory variable	Expected influence on dependent variable [a)]					
		Step 1	*Step 2*				
		Use any adaptation strategy	Farm adjustment	Seek treatment	Sell assets	Reduce consumption	Borrow
Shock experience							
Own shock frequency and severity	Frequency and severity of own shock experienced during a reference period	+	+	+	+	+	+
Other shocks frequency and severity	Frequency and severity of other shocks experienced during a reference period	+/-	+/-	+/-	+/-	+/-	+/-
Socioeconomic characteristics							
Poor	Dummy = 1 if household expenditure per capita belongs to 1st tertile, 0 otherwise	-	-	-	-	+	+
Food-insecure	Dummy = 1 if household experienced food shortage, 0 otherwise	-	-	-	-	+	+
Female-headed	Dummy = 1 if household head is female, 0 otherwise	+	+	+	+	+	-
Education	Years of schooling of household head	+	+	+	-	-	+
Age	Age of household head	-	-	-	+	+	+
Household size	Household size in adult equivalents [b)]	+	+	+	+/-	+	+/-
Assets	Household total current asset value of production equipments and major household furniture in 1,000 Kenyan Shillings (Ksh) [c)]	+	+	+	+	-	-
Off-farm income	Household income from off-farm employment in 1,000 Kenyan Shillings (Ksh) [c)]	+	+	+	+	-	-
Extension contact	Dummy = 1 if the household had contact with at least one extension service from government, NGOs or private companies	+	+	+	-	-	+
Associations	Number of associations the household belong to	+	+	+	-	-	+
Credit access	Dummy = 1 if the household had access to credit, 0 otherwise	+	+	+	-	-	+
Market distance	Distant to the main market from residence in kilometers	-	-	-	-	+	-
Farm management							
Farm size	Total farm size of the household in hectares	+	+	+/-	-	-	-
Share of flat plot	Percentage share of total land area which is characterized as flat	-	-	+/-	+/-	+/-	+/-
Area improved maize variety	Farm area of the household with improved maize variety in hectares	+	+	+/-	+/-	+/-	+/-
Livestock	Tropical livestock equivalent in Tropical Livestock Unit [d)]	+	+/-	+	+	-	+
Maize-legume intercrop	Dummy = 1 if the household practices maize-legume intercropping, 0 otherwise	+	+	+/-	+/-	-	+/-
Maize-legume rotation	Dummy = 1 if the household practices maize-legume rotation, 0 otherwise	+	+	+/-	+/-	-	+/-
Location							
Rainfall	Coefficient of variation of district rainfall	+/-	+/-	+/-	+/-	+/-	+/-
Temperature	Average district temperature in degree Celcius	+/-	+/-	+/-	+/-	+/-	+/-

[a)] Binary response (1 = yes; 0 = otherwise) [b)] As per the World Health Organization [c)] 1,000 Ksh = 11.7 USD as of 19th December 2013
[d)] 1 TLU=Ox, 0.8 TLU=Horse, 0.7 TLU=Cow, 0.7 TLU=Mule, 0.5 TLU=Donkey, 0.5 TLU=Heifer 0.5 TLU=Bull, 0.2 TLU=Calf, 0.2 TLU=Pig, 0.1 TLU=Sheep, 0.1 TLU=Goat, 0.01 = Chicken

Decision on whether or not to adapt and choice of adaptation strategies depend on the type, frequency and severity of shocks. Accumulated experience with shock, as measured by frequency of occurrence in the last time period, is potentially a positive influential factor in the adaptation decision (Tongruksawattana et al. 2013, Smithers and Smit 1997). In addition, it is hypothesized that experience with other shock types during the same period also has a potential influence on the decision to adapt to a particular type of shock (own shock). For example, a decision to adapt to drought may depend on whether a household has also frequently experienced crop pests and excessive rainfall during the same period. However, the expected relationship can be either positive or negative. A drought-affected household may be inclined to adapt to drought, if it did not suffer from frequent crop pests, and so remains with sufficient resources that can be used for adapting to drought. On the other hand, a drought-affected household may be inclined to adapt to drought even if crop pests have been frequent, because it cannot afford to continue with severe yield damage from both shock types.

A household's socioeconomic characteristics and local environment also influence the adaptation decision (Rashid et al. 2006, Takasaki et al. 2002). Relatively poor or less resource-endowed households have fewer resources, and hence are expected to have less ability to adapt to climate shocks than wealthier or more resource-endowed households (Silvestri et al. 2012; Hardaker et al. 1997). Per capita expenditure can be used as a proxy for wealth, where households are categorized as "poor" if their expenditure per capita falls within the 1st tertile of the entire sample as an indicator of relative poverty status. While poor households are expected to be reluctant to invest in farm adjustment, treatment of pests and diseases, or to sell assets, they are potentially more likely to reduce consumption and borrow as adaptation strategies. A similar hypothesis applies to food-insecure households. On the other hand, other household's wealth indicators such as assets and off-farm income are hypothesized in the opposite direction (Cutter et al. 2003, Glewwe and Gillette 1998). Gender of the household head is also considered to influence the adaptation decision. As the number of female-headed households is increasing in Africa, women assume more autonomy in making decisions for their households and farms (FAO 2011). However, women still have less access to, and control of, assets, agricultural inputs and credit than men, while provision of education and extension is usually aimed at men (Asfaw and Admassie 2004). Nonetheless, Nhemachena and Hassan (2007) found that female-headed households are more likely to adapt to climate shocks as women in female-headed households are responsible for a larger share of agricultural tasks than they are in male-headed households. Therefore it is hypothesized that female-headed households have a positive relationship with the probability of using all the adaptation strategies except borrowing, which could still be more restricted for women than men in terms of asset ownership and credit access.

High levels of education are associated with access to information on new technology and credit sources (Norris and Batie 1987; Igoden et al. 1990; Lin 1991). Household heads who have spent more years in school therefore have a high probability of adjusting farm practices, seeking treatment for crop pests and borrowing, as opposed to reducing consumption and selling assets. Similarly, contact with extension (e.g. government extension services, neighbors and farming relatives, seed

traders, agrovets and NGOs) as well as membership of associations and farmer cooperatives and groups are associated with access to information on new technology and credit sources (Deressa et al. 2009, Maddison 2007). These variables are therefore expected to have the same influence on adaptation as does education. In addition, access to credit is expected to have a positive relationship with adaptation, as credit generates the resources necessary to invest in new technology, treat diseases and pests and borrow for consumption smoothing. It is hypothesized that young household heads will be likely to adapt by adopting technology and seeking treatment, whereas older household heads will be more likely to sell assets, reduce consumption and borrow. Large households are expected to have a large pool of labour to be reallocated to on-farm and off-farm activities, but consumption per household member would be reduced when facing a decline in food production and income.

A household's capacity to adapt to climate change depends on its endowment of livelihood assets, e.g. natural, human, physical, institutional, social, and financial (Yohe and Tol 2002). A larger farm size allows for more flexibility in the adjustment of farming practices and adoption of new technology (Maddison 2007). Adaptation in terms of farm adjustment is expected to be less likely for flat areas as compared to sloping areas where soils are more prone to erosion. Households with existing exposure to new technology (e.g. adoption of an improved maize variety) can be expected to further adopt new technologies as an adaptation measure. A similar expectation applies to an existing practice of maize-legume intensification, except that households who rotate or intercrop maize with legumes may be less likely to reduce consumption as an adaptation strategy due to a larger supply of food provided by these two crops. Livestock as a form of asset may be liquidated for cash to purchase yield-enhancing inputs such as improved seeds, or to smooth consumption demand (Dercon 1998). Distance to the nearest market indicates the level of market access, and a positive relationship between proximity to market and adaptation may be expected (Maddison 2007).

Lastly, climatic conditions in a location may play an influential role in encouraging or discouraging an adaptation decision. Di Falco and Veronesi (2012) found evidence in Ethiopia that adaptation strategies undertaken by farmers were correlated with rainfall. Lack of rainfall but high temperatures may induce farm households to adopt improved maize varieties with drought and heat tolerance or water efficiency. On the other hand, farmers may be reluctant to invest in replanting if they expect low rainfall.

4. Data and study area

Data for this study are drawn from a SIMLESA baseline survey conducted in 2011. The survey purposively selected two regions in Kenya, taking into account their maize-legume production potential: the western highlands in the western region and the central highlands in the eastern region. Both regions have a bimodal rainfall pattern and two cropping seasons (i.e. March-April rainy season and September-November rainy season). A total of five districts were selected, of which two districts were from the western region (Bungoma and Siaya) and three districts from the eastern region (Embu, Meru and Imenti South) (Figure 2). However, due to its relatively small administrative size and close proximity to Meru, characteristics of Imenti South can be reflected by those of Meru.

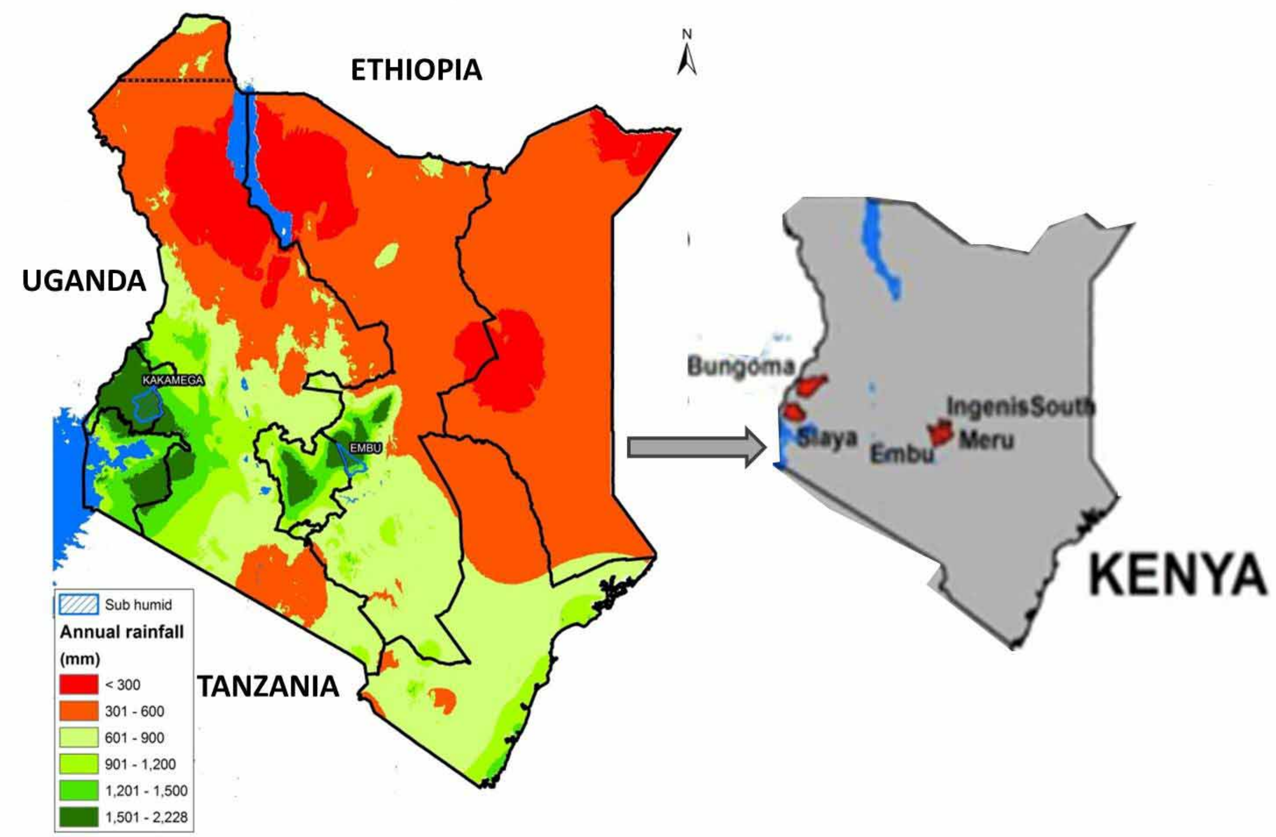

Figure 2: SIMLESA study sites in Kenya
Source: Adapted from SIMLESA

All the districts are considered to have good agricultural potential with well-drained soils and relatively high rainfall (1,100 – 1,600 mm per year), and are characterized by small-scale cash crop and subsistence farming systems (MOA 2006). Common food crops grown include maize, beans,

potatoes and vegetables, while the main cash crops are tea, coffee, sugarcane and cotton; cattle and small livestock are also widely kept (GOK 2005a, 2005b, 2007, 2009). Average size of plots of land under small-scale agriculture in both western and eastern areas ranges approximately from 0.7 ha to 1 ha. Despite a high potential for agricultural productivity, the number of people living on less than 1 USD per day in the districts remains substantial, with the highest poverty rate found in Bungoma (50.7%), followed by Siaya (40.1%), Embu (36.6%) and Meru (31.2%) (KIHBS 2006).

Compared to other districts, Bungoma has the highest average rainfall. Over the past 50 years (1961 – 2012) the amount of rainfall has been substantially fluctuating in all districts. The annual trend has been for rainfall to decrease in Siaya and Embu, remain constant in Meru and increase in Bungoma with statistical significance (Figure 3).

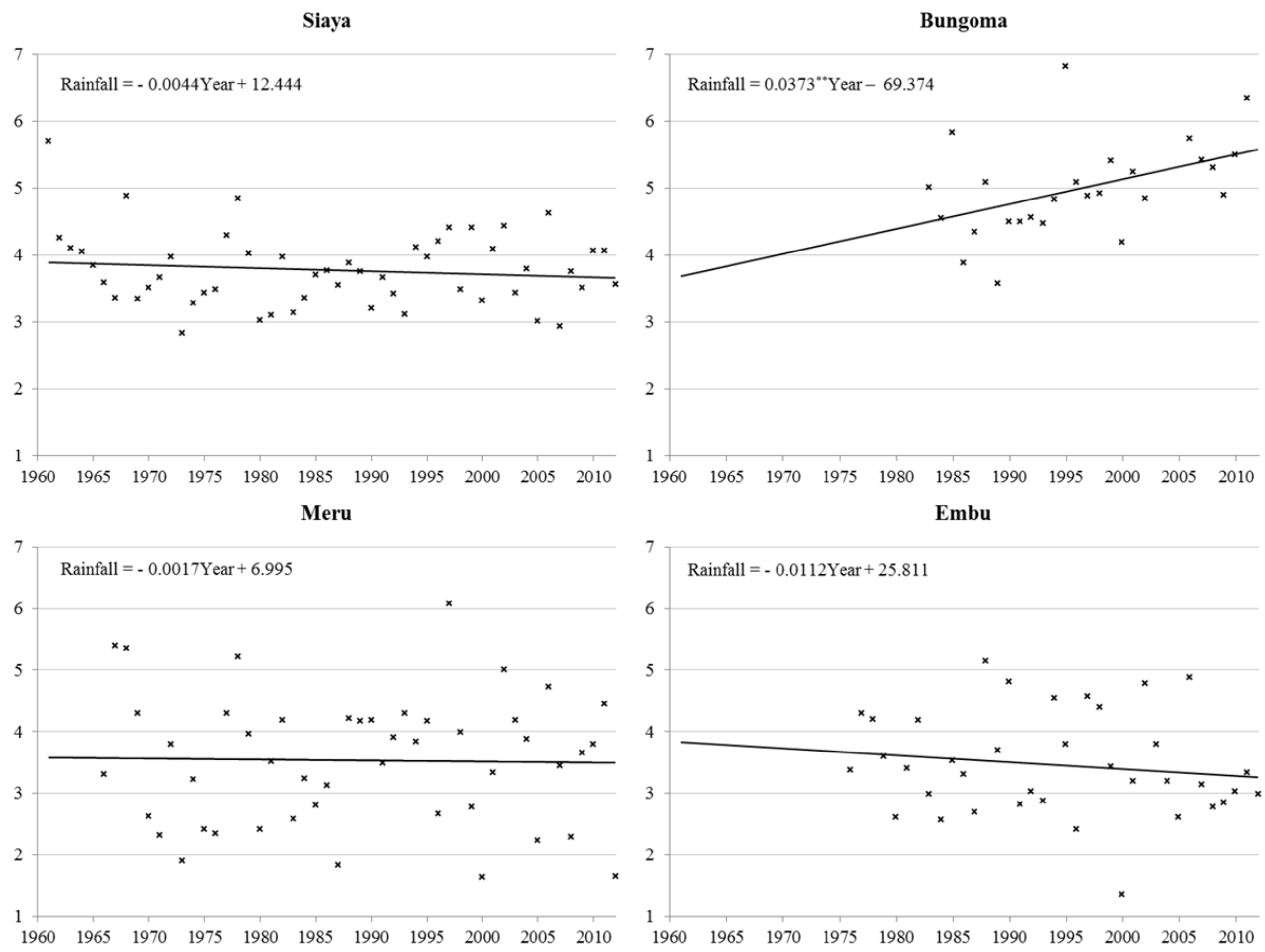

Figure 3: Average daily precipitation in study sites 1961 – 2012 (millimetre)

Note: Imenti South is omitted due to lack of data. *** significant at 1% level
Source: Kenya Meteorological Department

Situated closer to the Equator at a relatively lower altitude, the average temperature is higher in the western districts than in the eastern districts. Over the last few decades, meteorological data show statistically significant trends in changes in average daily temperature in all districts (Figure 4). While Embu, Bungoma and Meru have experienced an increase of 1°C in average daily temperature, in Siaya the average daily temperature has fallen by 2°C. These observed changes in patterns of precipitation and temperature put small-scale farm households in all districts under more pressure from production risks, as some crops and livestock are sensitive to certain temperature ranges. Maize, in particular, prefers moderately warm and wet environments. The crop is very sensitive to frost and waterlogging, but tolerates hot and dry atmospheric conditions as long as sufficient water is available (FAO 2013).

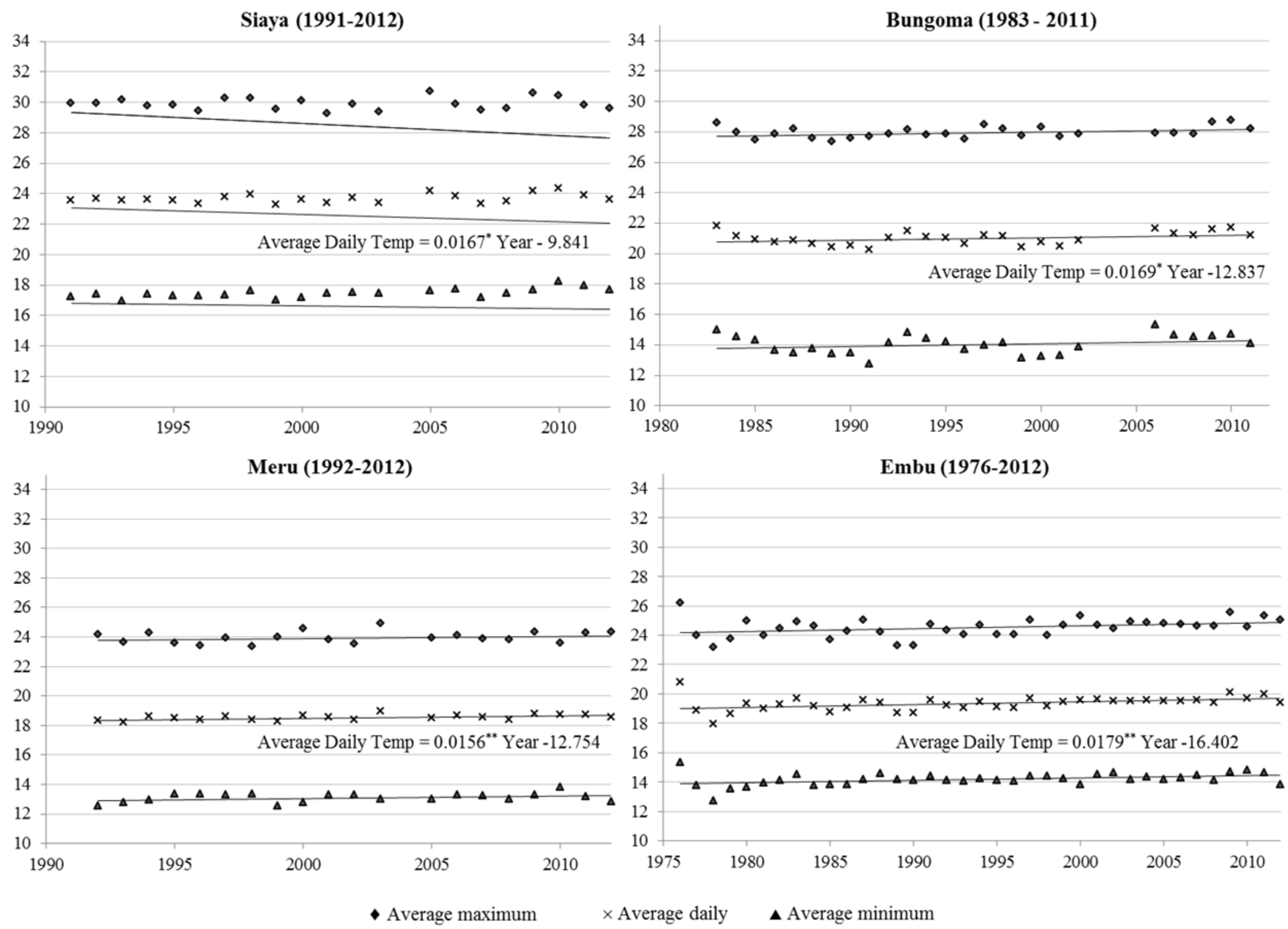

Figure 4: Average daily temperature in study sites (°C)

Note: Imenti South is omitted due to lack of data.
* significant at 10% level, ** significant at 5% level, *** significant at 1% level
Source: Kenya Meteorological Department

Proportionate random sampling was used to ensure representation of the sample depending on the population of the study areas. In total, 28 divisions - 17 from western Kenya and 11 from Eastern Kenya - were selected. A total of 613 households were sampled for this survey with an equal distribution of 300 in each region, i.e. 150 households per district in the western and 100 households per district in the eastern region. Next, the number of villages to be surveyed was identified proportional to the total number of households in each of the divisions and the sampled villages were randomly selected from each division. Similarly, the number of households to be surveyed was identified proportional to the total number of households in each village, and the sampled households were randomly selected from each village.

In both western and eastern regions, half of surveyed households were living in poverty with expenditure below 1 USD per capita per day (Table 2). The highest poverty rate was found in Siaya, followed by Meru, Embu, Imenti South and Bungoma. A similar observation was made in terms of relative poverty as measured by 1st tertile per capita expenditure. 70% of surveyed households in the western region compared to 30% in the eastern region identified themselves as food-insecure, with the highest proportion of food-insecure households found in Siaya. Almost 20% of households were female-headed in both regions, with the highest proportion of female-headed households found in Siaya and the lowest in Bungoma.

Table 2: Descriptive characteristics of sampled households

District	Number of surveyed			Sampled households (%)			
	Divisions	**Villages**	**Households**	**Poor (< US$ 1/day)**	**Poor (1st Tertile)**	**Food insecure**	**Female-headed**
Western region	**17**	**63**	**299**	**54.2**	**31.4**	**68.6**	**19.4**
Bungoma	10	20	150	49.3	27.3	66.7	12.7
Siaya	7	43	149	59.1	35.6	70.5	26.2
Eastern region	**11**	**114**	**314**	**54.5**	**35.0**	**29.0**	**19.4**
Embu	5	31	111	54.1	36.0	35.1	25.2
Meru	3	39	102	56.9	35.3	20.6	14.7
Imenti South	3	44	101	52.5	33.7	30.7	17.8
Total	**28**	**177**	**613**	**54.3**	**33.3**	**48.3**	**19.4**

Following the proposed empirical model, household-level data on frequency and severity of climate shocks on farm production were collected with reference to the last 10 year period (2000 – 2010). Due to the scarcity of technical resources for constructing and maintaining a meteorological station in sub-locations, the smallest coverage unit measurement of statistical weather data is only feasible at district level. Hence meteorological district data on rainfall and temperature in the last year (2010) were used as location variables. Moreover, the decision as to whether or not a certain level of rainfall

and temperature should be classified as a production shock depends primarily on the initial condition of a particular household and its farm. This study therefore captures climate shock variables based on a farmer's subjective assessment of frequency of the shock, and including the percentage reduction in food production and income due to that shock. To ensure common understanding of the shock variable, drought and excessive rainfall are defined as significant when there is an unexpected deviation in the amount and distribution of rainfall, relative to the normal level in the area, based on the subjective assessment of respondents. While drought refers to an event of rainfall shortage and/or erratic rainfall distribution such as late rain onset, early rain cessation or sporadic rainfall, excessive rainfall refers to an excessive amount of rain including flooding of farm land.

With 2010 as the reference period, socioeconomic variables collected from household heads included age, gender and education level in school years. Other socioeconomic variables collected at household level were household size, expenditure, assets, off-farm income, access to credit, contact with extension, membership of any association, and distance to the main market from residence in kilometres. In addition, the variable for food insecurity was based on a household's experience of occasional or frequent shortage of foods throughout 2010, taking into consideration all available food sources including own food production, purchased food, help from different sources, and food collected from forests, rivers and lakes. Data were also collected to reflect farm management practices based on the 2010 cropping year. These variables included farm size in hectares, proportion of flat land to total farm size, area of farm planted with improved maize varieties in hectares, total livestock units, and whether the household intercropped or rotated maize with legumes.

5. Results

5.1 Climate shocks on farm production and adaptation strategies

Between 2000 and 2010 drought was the most common climate shock on farm production suffered by the highest proportion of households, followed by crop pests and excessive rainfall (Figure 5). Drought, which on average occurred almost three times during the 10-year period, had the most severe effect on food-crop production (43.5%) and income reduction (29%), and was anticipated by almost 70% of households to be more important in the future due to climate change. Crop pests, which ranked second-highest in terms of frequency, had the second most-severe effect on households' food-crop production and income. Common pests of maize in the area are cutworms, armyworms, maize leaf aphids, stem borers, stalk borers and large grain borers, while maize streak virus, head smut, crazy top and common rust are common maize diseases (ACDI/VOCA 2007). In addition, Maize Lethal Necrosis (MLN) has emerged as one of the most serious maize diseases since its first outbreak in Kenya in 2011 (CIMMYT 2013). Excessive rainfall, although being less frequent than drought and crop pests during the ten-year period, had a substantial adverse effect on food-crop production and income.

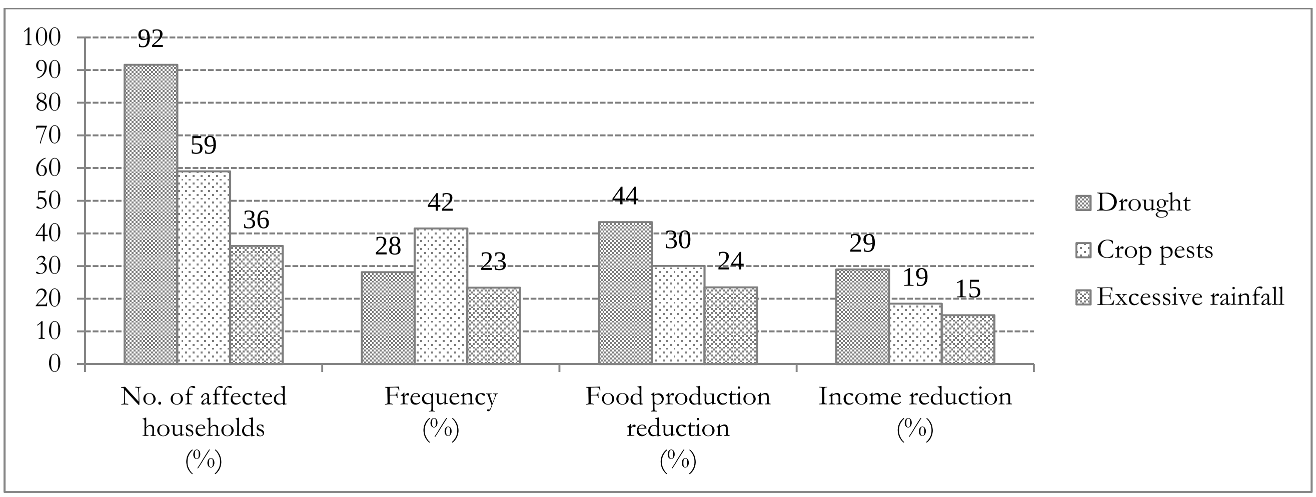

Figure 5: Climate shocks on farm production faced by all households during 2000 – 2010 (N = 613)

During the 10-year period, poor households with per capita expenditure in the 1st tertile were affected by drought, crop pests and excessive rainfall once to twice less frequently than households in the upper tertiles (Table 3). The effect of drought in terms of food production and income reduction is more severe for food-secure households than for their food-insecure counterparts. Although crop pests reduced food production with comparable severity for both food-secure and food-insecure households, the effect of crop pests on income reduction is more severe for food-insecure households. Adverse effect of crop pests on food production and income is also more pronounced for male-headed than for female-headed households. These results are contrary to what

might have been expected and should be treated with caution. One possible explanation may be related to the potential effect of having a large asset endowment and large-scale farm production, which makes the upper tertiles and food-secure households especially susceptible to climate shocks.

Table 3: Climate shocks on farm production by poverty, food security and gender

Shock type	Poor	Non-poor	t-test	Food insecure	Food secure	t-test	Female-headed	Male-headed	t-test
Drought (N = 558)									
Frequency (2000 – 2010)	2.5	3.0	**	2.8	2.9		2.5	2.9	
	(1.7)	(2.6)		(2.3)	(2.4)		(1.7)	(2.5)	
Food production reduction (%)	40.9	45.0		40.9	45.9	*	43.5	43.5	
	(28.8)	(28.8)		(29.4)	(28.2)		(28.4)	(29.0)	
HH income reduction (%)	31.4	27.9		26.1	31.6	**	27.2	29.4	
	(25.1)	(23.4)		(22.0)	(25.6)		(21.8)	(24.6)	
Crop pests (N = 360)									
Frequency (2000 – 2010)	3.2	4.6	***	4.0	4.3		4.0	4.2	
	(3.1)	(3.7)		(3.4)	(3.7)		(3.4)	(3.6)	
Food production reduction (%)	29.9	30.1		29.3	30.6	*	28.1	30.5	**
	(22.3)	(23.3)		(22.6)	(23.2)		(22.5)	(23.1)	
HH income reduction (%)	20.7	17.6		20.1	17.4	*	17.3	18.8	*
	(18.6)	(15.7)		(17.7)	(15.9)		(15.7)	(16.9)	
Excessive rainfall (N = 219)									
Frequency (2000 – 2010)	1.9	2.6	*	2.4	2.2		2.1	2.4	
	(2.0)	(2.4)		(2.3)	(2.3)		(1.6)	(2.4)	
Food production reduction (%)	23.4	23.7		26.6	19.3		32.6	21.5	
	(20.6)	(25.0)		(24.8)	(21.5)		(29.3)	(21.9)	
HH income reduction (%)	17.4	14.0		16.7	12.6		20.1	13.9	
	(14.5)	(16.1)		(16.4)	(14.4)		(22.3)	(13.7)	

Note: Standard deviation in parentheses. * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

Almost 90% of shock-affected households applied at least one adaptation strategy to cope with drought, excessive rain and crop pests. Most households reported to have adapted to drought (83%), followed by crop pests (78%) and excessive rainfall (73%). Once households decide to adapt to shocks, they make a decision which particular adaptation strategies to apply. To adapt to one type of shock, they may use only one strategy, or a combination of strategies simultaneously or sequentially. Although the sequencing of application cannot be observed in the dataset, survey results identified common adaptation strategies applied by all shock-affected households based on frequency of application (Table 4). To adapt to drought, four dominant strategies were found, ranked by the frequency of application: farm adjustment, selling assets, reducing consumption, and borrowing. A slightly different set of four adaptation strategies were identified and ranked by frequency of application for crop pests: farm adjustment, seeking treatment, selling assets and borrowing. On the other hand, farm adjustment appears to be the only dominant strategy for adapting to excessive rainfall.

Table 4: Adaptation strategies to cope with drought, crop pests and excessive rainfall

Shock type	No. of adapted households	Adaptation strategy (%)				
		Farm adjustment	Sell assets	Reduce consumption	Borrow	Seek treatment
Drought						
All households	462	54	21	13	12	
Poor	157	57	20	12	11	
Non-poor	305	52	21	14	12	
Food insecure	217	58	14	16	13	
Food secure	245	50	27	11	11	
Female-headed	96	56	16	12	16	
Male-headed	366	53	22	14	11	
Crop pests						
All households	280	45	18	1	10	26
Poor	87	53	20	1	10	16
Non-poor	193	42	17	2	9	30
Food insecure	110	43	15	2	18	23
Food secure	170	46	20	1	5	27
Female-headed	54	50	22	1	10	16
Male-headed	226	44	17	1	10	28
Excessive rainfall						
All households	163	74	9	6	10	
Poor	52	76	9	3	12	
Non-poor	111	74	10	8	9	
Food insecure	92	72	6	6	15	
Food secure	71	77	13	6	4	
Female-headed	36	71	7	9	13	
Male-headed	127	75	10	5	9	

To adapt to drought, the poor, food-insecure and female-headed households adjusted farming practices more often than the non-poor, food-secure and male-headed households. Food-secure households sold assets more than the food insecure, who reduced consumption and borrowed more often. While male-headed households preferred selling assets, female-headed households preferred borrowing. To adapt to crop pests, poor households adjusted farming practices and sold assets more than the non-poor, who preferred to seek treatment, while the food-insecure borrowed more often than the food-secure, who tended to adjust farming practices, sell assets and seek treatment. Female-headed households adjusted farming practices and sold assets more than male-headed households, who preferred seeking treatment to recover from crop pests. To adapt to excessive rainfall, farm adjustment is undertaken more often by poor, food-secure and male-headed households than by non-poor, food-insecure and female-headed households.

5.2 Standard probit estimation: Explaining adaptation decision

As the first stage of the adaptation decision, results from standard probit regression (step 1) show a number of factors influencing the decision to undertake at least one adaptation strategy to cope with drought, excessive rainfall and crop pests (Table 5). In this first stage, previous frequent experience of drought reduces the likelihood of adaptation to drought itself which is contrary to expectation. This may be due to the nature of drought which exposes farm land to lack of moisture and soil fertility degradation. In spite of possible attempts to adapt to drought, repetitive experiences with lack or unpredictability of rainfall resulting in repetitive crop failure and degrading soil fertility may increase the risk for farmers investing in any new adaptation measures. Similarly, previous experience with drought also reduces the likelihood of adaptation to excessive rainfall. On the other hand, previous frequent experience with crop pests significantly increases the probability of adaptation to all three types of shock as hypothesized. Although poverty and food security are not found to have a significant influence on adaptation decision for any shock, female-headed households are statistically 15% more inclined to adapt to excessive rainfall than male-headed households. Furthermore, the probability of adapting to drought increases with the number of associations or networks a household belong to. However, drought-affected households are less likely to adapt to drought if the household head has a high level of education, although the marginal effect is very small. The probability of adapting to drought also decreases with farm size (although with less than 3% marginal effect) and temperature, but increases by more than 10% with a 1% additional proportion of steep farm land.

Similar to drought, the probability to adapt to crop pests decreases with farm size (almost 7% marginal effect) and increases by more than 10% with a 1% additional share of steep farm land. One additional hectare of farm area planted with an improved maize variety is also found to encourage adaptation to crop pests by 10%. Large household size and credit access, on the other hand, have a negative influence on adaptation to crop pests, while market distance, high rainfall variation and cold temperatures increase the likelihood of adapting to crop pests. As hypothesized, contact with extension increases the likelihood of adaption to excessive rainfall. In addition, the practice of maize-legume intercropping increases the probability of adaptation to excessive rainfall by almost 30%.

Table 5: Probit regression results for at least one adaptation to drought, crop pests and excessive rainfall

Probit regression Step 1: Applied at least one adaptation strategy	1A - Drought[1] Coef.	Std. Err.	Marginal Effect		1B - Crop pests[2] Coef.	Std. Err.	Marginal Effect		1C - Excessive rainfall Coef.	Std. Err.	Marginal Effect	
Shock frequency 2000 - 2010												
Drought	-0.070	0.029	-0.016	**	-0.043	0.040	-0.011		-0.112	0.042	-0.032	***
Crop pests	0.045	0.021	0.010	**	0.101	0.030	0.026	***	0.100	0.031	0.028	***
Excessive rainfall	0.014	0.044	0.003		-0.026	0.055	-0.007		0.028	0.056	0.008	
Socio-economic characteristics												
Poor (1 = 1st expenditure tertile)	0.063	0.163	0.014		0.250	0.220	0.062		0.192	0.266	0.053	
Food insecure (1 = shortage)	0.169	0.163	0.038		0.119	0.212	0.031		-0.214	0.265	-0.059	
Female-headed (1 = yes)	0.192	0.203	0.040		0.085	0.246	0.022		0.655	0.353	0.153	*
Education (years of schooling)	-0.042	0.022	-0.009	*	0.023	0.027	0.006		-0.033	0.038	-0.009	
Age (years)	0.001	0.005	0.000		0.010	0.007	0.003		-0.005	0.009	-0.001	
Household size (adult equivalents)	-0.034	0.036	-0.008		-0.079	0.045	-0.021	*	-0.023	0.055	-0.007	
Asset (1,000 Ksh)	0.000	0.000	0.000		0.000	0.000	0.000		0.000	0.000	0.000	
Off-farm income (1,000 Ksh)	0.000	0.000	0.000		0.000	0.000	0.000		0.000	0.000	0.000	
Extension contact (1 = yes)	0.222	0.141	0.050		0.196	0.180	0.051		0.410	0.221	0.119	*
Association (number)	0.190	0.087	0.043	**	0.108	0.105	0.028		0.001	0.135	0.000	
Credit access (1 = yes)	0.226	0.146	0.050		-0.355	0.181	-0.093	**	0.084	0.237	0.024	
Market distance (km)	0.003	0.013	0.001		0.043	0.022	0.011	*	-0.010	0.021	-0.003	
Farm management												
Farm size (ha)	-0.120	0.073	-0.027	*	-0.264	0.107	-0.069	**	-0.045	0.113	-0.013	
Share of flat plot (%)	-0.574	0.151	-0.129	***	-0.533	0.187	-0.138	***	-0.261	0.246	-0.074	
Area improved maize variety (ha)	-0.027	0.120	-0.006		0.418	0.194	0.109	**	-0.145	0.208	-0.041	
Livestock (TLU)	-0.004	0.029	-0.001		-0.035	0.042	-0.009		-0.022	0.052	-0.006	
Maize-legume intercrop (1 = yes)	0.262	0.196	0.062		0.072	0.235	0.019		0.809	0.351	0.268	**
Maize-legume rotation (1 = yes)	-0.168	0.209	-0.036		0.245	0.229	0.068		-0.127	0.335	-0.035	
Location												
Rainfall (Coefficient of variation)	-0.240	0.171	-0.054		0.410	0.212	0.107	*	0.212	0.241	0.060	
Temperature (°C)	-0.150	0.045	-0.034	***	-0.107	0.061	-0.028	*	-0.111	0.081	-0.031	
Constant	5.017	1.184			1.276	1.515			2.760	1.872		
obs. P	0.8280				0.7861				0.7443			
pred. P	0.8582				0.8226				0.7971			
N =	558				360				219			
LR chi2(37) =	70.03				75.43				48.38			
Prob > chi2 =	0.0000				0.0000				0.0015			
Pseudo R2 =	0.1367				0.2018				0.1943			
Log likelihood =	-221.171				-149.147				-100.314			

[1] 1 failure and 0 successes completely determined. [2] 1 failure and 1 successes completely determined.
* significant at 10% level, ** significant at 5% level, *** significant at 1% level

5.3 Multivariate probit estimation: Choice of adaptation strategy

In the second stage of the adaptation decision, frequent experiences of the present shock as well as other shocks, and socioeconomic, farm management and location factors show various direction and intensity of influences on the choice of particular adaptation strategies for each type of shock. With regard to complementarity between adaptation strategies for drought, the coefficient of error terms (rho) in multivariate probit regression show that among four common adaptation strategies, farm adjustment is found to be a substitution strategy for selling assets and borrowing, whereas consumption reduction is a substitution strategy for selling assets but is complementary to borrowing (Table 6). Among shock variables, results show an unexpected significant negative relationship between experience of drought and consumption reduction as an adaptation strategy to drought. Furthermore, experience with crop pests is found to support consumption reduction while discouraging farm adjustment and borrowing. On the other hand, experience with excessive rainfall is found to support farm adjustment but discourage consumption reduction.

As hypothesized, farm adjustment as the most frequently-used adaptation strategy for drought is supported by an incremental increase in wealth as measured by household assets, contact with extension (7.5%) and number of associations (5%), credit access (12%), proportion of steep plot (11%), and adoption of improved maize varieties (8%). High rainfall variation and temperature also increase the probability of farm adjustment for drought adaptation by 8.5% and 5.5% respectively. However, farm adjustment is less likely for households with a large farm and livestock holding. Households with a large proportion of flat farm land and no credit access are more inclined to sell assets, especially if they have a large livestock holding and live far away from market. Selling assets is also found to be negatively related to temperature. As expected, food-insecure households are almost 10% more likely to reduce consumption than food-secure households although, surprisingly, non-poor households are also more likely to do the same when compared to households in the 1st tertile. The probability of reducing consumption increases with household size, following the hypothesis that consumption per member in a large household would be reduced when facing a decline in food production and income.Share of flat plot also shows significant influence on consumption reduction and borrowing. Rainfall variation and temperature are found to have a negative influence on consumption reduction. Poor households with no credit access are almost 10% more likely to borrow than the non-poor and those households who can access credit. In addition, households who do not intercrop maize with legumes are more likely to seek a loan than households who practice maize-legume intercropping.

With respect to adaptation to crop pests, the coefficients of error terms in multivariate probit regression show that farm adjustment is a substitution strategy for selling assets and reducing consumption, while selling assets is a complementary strategy for borrowing but a substitution strategy for seeking treatment, which is in turn a substitution strategy for borrowing (Table 7). Experience with crop pests significantly reduces the likelihood of asset selling and treatment seeking. Frequent experience with drought, on the other hand, encourages farm adjustment as an adaptation

strategy for crop pests. The influence of previous experience with excessive rainfall varies across strategies for crop pests, i.e. it reduces the likelihood of selling assets and borrowing but it increases the probability of seeking treatment.

As expected, farm adjustment to adapt to crop pests is more likely for households with older heads and more assets living in areas with big variation in rainfall and high temperatures, but this most common strategy is less likely for households with no credit access.

A similar inverse influence is found for the variable for maize-legume intercropping. Selling assets to adapt to crop pests is almost 15% more likely for households with female heads than for those with male heads, especially if they have a large household, earn additional off-farm income, and practice maize-legume rotation in a low-temperature area. Furthermore, borrowing is 12% more favoured by food-insecure households than by food-secure households. Similar to selling assets, off-farm income is found to have a positive relationship with borrowing. Households with a large area of flat land and low rainfall variation are 11% and 24% more inclined to borrow than those with steep plots and a high rainfall variation, respectively. Seeking treatment for crop pests is more likely for small households and for farms that have already adopted an improved maize variety. Seeking treatment to eradicate crop pests is also more likely for households living in areas with small variation in rainfall and low temperatures.

Poverty and food insecurity are shown to have a significant influence on implementing farm adjustment as the single dominant adaptation strategy for excessive rainfall (Table 8). Standard probit regression shows that the likelihood of farm adjustment is 7% higher for households in the 1st tertile than for households in the upper tertiles, and 6% higher for food-insecure households than for food-secure households. Age of household head, assets, off-farm income and membership of associations also significantly increase the probability of farm adjustment for adapting to excessive rainfall.

Table 6: Multivariate probit regression results for specific adaptation strategies for drought

Multivariate Probit regression Step 2A: Applied specific adaptation strategy for **drought**	Farm adjustment				Sell assets				Reduce consumption				Borrow			
	Coef.	Std.Err.	Marginal Effect		Coef.	Std.Err.	Marginal Effect		Coef.	Std.Err.	Marginal Effect		Coef.	Std.Err.	Marginal Effect	
Shock frequency 2000 - 2010																
Drought	0.010	0.050	0.002		0.020	0.034	0.004		-0.140	0.053	-0.030	***	0.051	0.037	0.011	
Crop pests	-0.066	0.026	-0.014	**	-0.027	0.024	-0.006		0.043	0.026	0.009	*	-0.078	0.028	-0.017	***
Excessive rainfall	0.225	0.078	0.048	***	-0.031	0.053	-0.006		-0.338	0.090	-0.071	***	-0.088	0.067	-0.019	
Socio-economic characteristics																
Poor (1 = 1st expenditure tertile)	0.232	0.190	0.049		-0.154	0.161	-0.033		-0.562	0.192	-0.119	***	-0.401	0.181	-0.085	**
Food insecure (1 = food shortage)	0.066	0.181	0.014		-0.205	0.155	-0.043		0.384	0.177	0.081	**	0.070	0.171	0.015	
Female-headed (1 = yes)	-0.129	0.215	-0.027		-0.158	0.184	-0.033		0.066	0.210	0.014		0.102	0.200	0.022	
Education (years of schooling)	0.005	0.024	0.001		-0.002	0.020	0.000		0.000	0.024	0.000		-0.035	0.023	-0.007	
Age (years)	0.006	0.006	0.001		-0.003	0.005	-0.001		0.009	0.006	0.002		0.001	0.006	0.000	
Household size (adult equivalents)	-0.015	0.046	-0.003		-0.020	0.038	-0.004		0.083	0.045	0.018	*	0.007	0.044	0.001	
Asset (1,000 Ksh)	0.000	0.000	0.000	*	0.000	0.000	0.000		0.000	0.000	0.000		0.000	0.000	0.000	
Off-farm income (1,000 Ksh)	0.000	0.000	0.000		0.000	0.000	0.000		0.000	0.000	0.000		0.000	0.000	0.000	
Extension contact (1 = yes)	0.353	0.154	0.075	**	-0.120	0.134	-0.025		-0.124	0.154	-0.026		-0.008	0.148	-0.002	
Association (number)	0.230	0.092	0.049	**	-0.007	0.076	-0.001		-0.050	0.090	-0.011		0.011	0.088	0.002	
Credit access (1 = yes)	0.547	0.164	0.116	***	-0.325	0.141	-0.069	*	-0.131	0.160	-0.028		-0.386	0.154	-0.081	**
Market distance (km)	-0.013	0.010	-0.003		0.032	0.014	0.007	**	-0.011	0.017	-0.002		0.011	0.009	0.002	
Farm management																
Farm size (ha)	-0.194	0.102	-0.041	*	-0.022	0.093	-0.005		-0.007	0.099	-0.001		-0.111	0.104	-0.023	
Share of flat plot (%)	-0.517	0.168	-0.109	***	0.340	0.146	0.072	**	0.456	0.168	0.096	***	0.426	0.160	0.090	***
Area improved maize variety (ha)	0.400	0.178	0.084	**	0.105	0.113	0.022		-0.206	0.173	-0.044		0.166	0.134	0.035	
Livestock (TLU)	-0.067	0.037	-0.014	*	0.050	0.028	0.011	*	-0.062	0.041	-0.013		-0.011	0.034	-0.002	
Maize-legume intercrop (1 = yes)	0.261	0.184	0.055		-0.001	0.166	0.000		-0.132	0.196	-0.028		-0.566	0.193	-0.120	***
Maize-legume rotation (1 = yes)	0.165	0.204	0.035		-0.220	0.179	-0.046		-0.022	0.213	-0.005		-0.007	0.204	-0.001	
Location																
Rainfall (Coefficient of variation)	0.401	0.211	0.085	*	0.248	0.187	0.052		-1.114	0.213	-0.235	***	-0.161	0.204	-0.034	
Temperature (°C)	0.259	0.063	0.055	***	-0.148	0.047	-0.031	***	-0.215	0.056	-0.046	***	0.025	0.051	0.005	
Constant	-6.388	1.636		***	2.315	1.260		*	6.497	1.544		***	-0.282	1.392		

/atrho21	-0.966	0.145	***	rho21	-0.747	0.064	***	Log likelihood	=	-730.45
/atrho31	-0.010	0.123		rho31	-0.010	0.123		Number of obs	=	462
/atrho41	-0.382	0.115	***	rho41	-0.364	0.100	***	Wald chi2(128)	=	243.56
/atrho32	-0.388	0.106	***	rho32	-0.370	0.092	***	Prob > chi2	=	0.0000
/atrho42	0.043	0.097		rho42	0.043	0.097		# draws	=	58
/atrho43	0.576	0.120	***	rho43	0.520	0.088	***			

Likelihood ratio test of rho21 = rho31 = rho41 = rho32 = rho42 = rho43 = 0: chi2(6) = 121.655. Prob > chi2 = 0.0000. ***, ** and * significant at 1%, 5% and 10% respectively.

Table 7: Multivariate probit regression results for specific adaptation strategies for crop pests

Multivariate Probit regression / Step 2B: Applied specific adaptation strategy for crop pests	Farm adjustment Coef.	Std.Err.	Marginal Effect		Sell assets Coef.	Std.Err.	Marginal Effect		Borrow Coef.	Std.Err.	Marginal Effect		Seek treatment Coef.	Std.Err.	Marginal Effect	
Shock frequency 2000 - 2010																
Drought	0.132	0.067	0.028	**	-0.018	0.069	-0.004		-0.167	0.116	-0.036		0.069	0.060	0.015	
Crop pests	0.033	0.042	0.007		-0.215	0.055	-0.046	***	0.067	0.059	0.015		-0.105	0.040	-0.023	***
Excessive rainfall	-0.123	0.100	-0.027		-0.461	0.168	-0.099	***	-0.332	0.139	-0.071	**	0.211	0.081	0.045	***
Socioeconomic characteristics																
Poor (1 = 1st expenditure tertile)	0.2117	0.241	0.046		-0.248	0.237	-0.053		0.009	0.330	0.002		-0.305	0.224	-0.066	
Food insecure (1 = food shortage)	-0.096	0.247	-0.021		-0.268	0.239	-0.058		0.563	0.319	0.121	*	-0.246	0.226	-0.053	
Female-headed (1 = yes)	-0.158	0.291	-0.034		0.687	0.276	0.148	**	-0.470	0.395	-0.101		-0.249	0.272	-0.054	
Education (years of schooling)	0.038	0.032	0.008		0.025	0.030	0.005		-0.071	0.046	-0.015		0.026	0.030	0.006	
Age (years)	0.013	0.008	0.003	*	-0.004	0.008	-0.001		0.006	0.011	0.001		0.010	0.008	0.002	
Household size (adult equivalents)	-0.018	0.065	-0.004		0.220	0.065	0.047	***	-0.040	0.077	-0.009		-0.141	0.060	-0.030	**
Asset (1,000 Ksh)	0.000	0.000	0.000	**	0.000	0.000	0.000		0.000	0.000	0.000		0.000	0.000	0.000	
Off-farm income (1,000 Ksh)	0.000	0.000	0.000		0.000	0.000	0.000	*	0.000	0.000	0.000	*	0.000	0.000	0.000	
Extension contact (1 = yes)	0.094	0.218	0.020		0.181	0.209	0.039		0.317	0.301	0.068		0.314	0.201	0.068	
Association (number)	0.063	0.127	0.014		-0.075	0.134	-0.016		-0.127	0.216	-0.027		0.044	0.114	0.009	
Credit access (1 = yes)	-0.393	0.233	-0.085	*	-0.119	0.213	-0.026		-0.065	0.318	-0.014		0.103	0.230	0.022	
Market distance (km)	0.001	0.012	0.000		0.010	0.015	0.002		-0.001	0.019	0.000		-0.028	0.024	-0.006	
Farm management																
Farm size (ha)	-0.073	0.162	-0.016		0.145	0.150	0.031		-0.080	0.163	-0.017		-0.231	0.133	-0.050	*
Share of flat plot (%)	0.074	0.222	0.016		-0.292	0.214	-0.063		0.510	0.289	0.110	*	-0.244	0.199	-0.053	
Area improved maize variety (ha)	0.301	0.225	0.065		-0.229	0.193	-0.049		0.109	0.240	0.023		0.343	0.183	0.074	*
Livestock (TLU)	0.028	0.064	0.006		0.069	0.057	0.015		0.033	0.064	0.007		0.031	0.063	0.007	
Maize-legume intercrop (1 = yes)	-0.371	0.231	-0.080	*	0.101	0.245	0.022		0.181	0.413	0.039		-0.146	0.228	-0.031	
Maize-legume rotation (1 = yes)	-0.369	0.266	-0.080		0.758	0.295	0.163	**	0.407	0.491	0.088		-0.054	0.247	-0.012	
Location																
Rainfall (Coefficient of variation)	2.893	0.375	0.623	***	-0.301	0.358	-0.065		-1.125	0.423	-0.242	***	-1.419	0.326	-0.306	***
Temperature (°C)	0.604	0.096	0.130	***	-0.262	0.084	-0.056	***	0.092	0.084	0.020		-0.338	0.098	-0.073	***
Constant	-20.363	2.583		***	4.651	2.285		**	-0.295	2.433			10.134	2.488		***

/atrho21	-0.805	0.191	***	rho21	-0.667	0.106	***	Log likelihood	=	-369.88
/atrho31	-0.469	0.262	*	rho31	-0.438	0.211	**	Number of obs	=	280
/atrho41	-0.107	0.137		rho41	-0.107	0.136		Wald chi2(128)	=	221.98
/atrho32	0.431	0.230	*	rho32	0.406	0.192	**	Prob > chi2	=	0.0000
/atrho42	-0.455	0.147	***	rho42	-0.426	0.120	***	# draws	=	13
/atrho43	-0.475	0.223	**	rho43	-0.442	0.179	**			

Likelihood ratio test of rho21 = rho31 = rho41 = rho32 = rho42 = rho43 = 0: chi2(6) = 62.9914. Prob > chi2 = 0.0000. ***, ** and * significant at 1%, 5% and 10% respectively.

Table 8: Standard probit regression results for farm adjustment as a dominant adaptation strategy for excessive rainfall

Probit regression - Excessive rainfall	Farm adjustment			
	Coef.	Std.Err.	Marginal Effect	
Shock frequency 2000 - 2010				
Drought	0.169	0.15	0.010	
Crop pests	0.028	0.05	0.002	
Excessive rainfall	0.163	0.16	0.010	
Socioeconomic characteristics				
Poor (1 = 1st expenditure tertile)	1.618	0.61	0.074	***
Food insecure (1 = food shortage)	-1.041	0.48	-0.061	**
Female-headed (1 = yes)	-0.374	0.48	-0.027	
Education (years of schooling)	-0.083	0.07	-0.005	
Age (years)	0.038	0.02	0.002	**
Household size (adult equivalents)	-0.084	0.11	-0.005	
Asset (1,000 Ksh)	0.000	0.00	0.000	*
Off-farm income (1,000 Ksh)	0.000	0.00	0.000	*
Extension contact (1 = yes)	-0.453	0.37	-0.024	
Association (number)	0.446	0.25	0.026	*
Credit access (1 = yes)	-0.026	0.42	-0.002	
Market distance (km)	-0.007	0.05	0.000	
Farm management				
Farm size (ha)	-0.017	0.22	-0.001	
Share of flat plot (%)	0.127	0.40	0.007	
Area improved maize variety (ha)	-0.361	0.35	-0.021	
Livestock (TLU)	0.139	0.12	0.008	
Maize-legume intercrop (1 = yes)	-0.113	0.58	-0.006	
Maize-legume rotation (1 = yes)	0.002	0.58	0.000	
Location				
Rainfall (Coefficient of variation)	0.306	0.40	0.018	
Temperature (°C)	0.177	0.14	0.010	
Constant	-4.558	3.59		
obs. P	0.8712			
pred. P	0.9747			
N =	163			
LR chi2(37) =	43.86			
Prob > chi2 =	0.0055			
Pseudo R2 =	0.3502			
Log likelihood =	-40.69			

Note: 0 failures and 3 successes completely determined

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

6. Conclusions

Adaptation to climate shocks is essential to building the resilience of small-scale farm households and to supporting sustainable intensification of agricultural production for food security of the poor. Over the 10-year period between 2000 and 2010, almost all of 613 surveyed maize-legume farm households in Western and Eastern Kenya reported drought as the most frequent and severe climate shock on farm production, followed by crop pests and excessive rainfall. Drought, which on average occurred almost three times during the 10-year period, had the most severe effect on food crop production and income when compared to crop pests and excessive rainfall. Based on farmers' assessment, poor households with per capita expenditure in the lowest tertile were affected by drought, crop pests and excessive rainfall less frequently than households in the upper tertiles. With regard to food security, the effect of drought as measured in food production and income reduction is more severe for food-secure households than for their food-insecure counterparts, although the effect of crop pests on income is more severe for food-insecure households. Concerning gender, the adverse effect of crop pests on food production and income is found to be more severe for male-headed than for female-headed households. These results are contrary to what might have been expected and should be treated with caution. One possible explanation may be related to the potential effect of having a large asset endowment and a large-scale farm production, which makes the upper tertiles and food-secure households especially susceptible to climate shocks.

A farm household's adaptation to climate shock follows a two-step decision-making process. As a response to the reduction in food production and income, a shock-affected household will first decide whether or not to undertake any adaptation action, before choosing a particular adaptation strategy from among the available options. Almost 90% of shock-affected farmers implemented at least one adaptation strategy, and most households reported having adapted to drought, with fewer reporting having adapted to crop pests and excessive rainfall. In the first step, probit regression results show the significant influence of previous frequent experience of drought on reducing the likelihood of adapting to drought itself and to excessive rainfall, while previous frequent experience of crop pests significantly increases the likelihood of adaptation to all three types of shock. Although poverty and food insecurity are not found to have a significant influence on the decision to adapt for any shock, female-headed households are statistically 15% more inclined to adapt to excessive rainfall than male-headed households. The role of information through extension and membership of associations is found to increase the probability of deciding to adapt to drought and excessive rainfall. Deciding to adapt to drought and crop pests is found to be more likely with an area of steep land on the farm, but less likely with increasing farm size. Current exposure to new technology is also found to influence the adaptation decision, as the adoption of improved maize varieties encourages adaptation to crop pests, and maize-legume intercropping encourages adaptation to excessive rainfall. However, education shows a negative influence on adaptation to drought, while household size and credit access show a negative influence on adaptation to crop pests. Distance to the main market and high rainfall variation show a significant positive effect on the probability to

adapt to crop pests. High temperature, on the other hand, tends to reduce the probability of adapting to drought and crop pests.

In the second step, results from multivariate probit regression identify complementarity and substitutability between adaptation strategies. Among four common strategies for coping with drought, farm adjustment (e.g. use of improved seed varieties with early maturity and tolerance to stress, replanting, use of external inputs, conservation agricultural practices, and crop diversification) is found to be a substitution strategy for selling assets and borrowing. Reducing consumption is found to be a substitution strategy for selling assets, but to be complementary to borrowing for adapting to drought. To adapt to crop pests, results show farm adjustment to be a substitution strategy for selling assets and reducing consumption. However, selling assets is a complementary strategy for borrowing, but is a substitution strategy for seeking treatment, which in turn, is a substitution strategy for borrowing. On the other hand, farm adjustment appears to be the single dominant strategy for adapting to excessive rainfall. Regression results from all three types of shock further highlight the reinforcing influence between different types of shocks for households that experienced not only one type of shock several times, but also multiple types of shock during the same period. The impact of a current shock may be aggravated by the impact of other shocks previously experienced. As shown from adaptation to drought, for example, frequent experience of crop pests is found to support reducing consumption while discouraging farm adjustment and borrowing, while frequent experience of excessive rainfall is found to support farm adjustment but discourage consumption reduction. Frequent experience of drought, on the other hand, encourages farm adjustment as a coping strategy for crop pests, while frequent experience of excessive rainfall reduces the likelihood of selling assets and borrowing, but increases the probability of seeking treatment to adapt to crop pests.

The sampled households in the poorest tertile are less likely to reduce consumption and to borrow as adaption strategies for drought, but they are more likely to adjust farm management to cope with excessive rainfall. Facing food and income reduction due to shocks, food-insecure households are more inclined to eat less to adapt to drought, and they are more inclined to borrow to cope with crop pests, but they are less likely to adjust farm management to adapt to excessive rainfall. Although there is no significant influence of gender on choice of adaptation strategy for drought and excessive rainfall, female-headed households are found to be 15% more likely to sell assets than male-headed households to adapt to crop pests. Other socioeconomic variables, particularly household size, asset ownership, off-farm income, membership of associations, contact with extension, and credit access, have diverse influences on the choice of adaptation strategies In terms of farm management variables, a small farm size encourages farm adjustment for adapting to drought, and seeking treatment for coping with crop pests. Having a large area of steep land on the plot is found to support adjustment in farm management to adapt to drought, but selling assets, reducing consumption and borrowing are more favoured by households with a large proportion of flat land. Exposure to improved maize varieties and having a small livestock holding further support farm adjustment for drought adaptation, while households with a large livestock holding are more

likely to sell the animals to adapt to drought. Households living in an area with big variation in rainfall variation and high temperatures are more likely to adjust farm management as an adaptation strategy for drought. On the other hand, households living in cooler areas are more likely to sell assets in order to adapt to drought and crop pests, whereas seeking treatment to eradicate crop pests is more likely for farm households in dry and cold areas.

7. Policy implications

Understanding that rural maize-legume farmers are frequently faced with climate shocks on farm production, and how they make decisions to adapt to these, are the first step in formulating policies directed at providing effective assistance. This study highlights the significant interdependency of shock types, and the reinforcing influence of frequency of other shock types on adapting for and choosing a strategy for a particular shock in both stages of adaptation decision-making. Therefore an effective policy to support adaptation should not promote adapting for any particular shock in isolation, but should incorporate the context and composite implication of other shocks. Climate change adaptation research and policy discussion should also recognize that a certain adaptation strategy can be applied for different types of shocks. For example, adjustment of farm technology and practices can be promoted for drought, crop pests and excessive rainfall. However, as farmers may choose to apply multiple adaptation strategies, it is important to take into account the complementarity and substitutability between different types of adaptation strategies. Moreover, assistance should target households belonging to the lower expenditure group who experience food shortages, and those led by female heads who are often disadvantaged in terms of asset endowment and access to technology and information necessary for adaptation.

For rural farm households, each available adaptation strategy for coping with climate shocks requires different preconditions and imposes different consequences. Adjusting farm technology and practices requires farmers to acquire information and capital in order to invest in improved seeds, inputs, implements and labour. Compared to other strategies, farm adjustment is considered long-term, as it requires a complete planting cycle before the yield can be harvested. In contrast, selling assets is considered short-term but unsustainable, as it directly depletes a household's accumulation of assets, and reduces a household's ability to adapt in the future. It also requires favourable market access and conditions, which remain a challenge for many rural households in remote areas.

Borrowing implies committing assets or future earnings for loan eligibility. This strategy is feasible for households who have a large asset ownership, high social status and access to credit channels. Alternatively, households may change their usual diet and search for substitutes which are cheaper and easier to find, but may not satisfy their preferences and nutritional requirements. This strategy is considered the most drastic, and has a substantial chronic effect on the functionality and growth of all household members, and especially of women and children. For households with few or no assets to invest in new farm technology and practices, the only viable options for coping with decreased food-crop production and lower income are borrowing, selling assets and eating fewer or less nutritious meals per day.

To prevent consumption reduction, public programs can be set up to enhance the adaptive capacity of the poor and the food-insecure in drought-prone areas by giving support for on-farm technology and providing training, provision of farm inputs, and access to credit. To cushion consumption reduction caused by drought, food aid can be arranged targeting especially the poor and the food-

insecure. Seeking treatment to eradicate crop pests requires access to services and accurate information, while taking into account the potential consequences for neighbouring areas as well as for the ecology and environment. It is important that households receive correct diagnoses and recommendations for their particular farm, and extension service should target female-headed households to discourage them from selling off productive assets and livestock.

This paper provides a first step in demonstrating the current relevance of climate shocks faced by rural maize-legume farming households in Kenya, and in showing possible adaptation options, especially for poor, food-insecure and female-headed households. This study focuses on farm household decision-making, and regards finance, insurance, labour and output markets as outside its scope. With the available cross-sectional dataset, it is not possible to observe long-term climate change adaptation behaviour or to differentiate clearly between *ex-ante* as opposed to *ex-post* adaptation for a shock incident. Consequently, additional research with panel data is needed to evaluate the effectiveness of each adaptation strategy on a household's income and food security over time. In particular, a more detailed analysis should examine a wide range of options for implementing farm adjustment of technology and management practices as an adaptation strategy, in order to identify factors affecting decision-making, and to assess the effectiveness of possible strategy combinations for rural maize-legume farm households.

References

ACDI/VOCA (2007). Kenya Maize Handbook. ACDI/VOCA – Kenya Training Manual No. 27

Adger, W.N., Arnell, N.W. and Tompkins, E.L. (2005). Successful adaptation to climate change across scales. *Global Environmental Change* 15: 77-86.

Asfaw, A. and Admassie, A. (2004). The role of household member's education on the adoption of agricultural inputs under different environments in Ethiopia. *Agricultural Economics* 30(3): 215-228.

Bebber, D.P., Ramotowski, M.A.T. and Gurr, S.J. (2013). Crop pests and pathogens move polewards in a warming world. *Nature Climate Change* 3: 985-988.

Cappellari, L. and Jenkins, S.P. (2003). Multivariate probit regression using simulated maximum likelihood. *The Stata Journal* 3(3): 278-294.

Cavatassi, R., Lipper, L. and Narloch, U. (2011). Modern variety adoption and risk management in drought prone areas: insights from the sorghum farmers of eastern Ethiopia. *Agricultural Economics* 42: 279-292.

CIMMYT (2013). Maize lethal necrosis (MLN) disease in Kenya and Tanzania: Facts and actions. http://www.cimmyt.org/en/where-we-work/africa/item/maize-lethal-necrosis-mln-disease-in-kenya-and-tanzania-facts-and-actions (accessed on 31st May 2013)

Claessens, L., Antle, J.M., Stoorvogel, J.J., Valdivia, R.O., Thornton, P.K. and Herrero, M. (2012). A method for evaluating climate change adaptation strategies for small-scale farmers using survey, experimental and modeled data. *Agricultural Systems* 111: 85-95.

Cooper, P.J.M., Dimes, J., Rao, K., Shapiro, B. and Twomlow, S. (2008). Coping better with current climatic variability in the rain-fed farming systems of Sub-Saharan Africa: An essential first step in adapting to future climate change? *Agriculture, Ecosystem and Environment* 126: 24-35.

Cutter, S.L., B.J. Boruff and Shirley W.L. (2003). Social vulnerability to environmental hazards. *Social Science Quarterly* 84: 242-261.

Dercon, S. (1998). Wealth, risk and activity choice: Cattle in Western Tanzania. *Journal of Development Economics* 55(1): 1-42.

Dercon S. (2007). Fate and fear: Risk and its consequences in Africa. Oxford: Oxford University. Paper prepared for the African Economic Research Consortium.

Deressa, T.T., Hassan, R.M., Alemu, T., Yesuf, M. and Ringler, C. (2009). Analyzing the determinants of farmers' choice of adaptation methods and perceptions of climate change in the Nile Basin of Ethiopia. IFPRI Discussion Paper 798. Washington, DC., 36 pp.

Di Falco, S. and Veronesi, M. (2012). How African agriculture can adapt to climate change? A counterfactual analysis from Ethiopia. Department of Economics, University of Verona. Working Paper Series 14.

Fankhauser, S., Smith, J., and Tol, R. (1999). Weathering climate change: Some simple rules to guide adaptation decisions. *Ecological Economics* 30: 67-78.

FAO (2013). Crop water information: Maize. Water Development and Management Unit. http://www.fao.org/nr/water/cropinfo_maize.html (accessed on 24th April 2013)

FAO (2011). The State of Food and Agriculture 2010-2011. Women in Agriculture, Closing the gender gap for development. FAO Rome

Geweke, J., Keane, M., and Runkle, D. (1997). Statistical inference in the multinomial multiperiod probit model. *Journal of Econometrics* 80:125-165.

Glewwe, P. and Gillette, H. (1998). Are some groups more vulnerable to macroeconomic shocks than others? Hypothesis tests based on panel data from Peru. *Journal of Development Economics* 56(1): 181-206.

G.O.K (2005a). Government of Kenya - Siaya District Strategic Plan 2005-2010 for Implementation of the National Population Policy for Sustainable Development.

G.O.K (2005b). Government of Kenya - Bungoma District Strategic Plan 2005-2010 for Implementation of the National Population Policy for Sustainable Development

G.O.K (2007). Government of Kenya - District Environmental Action Plan 2006-2011 Meru South District.

G.O.K (2009). Government of Kenya - Embu District Environmental Action Plan 2009-2013. Republic of Kenya, Ministry of Environment and mineral resources.

Greene, W. H. (2011). *Econometric Analysis*. New Jersey: Prentice Hall, 7th Ed.

Hajivassiliou, V., McFadden, D. and Ruud, P. (1996). Simulation of multivariate normal rectangle probabilities and their derivatives: Theoretical and computational results. *Journal of Econometrics* 72: 85-134.

Hardaker, J.B., Huirne, R.B.M. and Anderson, J.R. (1997). *Coping with Risk in Agriculture*. CAB International, Wallingford Oxon, UK.

Igoden, C., Ohoji, P. and Ekpare, J. (1990). Factors associated with the adoption of recommended practices for maize production in the Lake Basin of Nigeria. *Agricultural Administration and Extension* 29 (2): 149-156.

IPCC (2007). Climate Change 2007: Synthesis report.

Jalan, J. and Ravallion, M. (1999). Are the poor less well insured? Evidence on vulnerability to income risk in rural China. *Journal of Development Economics* 58(1): 61-81.

KIHBS (2006). District Poverty Data Kenya Integrated Household Budget Survey (2005/2006)

Kirimi, L., Sitko, N., Jayne, T.S., Karin, F., Milu, M., Sheahan, M., Flock, J. and Bor, G. (2011). A farm gate-to-consumer value chain analysis of Kenya's maize marketing system. Tegemeo Institute of Agricultural Policy and Development Working Paper No. 44.

Kochar, A. (1999). Smoothing consumption by smoothing income: Hours-of-work responses to idiosyncratic agricultural shocks in rural India. *The Review of Economics and Statistics* 81(1): 50-61.

KNBS (2013). Kenya National Bureau of Statistics

Kristjanson, P., Neufeldt, H., Gassner, A., Mango, J., Kyazze, F.B., Desta, S., Sayula, G., Thiede, B., Förch, W., Thornton, P.K. and Coe, R. (2012). Are food insecure smallholder households making changes in their farming practices? Evidence from East Africa. *Food Security* 4(3): 318-397

Lin, J. (1991). Education and innovation adoption in agriculture: Evidence from hybrid rice in China. *American Journal of Agricultural Economics* 73 (3): 713-723

MacFadden, D. (1981). Econometric Models of Probabilistic Choice. In Manski, C. and McFadden, D. (eds), *Structural Analysis of Discrete Data with Econometric Applications*. Cambridge, MA: MIT Press, 198-272.

Maddison, D. (2007). The perception of and adaptation to climate change in Africa. World Bank Policy Research Working Paper 4308. The World Bank, Washington, DC.

Mendelsohn, R. (2012). The economics of adaptation to climate change in developing countries. *Climate Change Economics,* 3:125006: 1-21.

Mercer, K.L., Perales, H.R., Wainwright, J.D. (2012). Climate change and the transgenic adaptation strategy: Smallholder livelihoods, climate justice, and maize landraces in Mexico. *Global Environmental Change* 22: 495-504

M.O.A (2006). Ministry of Agriculture- Farm management handbook of Kenya (Volume 2). Natural conditions and farm Management information 2nd Edition.

Nhemachena, C. and Hassan, R. (2007). Micro-level analysis of farmers' adaptation to climate in Southern Africa. IFPRI Discussion Paper 714. Washington, D.C., 30 pp.

Newhouse, D.L. (2005). The persistence of income shocks: Evidence from rural Indonesia. *Review of Development Economics* 9(3): 415-433.

Norris, E. and Batie, S. (1987). Virginia farmers' soil conservation decisions: an application of Tobit analysis. *Southern Journal of Agricultural Economics* 19(1): 89–97.

Nyoro J, Ayieko M and Muyanga M. (2007). The Compatibility of Trade Policy with Domestic Policy Interventions Affecting the Grains Sector in Kenya. Tegemeo Institute, Egerton University.

Osbahr, H., Twyman, C., Adger, N. and Thomas, D.S.G. (2008). Effective livelihood adaptation to climate change disturbance: Scale dimensions of practice in Mozambique. *Geoforum* 39: 1951-1964.

Pingali, P.L. (ed.) (2001). *CIMMYT 1999–2000 World Maize Facts and Trends. Meeting World Maize Needs: Technological Opportunities and Priorities for the Public Sector*. Mexico: CIMMYT

Rashid, D.A., Langworthy, M. and Aradhyula, S. (2006). Livelihood shocks and coping strategies: An empirical study of Bangladesh households. Paper prepared for presentation at the American Agricultural Economics Association Annual Meeting, Long Beach, California, 23-26 July, 2006

Roncoli, C., Ingram, K. and Kirshen, P. (2001). The costs and risks of coping with drought: Livelihood impacts and farmer's responses in Burkina Faso. *Climate Research.* 19: 119-132.

Rosenzweig, C., Iglesius, A., Yang, X. B., Epstein, P.R. and Chivian, E. (2001). Climate change and extreme weather events - Implications for food production, plant diseases, and pests. NASA Publications. Paper 24.

Silvestri, S., Bryan, E., Ringler, C., Herrero, M. and Okoba, B. (2012). Climate change perception and adaptation of agro-pastoral communities in Kenya. *Regional Environmental Change* 12(4): 791-802.

Smit B., and M.W. Skinner. (2002). Adaptations options in agriculture to climate change: A typology. *Mitigation and Adaptation Strategies for Global Change* 7(1): 85-114.

Smith, J. and Lenhart, S. (1996). Climate change adaptation policy options. *Climate Research* 6: 193-201.

Smithers, J. and Smit, B. (1997). Human adaptation to climate variability and change. *Global Environmental Change* 7(3): 129-146.

Stern, N. (2007). *The Economics of Climate Change: The Stern Review.* Cambridge University Press.

Tadesse, M., and Brans, M. (2012). Risk coping mechanisms and factors affecting demand for micro-insurance in Ethiopia. *Journal of Economics & International Finance* 4(4): 79-91.

Takasaki, Y., Barham B.L. and Coomes O.T. (2002). Risk coping strategies in tropical forests: Flood, health, asset poverty, and natural resource extraction. Paper prepared for the 2nd World Congress of Environmental and Resource Economists, 23-27 June 2002, Monterey, California.

Thompson, H.E., Berrang-Ford, L. and Ford, J.D. (2010). Climate change and food security in Sub-Saharan Africa: A systematic literature review. *Sustainability* 2: 2719-2733.

Thornton, P.K., Jones, P.G., Owiyo, T., Kruska, R.L., Herrero, M., Orindi, V., Bhadwal, S., Kristjanson, P., Notenbaert, A., Bekele, N. and Omolo, A. (2008). Climate change and poverty in Africa: Mapping hotspots of vulnerability. *African Journal of Agricultural and Resource Economics* 2(1): 24-44.

Tol, R., Fankhauser, S., and Smith, J. (1998). The scope for adaptation to climate change: What can we learn from the impact literature? *Global Environmental Change* 8: 109-123.

Tongruksawattana, S., Junge, V., Waibel, H., Revilla Diez, J. and Schmidt, E. (2013). Ex-post coping strategies of rural households in Thailand and Vietnam. In Klasen, S. and Waibel, H. (eds), *Vulnerability to Poverty: Theory, Measurement, and Determinants.* Palgrave, 216-257.

UNFCCC (2007). Uniting on Climate. A Guide to the Climate Change Convention and the Kyoto Protocol.

USAID KMDP (2011). USAID Kenya Maize Development Program.

Waibel, H., Tongruksawattana, S. and Voelker, M. (2013). Voices of the poor on climate change in Thailand and Vietnam. In Ananta, A., Bauer, A. and Thant, M. (eds), *The Environments of the Poor in Southeast Asia, East Asia and the Pacific.* Asian Development Bank. ISEAS, 170-186.

WEMA (2012). Water Efficient Maize for Africa. Reducing Maize Insecurity in Kenya: the WEMA project Policy Brief.

Wooldridge, J. (2010) *Econometric Analysis of Cross Section and Panel Data.* The MIT Press: 2nd Ed.

World Bank (2010). World Development Report 2010: Development and Climate Change. Oxford University Press: Washington D.C. 2010.

World Development Indicators (2012). The World Bank.

Yohe, G. and Tol, R.S.J. (2002). Indicators for social and economic coping capacity – Moving toward a working definition of adaptive capacity. *Global Environmental Change* 12(1): 25-40.

Young, G., Valdez, E.A. and Kohn, R. (2009). Multivariate probit models for conditional claim-types. *Insurance: Mathematics and Economics* 44(2): 214-228.

Ziervogel, G., Cartwright, A., Tas, A., Adejuwon, J., Zermoglio, F., Shale, M., Smith, B. (2008). Climate change and adaptation in African agriculture. Report prepared for the Rockefeller Foundation by the Stockholm Environment Institute.