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We gratefully acknowledge the inputs of Abel Lufafa and the support provided by the World Bank through contract number 7154451, from March 2010 to November 2011.

Citation: Thornton P K, Rufino M C, Karanja S, Jones P G, Mutie I, Herrero M (2011). Genesis Reversed: Climate Change Impacts on Agriculture and Livelihoods in Mixed Crop-Livestock Systems of East Africa. Final report to the World Bank. International Livestock Research Institute (ILRI), Nairobi. 150 pp.

Summary

Climate-induced livelihood transitions in the agricultural systems of Africa are increasingly likely. There has been only limited study on what such transitions might look like, but it is clear that the implications could be profound in relation to social, environmental, economic and political effects at local and national levels. The work here was set up to test the hypothesis that sedentary farmers who currently keep livestock in transition zones that may become warmer and possibly drier in the future may ultimately be forced to increase their reliance on livestock vis-à-vis cropping in the future. We carried out fieldwork in 12 sites in Kenya, Tanzania and Uganda to understand how farming systems have been changing in the recent past. We then evaluated what the impacts of these changes, and further changes in the same direction, may be on household incomes and food security in the coming decades, using crop and household modelling. We found no direct evidence for the hypothesised extensification of agricultural production in the study sites. Indeed, the processes of farming systems evolution in East Africa are substantially conditioned by powerful socio-cultural processes, it appears. Household activities are highly dynamic, however. Human diets have changed considerably in the last 30-40 years, as cropping has been taken up by increasing numbers of households, even in highly marginal places. Maize predominates, but some householders are increasing their crop and diet diversity, particularly in the locations with higher annual rainfall, and are willing to try drought-tolerant crops. Food insecurity was common at all sites with an annual rainfall of 800 mm or less, and critical levels were seen at the sites with less than 700 mm of rainfall. Households were self-sufficient in securing adequate dietary energy from food production in seven of the 12 sites, all with rainfall higher than 800 mm. The sites with high food insecurity were also those in which a large proportion of households receive food aid several times each year. Adaptation strategies varied across sites, with householders wanting to diversify incomes through cropping at the low rainfall sites, and others wanting to intensify crop-livestock systems with a diversity of crops and intercrops. Opportunistic income generation is an important strategy, reflecting the flexibility that many households show in adapting to their environment. People are, however, starting to think of options for a future with fewer cropping options if it were to become substantially drier; across all 12 sites householders are already pursuing diversification: crops in the lower rainfall areas, and more livestock in the wetter areas. Model results indicate that climate

change may actually create opportunities for diversifying cropping in some places and allowing cropping to start and/or become more intensive where it is not currently possible. Other places are likely to see substantial reductions in crop yields. Considerable uncertainty remains concerning the likely changes in rainfall patterns and amounts in the East African region, however. Drought-tolerant crops are likely to be an important component of future farming systems. Although many householders have some knowledge about them, few cultivate them: millet, sorghum and cassava are grown at six, five and three sites only, respectively, and by few households. Households need extension support to successfully innovate in cropping, particularly in the locations where cropping is a relatively new activity. At the same time, reliance on maize for regional food security may be increasingly risky in view of its susceptibility to climate change impacts. Policy measures aimed at increasing the consumption of cassava, sorghum, millet and legumes such as pigeonpea could be highly beneficial for future food security in the region. The vulnerability of households in the drier locations is already high, and policies will be needed to support them with safety nets and via market and infrastructural development. Households in the wetter areas need improved ways of managing risk and increasing cropping diversity. A critical requirement is knowledge transfer concerning the growing and utilisation of unfamiliar and untraditional crops.

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1 Background and Rationale

The increases in food production necessary to feed the growing global human population will have to occur at the same time as the climate is changing and as climate variability increases. Potential impacts of climate change on agricultural production have been assessed in several modelling studies, using methods grounded in an understanding of both crop and climate science (e.g., the review by Challinor et al., 2009). The inherent complexity of the climate-crop system, together with fundamental limits to climate predictability, mean that predicted yield ranges for major crops depend strongly on the methods and models used (Challinor et al., 2007). However, as in the current climate, these broad trends are likely to mask local differences caused by spatial variability in climate. The regional distribution of hungry people will change, with particularly large negative effects in sub-Saharan Africa (SSA) due to the impact of declines in crop yields on both food availability and access (IPCC, 2007).

The actual impacts of climate change on agricultural systems that are experienced in developing countries will depend on location and adaptive capacity. But adapting to and coping with a changing climate are not infinitely plastic and there are places where it is likely that climate change will alter agro-ecological conditions to extents beyond the 'coping range', buffering capacity and viability of known adaptation measures. In such places, it may well be that livelihood options will have to change.

Jones and Thornton (2009) point to the possibility of one such climate-induced livelihood transition in the mixed crop-livestock rainfed arid-semiarid systems of Africa, altering the relative emphasis that agropastoralists currently place on the crop and livestock components of the farming system in favour of livestock. In these systems, cropping may become increasingly risky and marginal, perhaps leading to increased dependence on livestock keeping or increasing diversification into non-agricultural activities and migration to urban areas. Such areas may, to all intents and purposes, "flip" from a mixed system to a predominantly rangeland-based system: some 730,000 km^2 of SSA may be at risk of such flipping, of which about 16% is located in areas within 3 hours' travel time of a population centre with more than 250,000 people, a proxy for "good accessibility to markets" (Jones and Thornton, 2009). In a plus five degree world, the transition zone increases in size to some 1.2

million km^2, about 5% of the land area of SSA (Thornton et al., 2011). Moreover, with such warming, the proportion of this transition zone that is in areas of high accessibility increases to about 50%. Such conditions would mean considerable loss of cropland in SSA (cropping would become too risky in about 35% of the mixed rain-fed arid-semiarid systems); and increasing amounts of this land would be in the hinterlands of large urban areas with already high population densities. This could be prevented by investments in adaptation creating the right environment for technology change and uptake.

The project reported on here was set up as a test of the hypothesis that sedentary farmers who currently keep livestock in these transition zones or “hotspots” may ultimately be forced to increase their reliance on livestock and eventually to adopt nomadic pastoralism in the future. The hypothesis cannot of course be tested directly at this time (these future conditions do not yet exist in these hotspots), but we attempt to test the hypothesis first by understanding how farming systems in these zones have been changing in the recent past, and second by evaluating what the impacts of these changes, and further changes in the same direction, may be on household incomes and food security in the coming decades. Field surveys were used for the first part, and household modelling work for the second.

There is a considerable literature on the nature of agricultural intensification, from a variety of perspectives and schools of thought. The Boserupian view holds that increasing human population pressure on relatively fixed land resources is seen as the driving force, which leads to an evolutionary process of agricultural intensification as populations increase with time (Boserup, 1965). Intensification can take place not only at the farm level; it may also play out and be driven by decision makers at community and broader levels. There may be exchanges and market-mediated interactions between different producers who may be widely separated geographically. Examples of this “area-wide integration” are common in parts of South Asia, for example, where manure and crop residues for animal feed may be transported many hundreds of km (Baltenweck et al., 2003). The intensification process can be viewed (see McIntire et al. (1992), for example) as follows (the text that follows is from Thornton et al., 2012). At low human population densities, production systems are extensive, with high availability of land and few direct crop-livestock interactions. As population densities increase, the level and types of crop-livestock interactions also increase, through increases in demand for crop and livestock products that in turn increases the value of manure and feed resources, for example, leading to increases in both crop and livestock productivity. The final stages of intensification see a movement towards specialisation in production (and thus reduced crop-livestock interaction) as relative values of land, labour and capital continue to change: fertilizer replaces manure, tractors replace draft animals, and concentrate feeds replace crop residues, for example (Baltenweck et al., 2003). While there is considerable observational and theoretical support for the basic hypothesis of Boserup, there are various other factors beside population growth that are now understood to modify the intensification process. For example, environmental characteristics play a significant role in determining the nature and evolution of crop-livestock systems, as do factors such as economic opportunities, cultural preferences, climatic events, lack of capital to purchase animals, and labour bottlenecks at key periods of the year that may prevent farmers from adopting technologies such as draft power (Baltenweck et al., 2003).

The hypothesis examined in this project is essentially that the intensification process outlined by Boserup (1965) is reversible, and that “extensification” of agriculture can occur in the presence of suitable drivers. One driver could be a changing climate, and another could be human depopulation because of pestilence or conflict, for example. Not much attention seems to have been given to this notion in the literature, and while in some ways it is antithetical to the normative genesis of agriculture (the “genesis reversed” of the project title), it does appear plausible, particularly in regions that are heavily dependent on rainfed agriculture and far from markets, and in which there are few if any alternative livelihood options for those engaged in cropping.

If climate change in the coming decades in SSA does induce an extensive reversal to agriculture dominated by mobility of the means of production and of residence, the implications would be profound in terms of the social, environmental, economic and political effects at local, national and even regional levels, if the process were not properly manage and facilitated (and perhaps even if it were). The rationale for the work described here was to provide a starting point for an examination of these implications and for considering the technological, social and political requirements if such a transition were to appear likely or imminent in particular places.

2 Study objective and general methodology

The objective of the study was as follows: to identify areas in the mixed crop-livestock systems in a part of arid and semi-arid Africa where climate change may compel current sedentary farmers to abandon cropping and to turn to nomadic pastoralism as a livelihood strategy, and (as far as possible) to assess the social, economic and environmental impacts of such a transition at the household, community and national level. This is designed to be one input into a broader study that will identify policies and institutional measures that would support and guide the transition to nomadic pastoralism with minimal social, economic and political disruptions.

The general methodology for the work was to build on Jones and Thornton (2009) using high-resolution methods to identify, analyze and characterize hotspots where climate change might induce system extensification in the future. To do this, we went through a site selection process to come up with case studies for in-depth analysis, to reflect a balance between two competing considerations: working across contexts that are sufficiently heterogeneous to ensure that outputs and recommendations of the studies are scalable and have wider application and relevance at other sites, and on the other hand ensuring that limited resources are used effectively.

In the original project document, the following key questions were raised:

1. How will agriculture and agriculturally-based livelihood systems in the country's semi-arid mixed crop-livestock systems evolve in light of climate change and the changing set of biophysical challenges?

2. Where are the places in the mixed crop-livestock systems where climate change may lead to total abandonment of cropping and the adoption of nomadic pastoralism as a livelihood strategy?

3. What are the thresholds or tipping points (biophysical) in crop adaptability and system productivity / vulnerability that would trigger a transition from crop agriculture to nomadic pastoralism?

4. What are the effects (social, economic, political, environmental, etc) of such a transition on farmers, communities, the nation, and other actors?

5. What are the necessary policy and institutional measures required to appropriately support or manage the transition?

In this document, we attempt to provide some answers to the first three of these, with some speculation in the conclusions on questions 4 and 5. The general approach for the project was as follows:

Step 1. For the target countries, Kenya, Tanzania, Uganda, refine the original "hotspot" analysis of identifying transition zones, using up-to-date data layers. Methods were similar to those used in Jones and Thornton (2009).

Step 2. Develop a sampling framework using cluster analysis, sample the transition zones, and identify a relatively small number of locations in each country, giving a total of 12 study sites in all, in which we would carry out point-based agricultural impacts modelling using existing crop and livestock models, to ascertain what the shifts in production in response to different emission scenarios may be.

Step 3. Carry out simple household-level analyses, to compare indicators of well-being now and in the future (such as household income and food self-sufficiency changes as proxies for food security), and to enable something to be said about the nature of the transitions that might be needed to maintain target levels, such as crop substitution and species substitution, for example.

Step 4. Using the sampling framework developed in step 2 above, upscale these results to appropriate domains within the transition zones identified in step 1, to estimate total impact. This will then feed into subsequent project activities such as elucidating the necessary policy and institutional measures that may be required to appropriately support or manage the transitions identified.

To accomplish step 3, we collected on-the-ground information from each study site on what the systems are in each place, via key-informant interviews and relatively quick, simple surveys to find out details about prevalent crop and livestock systems in each place, together with information on cropping calendars, input use, production levels, and local prices. The agricultural impacts models were then calibrated to current conditions with current weather with these data. The impacts models were subsequently run for a range of different climate models and emission scenarios to assess possible production changes in the future, that then fed into the other parts of the analysis.

3 Climate downscaling, weather modelling, sampling frame design

Climate downscaling and weather modelling

We had access to outputs from several General Circulation Models (GCMs) for the three emissions scenarios (A2, A1B and B1) used for the IPCC's Fourth Assessment Report (IPCC, 2007). These outputs were in form of climate anomalies for several different time slices at a resolution of 1° latitude-longitude. In general, there are several ways to increase the spatial resolution of climate model outputs, all of which have their own strengths and weaknesses (see a review by Wilby et al., 2009). Here, we were also concerned to increase the temporal resolution of climate model outputs, from monthly means of key variables to characteristic daily data that could then be used to drive crop and livestock models. We used historical gridded climate data from 1-km-resolution WorldClim (Hijmans et al., 2005), aggregated to 5 arc-minutes to speed the analysis, which we took to be representative of current climatic conditions. We produced a grid file for Africa of climate normals for future conditions at 5 arc-minutes by interpolation using inverse square distance weighting, one of the methods that Wilby et al. (2009) refer to as "unintelligent donwscaling". To increase the temporal resolution of the climate model outputs, we generated the daily data needed (maximum and minimum temperature, rainfall, and solar radiation) for each grid cell using MarkSim, a third-order Markov rainfall generator (Jones et al., 2002) that we use as a GCM downscaler, as it uses elements of both stochastic downscaling and weather typing on top of basic difference interpolation. MarkSim generates daily rainfall records using a third-order markov process to predict the occurrence of a rain day. It is able to simulate the observed variance of rainfall by way of stochastic resampling of the relevant markov process parameters. MarkSim is fitted to a calibration data set of over 10,000 weather stations worldwide, clustered into some 700 climate clusters using monthly values of precipitation and maximum and minimum temperatures. All weather stations in the data set have at least 12 years of daily data, and a few have 100 years or more. Some of the parameters of the MarkSim model are calculated by regression from the cluster most representative of the climate point to be simulated, whether that climate is historical or projected into the future. More details of the methods used are given in Jones et al. (2009).

Sampling frame

To generate a sampling frame for the work, we started with a data image with 156 columns and 204 rows of 5-arc-minute pixels covering the window from longitudes 29° E to 42° E and latitudes 12° S to 5° N, masking out the countries bordering Tanzania, Kenya and Uganda. A further mask of areas of interest was calculated from the transition zones in Jones and Thornton (2009). Maps of season failure rates for current conditions and for a future world with +4 °C of warming were taken as endpoints. The season failure rates for the future scenarios were then extracted for use in the classification scheme, while current failure rates were used to create the sampling frame mask.

Soil characteristics data were taken from the digital version of the FAO soils map of the world at 1:5,000,000. Soil mapping units were taken from the shapefiles (FAO, 1998; FAO, 2009) and collated with soil profile information following Gijsman et al. (2007), using a set of profiles specially selected for Africa. Only the major soil of each mapping unit was considered, except in the cases where this was not an acceptable agricultural soil, and values for pH, cation exchange capacity (CEC), base saturation (BS), silt and clay contents of the topsoil were assigned to pixels from the associated database. Soil water holding capacity was calculated by summing the available soil water throughout the profile to the rooting depth.

Elevation and slope data were compiled from SRTM data at 3 arc-seconds taken from the void-filled datasets of Jarvis et al. (2008). The slopes were calculated from adjacent pixels allowing for projection changes in pixel centre distance. Modal slopes and mean elevation were compiled to a 5 arc-minute grid for the sampling frame.

Human population was derived from GPWv3 (CIESIN/CIAT, 2005) for Kenya and Uganda using data for the year 2000. The GPWv3 data for Tanzania were judged inadequate, being at best at the second administrative level, and the shapefile from ILRI (2006) for Tanzania was grafted into the sampling frame image. Livestock densities were derived from Robinson et al. (2007); images for cattle, sheep and goat densities were cut and trimmed to the sample frame. Images of the extent of land cropped in maize, sorghum, beans, cassava, cowpea and pigeonpea were cropped from those provided by Monfreda et al. (2008). Unfortunately, the data for groundnut and millet were judged to be unsound due to either large differences between countries or widespread missing data. The proportions of each pixel under cultivation and in pasture were obtained from Ramankutty et al. (2008).

To proceed, all pixels with current crop failure rates of fewer than 1 year in 10 and greater that 4 years in 5 were excluded; all remaining pixels were taken to represent areas where cropping was possible but risky. Of these, pixels with less than 3% cropland were omitted, thus eliminating all pixels with less dense cropland. Pixels with a human population density in excess of 800 persons per square km were excluded as urban.

Information was extracted for each pixel in the sampling mask to create a dataset for principal components analysis. Twenty variables were extracted, and all variates were standardised to zero mean and unit variance (Table 1) and a principal components analysis was performed using GenStat (Payne et al., 1987). Chi-squared tests for equality of the last eigenvalues showed that all were statistically distinct, although the first eight took up 77.3% of the variance. Although this left almost 23% of the variance in the remaining components it was judged sufficient for the present exercise (Table 2).

Table 3 shows the first eight eigenvectors with important variates highlighted. It is not always possible to interpret the loadings in the eigenvectors, but here some stand out with clear implications. The first is heavily weighted for crops and cropland. Note that the signs within the eigenvectors are ambiguous: all could be reversed without altering the analysis but relative signs are important. The second weights livestock, topography and human population the same way, but soil characteristics inversely. Eigenvectors 4 and 5, interestingly, weight both cassava and sorghum heavily the same way but ignore other crops. Both of these crops are potentially drought tolerant. Having eliminated much unwanted variance from the dataset, we then carried out a cluster analysis using the first eight eigenvalue scores to minimise the sums of squares within clusters. Twelve distinctive clusters were produced from the data. These are mapped in Figure 1. It is apparent that the 12 clusters vary greatly in size. This is an outcome of the fact that the clustering was designed to maximize the between-cluster distances and minimize the within-cluster variances. In order to spread the samples as widely as possible, to stabilize the regressions that we would use later on to extrapolate project results, we sampled one point from each cluster. To try to minimize logistical problems, we chose a sample pixel from each cluster that was close to the main road network. Even so, many of these sample pixels are in marginal areas (due to the nature of the clustering), and logistical problems played a substantial role in data collection. The selected sample pixels are mapped in Figure 2.

4 Farming system characterization in the sample sites

Some general characteristics of the farming systems, taken from existing data sources, are tabulated in Table 4. Much more detailed information was collected in each sample pixel via key informant interviews and a rapid survey of farming system conditions in each place. Using the coordinates of the sample pixels a working map for each site was developed at ILRI to identify province, district, division, location and sub-location where each of the pixels was situated and where the survey was to be carried out. Since the coordinates represented a point at the centre of each pixel, the developed working map, drawn to scale, covered an area larger than the pixel. The maps served as a source of secondary information for each site to identify main trading centres, health facilities, schools, rivers, boreholes and the dominant type of vegetation. The coordinates were then uploaded into global positioning system (GPS). The GPS and working area map were used as a guide to the specific location of the site in the field. At each site, the administrative officer of the location (the chief) was identified, and the objective of the study explained. The chief was then asked to help organize the households for a Focus Group Discussion (FGD). All households in each site falling within the area in the pixel were eligible to participate. During the FGDs, we explained the objective of the visit and discussed climate change and variability and opportunities for dealing with climatic uncertainty. We asked about the observed changes in the last 2-3 decades and associated coping and adaptation strategies. We conducted key persons' interviews and household surveys. Key persons were mainly government appointed administration officers for each location[1]. They include: chiefs in Kenya, Village Executive Officers (VEOs) in Tanzania and Local Councillors (LC1) in Uganda. In some sites, where present, the agricultural Extension Officers (EO) were also interviewed. The key persons helped in selecting a random sample of 10 households, taking into consideration the differences in villages and social differentiation. Thus the selected households were spread across each site and comprised crop farmers, pastoralists and agro-pastoralists. This was then followed by a visit to the household homes for actual interviews. To facilitate ease of information exchange during the interviews, the key persons introduced us to the households. This was followed by a short explanation of the study objective.

The surveys were conducted between August 2010 and February 2011 and covered 120 households. The survey comprised detailed information on various aspects of household livelihoods: household composition, livelihood strategies and assets, livestock ownership and management, welfare outcomes (food consumption and health), and a vulnerability analysis.

Detailed information on crops grown, crops harvested, inputs (land preparation, seeds, fertilizer, and herbicides), outputs and prices were collected at plot level for each household. Information on livestock (types, breeds, number, inputs and management cost) and other assets such as land (size, and type of ownership) were also collected. Data on the main sources of income for the household heads were captured. The main income categories were: crop income (from revenues net of input costs), livestock income (income from sale of livestock and livestock product less production cost), and off-farm income (salaried income, remittances, business income, income from casual labor and sale of forest products such as charcoal). The survey also collected comprehensive data on household food consumption

[1] Local administration in Kenya is divided among eight provinces each headed by a *Provincial commissioner.* Provinces are divided into *distric*ts. Districts are divided into *divisions*. Divisions are then divided into *locations* and finally locations are divided into *sub-locations.*

and expenditure on purchased food items. On consumption, information was also collected on: food availability during the drought period; the preferred crops type especially during drought; and the need for food aid and its availability. The vulnerability context captured data on the main concerns facing the household and how they tackle each concern in terms of coping and adaptation.

Except in Samburu (cluster 4), where farmers have never practised cropping, the common crops encountered across the sites were maize (*Zea mays*), common beans (*Phaseolus vulgaris*), pigeon pea (*Cajanus cajan*), cowpea (*Vigna unguiculata*), millet (*Pennisetum glaucum*), green gram or Mung bean (*Vigna radiata*), banana (*Musa* spp), sorghum (*Sorghum bicolor*); and cassava (*Manihot esculenta*). Livestock kept included cattle, sheep, goats and camels.

Cluster 1 (Taru, Kwale, Kenya)

Livestock and crops are the main source of livelihood for the majority of households. The main crops are maize, cowpea, pumpkins and cashew nuts. Livestock consist mainly of indigenous breeds and comprise cattle, sheep, local goats and chicken. Crops and livestock provide approximately 80 and 20%, respectively, of household food. The basic facilities within this area include: the Taru trading centre, from where households purchase farm and livestock inputs; piped water at a central point freely accessible by all households; and five water pans and a cattle dip. The main livestock market is approximately 15 km away. Land is communally owned. However, because some areas are better suited to cropping than others, the cropped areas are divided according to clans, but the grazing area remains communally owned. Each clan then allocates a portion of its crop land to its family members.

The major sources of water for livestock are the water pans, which are managed by a committee elected jointly by community members and the local authorities (i.e., the chief and division officers). Community members are free to graze their animals anywhere within the communal land. During drought, livestock from outside the community, which come for watering at the community pans, are charged 5-10 KSh (Kenyan Shillings) per head [2]. The

[2] About USD 0.05 – USD 0.10 at the time of writing (November 2011)

main risks faced by households include uncertain onset of rainfall, shortage of water, damage of crops by wild animals, particularly zebra and elephants (the area borders Tsavo National Park to the east), and theft of crop produce and livestock. Households in the area supplement their income with casual labour to the nearby sisal estate and selling charcoal and diesel (though illegal) along the Nairobi-Mombasa highway. Indigenous breeds of cattle are preferred as they can walk long distances in search of water if drought is prolonged. To protect their crops and livestock from theft, some households use witchcraft.

Cluster 2 (Kolandoto, Kishapu, Tanzania)

Livestock and crop farming are the main sources of income for the households. The proportion of livestock keepers and crop farmers is approximately 30 and 70%. Livestock consists of cattle, sheep and goats. Crops comprise cotton, maize, groundnut, millet, sorghum, cowpeas and sweet potatoes. The main facilities in the area include a local trading centre, cotton collection points in each village, four primary schools, two secondary schools, and a dispensary. Each village has a water pan, from which livestock drink water. The main cotton market is 15 km away. Each household owns an average of 2 ha of land, and most have title deeds. Grazing of livestock is done only along the road or on the household's property. Conflicts caused by livestock grazing other people's crops are common. Resource management such as maintaining the water pan is done through VEOs and EOs. Conflicts related to livestock grazing on crops and those arising at water points are resolved through the VEO and village elders appointed by the community members. For firewood, households depend on pruning trees on their own farms as there are no public woodlands in the area. Moreover, if a farmer wants to cut down a tree even on his or her own property, permission has to be obtained from the VEO.

The main constraints in the area are: water (the main source is a seasonal river), crop diseases (leaf blight) and pests (aphids on millet and cotton), and shortage of food during the dry season. To cope with water shortage, households buy water at 300 TSh (Tanzanian shillings) per 20 litres. For food security, most households store grain when the harvest is good. To control diseases and pests, farmers practise early and late planting.

Cluster 3 (Nginyang, Baringo, Kenya)

The dominant ethnic group is the Pokot, whose main source of livelihoods is pastoralism. Livestock is the main income-generating activity (85-90% of household income), with goats the major species. Some 20-30% of the households are engaged in cropping. The main crop is maize, but millet and green grams are also common. The main facilities in the area include the district administrative facilities (East Pokot district headquarters is at Nginyang, which is within the sample pixel), Nginyang trading centre, a primary and a secondary school, and a dispensary. The main watering point for livestock is the Tangulbei River, which is permanent. Two government-dug boreholes and the river are the main sources of water for human consumption.

Land is communally owned. However, community members allocate the land to themselves based on clan rules. Each clan has a piece of land close to the river for cropping and in the upper land for grazing. Despite the sub-division of land, livestock are free to graze anywhere without restrictions.

Cluster 4 (Seredupi, Samburu, Kenya)

The main source of livelihoods is pastoralism. Livestock is thus the major income-generating activity, with goats as the main species. Other livestock include cattle, sheep and camels. The main facilities in the area include a boarding primary school, a health centre and a borehole. The land is communally owned and managed as a group ranch by officials who are elected by the community. The management stipulates that households can use resources such as trees for constructions of houses or for firewood but not for commercial purposes. Households have free access to resources such as water from the borehole for consumption and for livestock. Livestock are free to graze anywhere without restrictions. The main constraints include lack of markets, cattle rustling, and frequent droughts. Livestock markets are located at Wamba-Samburu and Archers Post, at approximately 24 and 18 hours walking distance, respectively. Cattle rustling is common at this site (from Borana and Somali communities).

Some of the coping strategies include moving livestock during droughts to Komo and Koya, situated approximately 40-60 km away from Seredupi; receiving structural food aid; brewing of alcohol, and sending sons to look for casual work in towns. The community has recently started a conservancy project for income generation. During drought, households depend on experienced herders who are paid on a monthly basis to move and graze livestock.

Cluster 5 (Chiruhura, Mbarara, Uganda)

The main sources of livelihood are both crop and livestock farming. The main livestock are goats and cattle. The main crops include maize, bananas, cassava and beans. The closest inputs market is Lyatonde trading centre (9 km away).

The main constraints include wild animals (zebras and leopards), which frequently destroy crops and kill livestock, lack of livestock markets, low crop productivity, lack of water during drought, and tick-borne diseases such as East Coast Fever (ECF). Sometimes there are outbreaks of foot and mouth disease (FMD). To cope with these constraints households rely on purchased grains using income realised from milk sales. Each household has a shallow well for watering their livestock and for household consumption. During drought, the farmers purchase water for consumption from water traders. To cope with lack of livestock markets, households keep a list of phone numbers for brokers, whom they call using cell phones to come and buy the livestock for resale at the livestock market in Kampala. To boost crop productivity some households use cattle and goat manure. Whenever there is an outbreak of disease, the government veterinary department calls for a quarantine and provides vaccination. During drought, to prevent heavy losses, households sell their animals and restock later when pasture and water are readily available.

Cluster 6 (Mua Hills, Machakos, Kenya)

The main sources of livelihood are crop and livestock. The main crops grown in the area include maize, beans, onions, sorghum, peas, millet and sweet potatoes. Farm inputs are purchased at Machakos town (16 km away), which is also the main market for farm produce. The main facilities in the area include a primary and secondary school, a public borehole, and a local (Mua Hills) trading centre. Land is privately owned and grazing of livestock takes place on-farm. The public borehole is managed by a committee appointed jointly by the authority (the chief and assistant chief) and community members through a community meeting.

The main limitations to food production are the small farm sizes and low yields of millet and sorghum largely due to birds. Coping strategies that farmers use in dealing with food shortages include storing food when the harvest is good, planting fast-maturing crops, intercropping, and saving money. The storage of grain can last for 2-3 cropping seasons. Households receive food aid and people walk far to fetch drinking water from public wells. However, livestock deaths related to drought are not common. According to the EO, farmers are used to drought-resistant maize cultivars and plant cultivars of different maturity cycles. Sweet potatoes are being promoted at the moment. The chief believes that farmers will not go back to nomadic pastoralism: in this highland area crops do relatively well compared to the lowlands.

Cluster 7 (Pakwach, Nebbi, Uganda)

Mixed farming is the main source of livelihood. Crops alone contribute about 90% of household income. Farmers keep cattle, sheep and goats. Crops include maize, sorghum, millet and cassava. Cash crops include sesame and cotton. Farmers believe productivity has declined: 10 years ago an acre could produce 900 kg of maize but currently it produces about 540 kg. Land is communally owned, but in a customary way, so if a man had occupied a certain area for a long time, his sons become the heir to the same land. The main constraints relate to high fluctuation in prices of sesame and cotton, water for consumption is far away (9 km), livestock diseases (diarrhoea and sudden death) are common, lack of education (80 % of the households are illiterate), livestock markets are not developed in the area, and the frequency of droughts is increasing. Conflicts at water sources are common, and are usually handled by the village elders who are appointed by the local councillor (LC1).

To cope with these constraints, householders have to walk between 9 and 10 km to get water for consumption from piped water (at the closest town) or from the Nile river. Livestock are taken to drink water from the Nile. Experienced herdsmen are called on to administer treatment to animals. Households receive food aid in times of drought. Burning of charcoal for selling is a common practice for earning income. Local butchers are the main livestock buyers.

Cluster 8 (Madewa, Singida, Tanzania)

Because the survey site falls on Singida town, many household members practice urban trading rather than agriculture. Livestock keepers practise zero-grazing. Farmers cultivate horticultural crops, grains and fruits. Nomadic pastoralism is almost non-existent due to urbanization. Most farmers are involved in cropping. The major grains are millet and sorghum, plus some maize. Livestock comprise cattle, sheep, goats and pigs. Cattle crossbreeds are slowly being introduced. Land is communally owned. The land is further subdivided into clans. Clans that settled first in the area own large pieces of land. Households are allocated cropping land by their clans. As Singida town expands, the owners of farms close to the road are relocated elsewhere away from the town by the town council, who are taking over many aspects of land management in Singida.

The main constraints facing the remaining farmers include the unpredictability of rain; livestock diseases such as FMD and ECF during the rainy season, and lack of water. Coping strategies include: growing fast-maturing varieties of sorghum, millet and maize, storage of grain after harvest, reserving pastures in some portion of their farm land for livestock, intercropping various crops, and mixing of crops and livestock are all considered diversification strategies by these households.

Cluster 9 (Kisanju, Kajiado, Kenya)

The main source of livelihoods is livestock keeping. However, households in the area also depend on several other sources of income such as cropping, livestock trading, and informal (on flower farms) and formal employment (by government). The main crops include maize, beans, vegetables, pumpkins and horticultural crops. The main livestock include cattle, sheep and goats. Goats are the main livestock in the area. The main facilities in the area include a trading centre, a primary and a secondary school, and many private boreholes. Livestock markets are found at Kitengela and Isinya, situated 5-10 km away. Extension services are available, but they are demand driven, i.e. they have to be invited by the farmers, who want to receive training on crop or livestock production.

Land is privately owned with title deeds. The main constraints include increased drought frequency, water shortage and the continued fencing of own farms which impedes livestock movement in search of water and pastures. This area also suffers from livestock deaths due to droughts. To cope with this constraint some households drill bore holes to provide water for livestock and crops. Households have joined together to start a community organisation for facilitating restocking after drought. Households are diversifying their income sources by growing crops. Land privatization and fragmentation are believed to have aggravated livestock mortality during droughts. Vegetable production and planting of trees are perceived negatively because they increase water shortages. According to farmers, reduction of stock and intensifying livestock and crop production could be good adaptation strategies. The EO believes that farmers in the area will intensify farming because of land subdivision and increasing frequency of drought, while at the same time continuing with nomadic pastoralism.

Cluster 10 (Lwengo, Masaka, Uganda)

The major sources of livelihood are crops and livestock. Mixed farming has been practised for over 50 years. The main crops are cooking bananas, maize, beans, groundnuts, cassava and sweet potatoes. Tree crops include mangoes, avocadoes and jack fruits. Livestock consist of cattle, sheep, goats and poultry. Crops contribute 78% to households' food security. Most households are engaged in cropping. Livestock keepers make up only 5%. Coffee is the main cash crop. Piped water is available (20% of households have piped water). Households without piped water have boreholes. Land is privately owned but without title deeds. Households get firewood from their own farms, and so some have started planting trees from which they can harvest firewood. Water is readily available and there are no conflicts in the use of water resources.

The main constraints in the area are highly volatile prices for crop produce, low crop productivity due to decline in soil fertility, and crop diseases and pests such as cassava mosaic and banana weevil. The LC1 believes that drought frequency is increasing. Livestock markets are far: about 30 km away. Coping strategies include the use of wood ash mixed with human urine as a pesticide for banana weevil. Storage of grain is common when the harvest is good. Intercropping is used to increase crop yields and as an income diversification strategy. Households receive food aid during drought. Households plant hybrid varieties of maize (Kawada hybrid seeds). But for beans they use their own saved seed. For cassava, sweet potatoes and bananas, households use recycled material for planting. The LC1 believes that because of land subdivision it is impossible for households to start up a nomadic way of life.

Cluster 11 (Lomut, West Pokot, Kenya)

Crops and livestock are the main sources of household income. Livestock comprise cattle, sheep and goats. Goats are the major livestock species; cattle are few because of mortality from past droughts. The main crops are maize, sorghum, millet and cowpeas. Maize and millet are grown in the first season and cowpeas in the second season on plots situated along the river banks. Infrastructure in the area includes two primary schools, a secondary school, five nursery schools and a dispensary. There are two local trading centres at Weiwei and Lomut, which serve as livestock and crop markets for the area. However, veterinary drugs for livestock are purchased at Kapenguria 100 km away. Land is communally owned and households are free to practice either crop or livestock farming or both. Plots for crop farming are found along the banks of the Suam river. Resources such as woodland and water from the river are freely accessible by all households, but strictly prohibited for commercial purposes. The main constraints include lack of pastures, livestock theft, water shortage, destruction of crops by elephants, crops pests, livestock (tick-borne) diseases, and lack of veterinary services. Crop pests are mainly worms that attack maize and millet at the start of tasseling. Four kinds of conflict are common in this area: i) lack of pastures and water create conflicts related to livestock theft (cattle rustling); ii) lack of water also creates conflict between crops and livestock farmers as some want to have more control and larger access rights than others; iii) conflict between crop farmers and livestock keepers due to damage on the crops by livestock; and iv) conflicts between charcoal burners and livestock farmers who keep goats: charcoal burners cut down Acacia trees from which livestock keepers harvest the pods and leaves to feed goats during the dry season.

The chief of Lomut said that cattle rustling is a for the households cultural way of life. Because livestock are so susceptible to drought and disease, livestock keepers often invade the neighbouring Turkana community in the north and steal their livestock. Cattle rustling is perceived as a kind of diversification strategy. To cope with lack of pastures, livestock are moved toward the north to Kainuk (at a distance of between 100-160 km). To control pests on millet and maize, wood ash is applied to the crops just before tassling. Due to lack of veterinary services each livestock keeper has learned how to detect disease and administer treatment. To curb food shortages, farmers use short-season maize and millet varieties, whose seed are mainly recycled. The problem of water shortage is solved through several households joining forces and digging a bore hole along the river bank. In such cases only those who contribute toward its drilling or digging have access rights to the water from the borehole. Farming is done in groups of about 10 farmers in schemes of labour sharing. Farmers get organized to share knowledge and labour and to obtain inputs, particularly those that can only be obtained in Kapenguria. Conflicts relating to water are resolved through community elders, who are appointed by the chief.

Cluster 12 (Lokichar, North Pokot, Kenya)

Mixed farming is the main source of livelihood in this area and is practiced by nearly all households. Livestock comprise cattle, sheep, goats, and a few camels. Camels are new in the area. The main crops are millet, sorghum, maize, pumpkins and green grams. Both crops and livestock contribute equally to household food security. Other sources of income include the extraction of fluid from Aloe vera plants in the bush, which can be sold at 200 KShs per litre at the local trading centre (Orworwo), and the provision of casual labour for cropping, masonry and bush clearing. The main infrastructure in the area consists of a primary school and a trading centre from which farm and livestock inputs can be purchased, although these are very expensive compared with the main market in Kapenguria 50 km away.

Livestock are free to graze anywhere within the location. Households are free to use woodlands for construction and fuel but not for commercial purposes. The main constraints are lack of enough water, lack of pastures, cattle rustling, livestock diseases (ECF, diarrhoea and CBPP, Caprine Bovine Pleuro Pneumonia) and increased frequency of drought. To cope with lack of water household members walk up to 10 km in search of water. During drought livestock are moved to areas around Mount Elgon for grazing, and they may also be taken cross the border to Uganda to Karamojong. Households receive structurally food aid. Short-season maize hybrid varieties (Katumani, H 513 and PH 04) are commonly grown.

5 Historical changes in the sample sites

Changes in livelihoods

In this section we report the main changes in diets, agricultural activities and the environment as perceived by the key informants. Several of the study sites do not have a long history of cropping. In Figure 3, we show the time line of the introduction of cropping at each of the sites reported by the key informants. Especially in the remote sites (i.e., Baringo, North and West Pokot), cropping is relatively new to the households, who were traditionally livestock keepers. Changes in human diets have been related to the introduction of cropping and of road infrastructure. Maize is the main staple in the whole region, followed by cassava, cooking bananas, sorghum and millet.

In Kwale, according to the chief, crop farming started some 50 years ago, mainly as a livelihood diversification strategy. Before, the Duruma people (the major tribe in the area, Table 4) used to hunt wild animals such as giraffe, gazelles and dik dik. Currently their diet consists mainly of cereals: millet, sorghum and maize. Although maize is the preferred food, millet and cassava are eaten when times are hard and the maize crops fail. Households receive food aid during drought. The chief believes that local farmers will never become nomads.

In Kishapu, most households have maize as their staple food, but about 50 years ago millet and sorghum were the main diet. Yet, most households even today allocate some portion of their land to growing millet for food just in case the maize does not do well. Setting aside a portion of land for growing millet and sorghum is advised by the government, as a way of curbing food insecurity in the region. Both the VEO and EO believe that households will not change from cropping to nomadic pastoralism as a livelihood strategy.

In Baringo, ten years ago farmers were hardly engaged in cropping. This changed because of livestock deaths and farmers wanting to diversify. However, cropping is perceived as being a risky activity compared with livestock, since livestock can walk to other areas in search of water and pastures. Cropping started around the mid-1990s. Maize became a common food in the 1960s. Before that, the diet consisted mainly of meat, milk, blood, and honey. The chief and the EO believe that households are not going to abandon cropping for nomadic pastoralism, and more households will mix crop farming with livestock keeping in the future.

In Samburu, people´s diet until the 1980s was mainly meat, milk and blood. However, a majority of households nowadays combine milk, meat and maize. Maize is purchased in towns. According to the chief and his assistant, the people of Seredupi have never grown crops, and their culture is strongly attached to livestock keeping. Both the chief and the assistant believe that households will continue being nomadic pastoralists.

In Mbarara, crops were introduced into the area in the 1970s. Before that households were pure pastoralists. At the moment, the main diet is maize flour, milk, meat and sometimes blood, but some 20 years ago the main diet was meat, milk and blood. The chief believes that households are not likely to go back to a nomadic way of life, as a majority get involved in crop farming, particularly maize which comprises a major part of households' diets. In 1982, the area close to the village was declared a national park (Lake Mburu National Park). As a result, killing of wildlife was prohibited. Government officers enforce the rules for the National Park. All households have free access to Lake Mburu (6 km away). In 1980 the average land size per household was 5 square miles, but it was later (1986) reduced to 2 square miles of land per person and with title deeds. In the early 1990s people started fencing their land, thereby hindering free movement of livestock in search of water and pastures. At the moment farmers graze animals on their own land.

In Machakos, crops that used to be present 20 years ago but are absent today include sugarcane, millet and sorghum. In the 1970s there used to be one cropping season per year because of cold temperatures. Bananas used not to grow, but they currently do well. At the same time herd sizes have declined due to reductions in land sizes.

In Nebbi, the study site was covered by trees approximately 30 years ago, but because of poverty, people have cut down most of the trees for charcoal burning to generate income. The charcoal burning started around 1970. According to the LC1, mixed crop-livestock farming has been practised for the last 50 years and for that reason, he sees no possibility of households reverting to a nomadic way of life they left more than half a century ago.
Fifty years ago the main household diet was cassava, millet and sorghum plus milk and meat. Today the human diet has remained the same way only that maize consumption has been adopted by nearly all the households. Approximately 10-15 years ago, crop yields were higher than now. On average an acre produces 6 (90 kg) bags of maize currently. However, 10-15 years ago the one acre could produce 10 (90kg) bags of maize.

In Singida, farming has been practised since the colonial times. However, at the moment farming is slowly declining as the Singida urban centre expands. Fifty years ago the main diet of people was millet and sorghum plus some maize. Today, the diet is still the same but with no maize except during severe drought when the government donates maize (including yellow maize). In this area crop production fails in patterns, that is maize can perform poorly while sorghum and millet perform well or vice versa. There has never been a total crop failure. Herd sizes are small because most of the households have moved their animals to other far areas due to lack of pastures around Singida town. In the near future, livestock keepers will only be practising stall feeding. The VEO and EO believe farmers will not go back to nomadic pastoralism; instead they will continue with crop farming, and zero grazing.

In Kajiado, crops were first introduced in the mid 1970s. Commercial horticultural farms have become common over the last five years. Over the last decade, there has been a large increase in the number of boreholes as regulations from the ministry of water have not been adhered to. The practice of nomadic pastoralism is still in place, in that there is migration to other areas such as Taita, Taveta, Voi and Lamu in search of pasture and water during drought. About 40 years ago, wildlife populations were large. In the 1960s the government allowed wildlife to be killed. Since then, irrigation of the land started, followed by flower farming and land privatization, including fencing. A few decades ago, people used to have fewer goats and sheep than cattle; however the trend has changed and small ruminants are now more abundant than cattle.

In Masaka, twenty years ago people used to own 2-8 ha of land but currently on average households own less than 2 ha. Diets 25 years ago used to be mainly bananas but currently the diet for majority households is mainly maize. The diet is changing because bananas are no longer producing well. The reasons given as to why banana yield is declining include banana weevil, decline in soil fertility, poorer methods of banana production (such as intercropping bananas with coffee), and changing preferences from banana to maize across households. Maize is preferred as it is easier to store.

In West Pokot, the main diet for most people is maize, and its production started around 1980. Before then, millet and sorghum made up most of the diet in the area. According to the chief, households in this area are still practising nomadism, but slowly turning to mixed farming, as most now have plots close to the Parkino river and are reducing their livestock numbers and mobility. According to the EO, farmers who practise mixed farming are considered wealthier than livestock farmers, because they have diversified their sources of livelihood. Households in West Pokot are in transition from nomadism to mixed farming.

In North Pokot, maize farming started in the mid 80s and maize has become the main food; previously, millet and sorghum were the main food crops. Land is communally owned and each household has the right to cultivate anywhere including along the river banks. However, the size of land holdings along the river bank is not equal. Clans whose grandfathers used to grow millet along the river banks long ago have larger plot sizes. The chief believes that nomadic pastoralism is slowly decreasing mainly because of shortage of pasture and grazing areas. Cropping is considered to be a diversification strategy, and so it is unlikely that farmers will stop cropping and go back to nomadic pastoralism.

Changes in herd sizes and mortality

Across study sites 72% of household reported changes in livestock populations. These changes have been attributed to the recurrence of droughts and to the incidence of diseases. Along the rainfall gradients, household reported a high incidence of drought and water shortages. Probability of drought varied between once in two to three years, with very high values for Mbarara and North Pokot, where households indicated a probability of drought of 0.6 and 0.8 (Figure 4 A). We did not ask households to define a drought or water shortage. They indicated having water shortages in most sites, and the trend followed the probability of having a drought. However, the probability of having a drought was not translated into experiencing problems due to water shortages (Figure 4 B). Access to rivers, wells, boreholes, and dams allowed households to cope with water shortages (Table 5). Households who experience water shortages were mainly those who depend on rivers and shallow wells.

At all sites, mortality of livestock was overall much higher in bad years (Figure 5 and Table 6). For cattle, mortality rates of indigenous cattle were higher than those of crossbred and exotic. Mortality of sheep was lower than that of goats and indigenous cattle. Mortality rates of indigenous goats were higher than for other species, probably related to the high incidence of diseases reported by households (mainly of CBPP, diarrhoea and ECF) (Table 7). Households explained that goats have less resistance than cattle to diseases, and that they die more frequently.

6 The present: diversified livelihoods

The results of the household surveys are reported using a rainfall gradient, with the lowest rainfall site to the left (Samburu), and the highest rainfall site (Mbarara) to the right of the gradient. Except for the Samburu site (cluster 4), where people do not practise cropping, households are all engaged in cropping, livestock keeping and off-farm activities. Farm sizes are small, with maize cultivated in most sites (Table 8). Small ruminants are the most common livestock, with two of the sites specialized in dairy. The importance of cattle and their contribution to household income increase with increased annual rainfall. We observe no trend in herd size with increasing rainfall: there are large herds in Kajiado (with an annual average rainfall of 655 mm) and in Mbarara (with 900 mm).

At all sites, most households own their houses, although their quality varies across sites.

Thatched roofs with poles and mud walls and few rooms dominate in the poorest sites (i.e. Samburu, Baringo, West Pokot and Singida) (Table 9). Households own livestock in all sites, especially in the low rainfall areas. Increasing annual rainfall allows households to depend more on agricultural activities, and therefore they engage less in off-farm activities. Access to electricity, mobile phones and mobile banking varies largely across sites with Kenyan sites having in general more access to both (Table 10).

At all sites, households reported having food shortages. However, the length of the period with food shortages varied substantially across sites, decreasing with increasing rainfall. In the six of the wetter sites with annual rainfall above 900 mm, periods of food shortage lasted fewer than 4 months per year (Figure 6 A, B). The proportion of households having food shortages was not directly related to water shortages or perception of recurrence of drought (Figure 7 A, B). However, the length of the period with food shortages and the proportion of household with food shortages were related to household income and to annual mean rainfall (Figure 7 C, D).

We calculated energy availability for each household member based on production and food consumption. Households indicated the amount of food items derived from on-farm production and those which were purchased. With this information we calculated a food security ratio and a food self-sufficiency ratio to reflect the reliance on farm production and purchases to meet energy needs, calculated using WHO standards. Food insecurity (a ratio less than 1) was common in the four sites with annual rainfall lower than 800 mm, and critically low (less than 0.5) in the sites with rainfall lower than 700 mm (Figure 8 A). As expected, the contribution of farm produce to the energy availability per household member increases at the sites with higher rainfall, although there is considerable variability among households (Figure 8 B). Households were self-sufficient in securing energy from food produce in seven of the sites, all with rainfall higher than 800 mm. The sites with high food insecurity were also those in which a large proportion of households receive food aid several times each year (Figure 9).

Incomes and perceptions of the importance of different livelihood activities

Households ranked livestock production and trade as the most important income-generating activities in the sites with less than 900 mm of annual rainfall, excluding those very close to urban centres (Kwale and Singida). There, employment and non-agricultural trade were the most important activities (Figure 10). At higher annual rainfall, the importance of crops increases, except in Mbarara which specializes in dairy production.

In five of the sites - Samburu (Ke), Baringo (Ke), West Pokot (Ke), Singida (Tz), and Nebbi (Ug) - net incomes were critically below the poverty line (Figure 11 A). Most income (>60%) was derived from off-farm activities, except for Nebbi in which cropping was the most important income-generating activity. The relative contribution of livestock and off-farm employment decreases with increasing annual rainfall (Figure 11 C, D), although dairy represents a large share of the income in two of the high rainfall sites (Mbarara and Machakos). Livestock contributes substantially to the generation of cash in Kajiado, Mbarara and Machakos. The absolute amount of cash income generated increases with increasing rainfall (Figure 11 B).

Crop and livestock production

Although livestock ownership is generalized across sites (see Table 10), livestock species and numbers vary largely between sites (Figure 12 A). Cattle herds are largest in Mbarara (Uganda), followed by Kajiado (Kenya). In the other 10 sites, households have few cattle (less than 5 heads). Goats are present in most sites, except in Masaka (Uganda). Flocks are relatively large (more than 20 goats) in Baringo, West Pokot, Mbarara and North Pokot. Sheep are less common in the study sites, with relatively large flocks only in Kajiado and West Pokot.

The asset value of livestock is considerably larger at Mbarara and Kajiado than in other sites (Figure 12 B). This is not only the result of the larger livestock populations but also of the exclusive presence of crossbred cattle, and higher sale prices for all the species (Table 11 and Table 12). In the Kenyan sites, livestock prices are in general higher than in the Ugandan and Tanzanian sites. Households have exotic breeds of livestock only in Machakos. All livestock owners sell and buy animals at times, but not all of them sell all sorts of livestock products.

Cattle owners usually sell milk, and few of them sell hides and manure (Table 13). Few households sell goat milk, and none sells sheep milk. Selling skins, manure or wool is also uncommon in the study sites.

Livestock production is relatively low at all study sites, with few animals lactating (median of 3, range 1-37) and low milk yields (median 280, range 37-3200 kg per cow per year) (Table 14). Although 72% of households' recognized livestock populations changed in the last 10 years, offtake rates and recruitments were relatively low (Table 15). Offtake rates for goats were considerably higher than the recruitment rates, and both offtake and recruitment rates of goats were larger than those of cattle. Households did not report selling or buying large numbers of sheep, camel or pigs.

Households cultivated a large number of crops, remarkably more in the wetter sites. The most common crops were maize, cultivated in 11 of the 12 sites, common beans, sorghum, and millet (Figure 13). Cereal grain yields ranged between 1000-2000 kg per ha, and grain legume yields were highly variable, ranging between 100-2000 kg per ha (Figure 14 and Figure 15). Variability within sites was also large, with maize yielding between 200-3000 kg per ha in the same site. There appears to be a relationship between crop diversity and incomes. Household income and incomes from cropping increased with the number of crops cultivated (Figure 16 A, B). The number of crops cultivated increased with mean annual rainfall, with Kajiado as an exception, with 13 crops being cultivated in the site. There was some relationship between the number of activities a household engaged in and annual mean rainfall, and a strong relationship between net income per year and the number of activities per farm (Figure 16 C, D).

Costs of production for the same crops and rearing costs of livestock species varied substantially between sites (Table 16 and Table 17). Costs of maize ranged between 100 and 16,000 Kenyan shillings per ha. This large variability is explained with variable input use across sites: hired labour is the main ingredient of the production costs, especially at Kajiado, Mbarara, and Machakos where wages are higher than in remote places such as North and West Pokot. Very few farmers (less than 10%) purchase mineral fertilisers or hybrid seeds. Instead they use animal manure and conserve seeds for planting next season.

Main concerns on current and future problems, coping and adaptation

Households were asked to list their main concerns about what could happen in the future to the farming household. To compare sites, we sorted the answers into three categories: (A) related to cropping, (B) related to livestock keeping, and (C) related to household members (Figure 17). Households at all 12 sites were concerned about water-related issues, either drinking water, water for livestock, or crop failure due to drought. Not having enough drinking water was ranked highly by 48% of the respondents, not having enough water for livestock also by 48%, and crop failure by 16%. In 10 of the 12 sites, households were concerned about not having enough food for the family (38% of the respondents), while in seven of the 12 sites household were concerned about not having enough pastures for the livestock (28% of the respondents) (Table 18).

Water for both human consumption and for livestock is thus the most important concern across all sites. Searching for water is the main coping strategy, while drilling boreholes emerged as an adaptation strategy. Households cope with the lack of food by buying food or relying on food aid, and by reducing consumption. Adaptation strategies against food deficits vary across the rainfall gradient: in the low rainfall sites, households mentioned income diversification, expansion of cropping, diversification of crops and increasing herd sizes. In the higher rainfall sites, households mentioned increasing the storage of food, planting drought resistant cultivars, and intercropping. Households respond to the lack of pastures for livestock by increasing livestock mobility. In some of the sites, households mentioned conservation of feeds, use of irrigation, and use of drought-tolerant grasses as adaptation strategies. When households were asked specifically how to deal with the effects of drought, they came up with similar strategies across sites: storage of grains and saving cash, and selling livestock and labour (Table 19). However, to adapt to drought, strategies varied across sites, with people wanting to start cropping at the low rainfall sites to diversify incomes in good years, and people wanting to intensify crop-livestock systems with a diversity of crops and intercrops.

In Samburu, food shortages occur at least twice a year. Insecurity and violence increase substantially during times of drought, and households had no suggestions as to how to reduce it. They noted that government-enforced disarmament has (according to the respondents) increased insecurity and cattle raiding. Feed deficits occur twice a year as well. Households then move livestock in search of pastures. The same happens with water for human and livestock consumption: deficits occur twice a year and people move, in the search for water.

In Kajiado, people were mainly concerned about the effects of drought, which resulted in lack of water for livestock, and of pastures and crop failure. To cope with food shortages, most households suggested the storage of grains. To solve water-related problems, households suggested that more boreholes be constructed, which need to be managed by a community committee. People were also interested in using water harvesting techniques. Several respondents suggested reducing animal numbers to release the pressure on both water and feed resources. In Kajiado, where cropping is already an important component of household income (average of 24%), people were interested in planting drought-tolerant crops and intensifying cropping.

In Baringo, with a short history of cropping, people were interested in intensifying crop production and trying irrigation to adapt to food deficit problems. They are also keen to receive assistance on treating and preventing livestock diseases. To adapt to feed deficit problems, households suggested using supplementary feeding combined with moving livestock to other areas.

Households in West Pokot thought of intensifying both crop and livestock production, diversifying crops, and increasing livestock populations. Because households experience feed deficits, they thought of adapting by increasing mobility. In this site too, there is a demand for extension to deal with livestock diseases.

In Kwale, people were interested in intensifying crop production although they recognize that options are seriously limited by water deficits, which affect livestock and even human consumption. Constructing boreholes and expanding the capacity of a nearby dam were suggested.

In Singida, in a more urban environment, households mentioned diversification as their main adaptation strategy. This included producing and selling charcoal, looking for casual employment, and migration to other areas.

In Kishapu, people mentioned intensification of crop-livestock production as a way to adapt to lack of food and loss of income. Migration was also suggested, as a strategy to adapt to the lack of suitable cropland.

In Mbarara, the main concern of households was wildlife conflicts, associated with proximity to a national park. They cope with this by investing in labour to guard their crops during the growing season, and mentioned fencing as a way to adapt. Access to water for livestock was also perceived as a problem, and people mentioned moving livestock to a lake within the national park to drink. This of course creates some problems with the park authorities.

In North Pokot, all households were concerned about the incidence of diseases and were demanding extension services, as in West Pokot and Baringo. These areas are located relatively close to each other and have in common difficult access with roads in very poor condition. People did not have ideas as to how to deal with food shortages and crop failure, other than relying on food aid.

Loss of off-farm income was a highly-ranked concern in Nebbi. To cope with this, households resort to casual employment or to sell firewood. To adapt, households suggested to diversify cropping and to increase herd sizes. To cope with the effects of drought and crop failure, households preserve cassava in their fields, practise early planting of other crops, and suggested cultivating millet.

In Masaka, households mentioned a long list of concerns. However, they have ideas on how to cope with, and adapt to, a few of them. For example, they were concerned about losing off-farm income. As coping strategies they mentioned casual work and work for food. To adapt, households plan to intensify cropping (practising intercropping), and diversify income by renting out land, for example.

In Machakos, most households were mainly concerned about crop failure and water deficit-related issues. To cope with these, they suggested increasing water storage capacity and using irrigation, while to adapt households would plant drought-tolerant crops and use several planting dates.

Crops to adapt to recurrent drought

In nine of the 12 sites, households mentioned changes in cropping to adapt to lack of food due to drought or other reasons. Most people want to diversify cropping, by including drought-resistant crops and cultivars, and some people suggested trying intercropping. We asked households which were their preferred crops because of their resistance to drought. People named 17 crops in total, but there were five which were often mentioned across sites (Figure 18). Millet (including brush, finger and sugar millet) was mentioned by 57% of the respondents at 10 sites, cassava by 53% and sorghum by 43% both at nine sites, cowpeas by 13% at four sites, and maize by 12% at seven sites. Cassava was more often mentioned at the high rainfall sites, while sorghum and millet were chosen at the lower rainfall sites.

Knowledge of drought-tolerant crops contrasts with the cocktail of crops that households plant on their farms (see Figure 13). Millet is only grown at six sites, and by few households (15% of the households), sorghum is grown at five of the sites (10% of the households), and cassava is grown at three of the sites (12% of the households). Maize is the dominant crop present at most sites.

We asked households what would be the options for the future if it gets drier and rainfall becomes more erratic. The respondents mentioned fewer options (13 crops) drawing from the list of crops known to be tolerant to drought (Figure 19). Millet, sorghum and cassava were still the main choices, but the number of sites and people mentioning them decreased. Millet was mentioned at seven sites by 33% of households, and sorghum at seven sites and cassava at eight sites, both by 21% of households. The shorter list of crops for a much drier future reflects farmers' perceptions that they may run out of farming options. We did not ask householders to compare the effectiveness of on-farm versus off-farm activities. It seems though that they may pursue as diversified as possible farming and non-farming portfolios.

Plans for the future changes in livestock production

We asked livestock owners whether they had plans to modify their livestock populations in terms of numbers and species. The basis of comparison for the planned changes was the number of livestock that the household owned at the time of the survey.

Most livestock owners plan to increase their livestock numbers in the future (Figure 20). Except for Masaka where households are not interested in goats, and Kajiado where few households plan to increase their numbers (30% of the households), most households (60-100%) at the other 10 sites said they had plans to increase flock and herd sizes.

Sheep were present in fewer sites than goats and cattle. In North Pokot and Kajiado more than 50% of the households reported plans to increase flock size in the future. At the other sites, 30% of households in West Pokot and 20% in Samburu and Baringo plan to increase the number of sheep in their flock.

Plans to decrease cattle and goat numbers were mentioned in Kajiado and Kwale. Between 10 and 33% of livestock owners in six sites (Figure 20 C) indicated no plans to change their herd sizes in the future. These were 10 % in Kajiado and West Pokot, 13% in Machakos, 33% in Singinda, and 20% in Chiruhura and Lwengo. In Kajiado and Baringo, 20 and 10% of the households, respectively, reported no plans to change their sheep numbers. In both Baringo and Kajiado about 20% of the households reported no future plans to change the number of goats.

Households mentioned various reasons to increase their livestock numbers, most of them more related to commercial purposes (e.g., sale of milk, animals sales, and financing purposes) than to increasing consumption of animal products (Table 20). Having more livestock as a form of savings, and to finance future expenditures or unexpected emergencies, was mentioned at all 12 sites. At 10 of the sites households were interested in increasing livestock numbers to increase the volume of milk for sale for both cattle and goats.

The main strategies to increase cattle and goat numbers were increasing recruitment rate (mentioned at nine of the sites), improving health (eight sites), increasing genetic merit (six sites), and increasing reproduction rates (three sites) and reducing mortality rates (two sites). Fewer households had sheep. The main strategies suggested to increase sheep numbers were increasing recruitment rates and improving health.

Increasing livestock productivity

We asked households how they intended to increase livestock productivity and which strategies they might use to achieve this. They listed one or more strategies and ranked them according to their expected effectiveness to achieve increases in production.

In 10 of the 12 sites, households wanted to increase the productivity of all their livestock species. Clear exceptions were Kishapu in Tanzania, and Nebbi in Uganda, where few households were interested in increasing livestock productivity. The ranking of the strategies varied across sites (Table 21). However, improved breeding was the highest ranked strategy for the higher-income sites (Kajiado, Kishapu, Mbarara, Nebbi, Masaka, and Machakos). Improved feeding was mentioned at all sites, but ranked higher in the relatively low income and low annual rainfall sites. Improving livestock health was ranked high in three sites, West and North Pokot in Kenya and in Singida.

7 Possible future changes in the sample sites

Possible changes in crop yields as a result of climate change

For the 12 sampling points shown in Figure 2, several of the crop models in the Decision Support System for Agrotechnology Transfer (DSSAT) software suite (ICASA, 2011) were run, to estimate changes in yields as a result of climate change from current conditions to the 2090s. Crop models were run for maize, cassava, millet, sorghum, bean, and cowpea.

For input data to the crop models, the best available agricultural soil (Table 22) was selected from those available from the FAO soil mapping unit (FAO, 1998). Although this might not be the soil occupying the major area of the mapping unit, it was selected so that there would be sufficient area for the cultivation of crops. This method was chosen against using the major soil of the area because all of the sample areas are at least somewhat marginal for cropping and so crops could reasonably be expected to be restricted to the best available soil. Climate data were simulated for the ECHAM5, CSIRO3, MIROC3 and CNRM_cm3 climate models using the GCM4 module (Jones et al., 2009). Fifty-two replicate years were simulated for each of the SRES emission scenarios A1b, A2 and B1 for each of the 12 sample sites. The same initial random number seed was used for each run to entrain the simulations as much as possible. Fifty replicates were used for model runs, the extra years allowing for carry-over of season from one year to the next.

The design of the simulation experiments allows for a variety of analyses of variance. There is the variance within each run of 50 replications. This is of particular interest when considering the number of years on which a farmer will get a sufficient yield, but is difficult to incorporate into comparisons of treatments, sites, GCM models and scenarios used in the simulation. The standard error of the mean of the replicated runs is defined by the number of replicates in the run, so the longer the run, the smaller the standard error of the mean of the run. This clearly cannot be used as an error term in any analysis of variance. We thus looked at the number of years in which yield falls below a given criterion. That is analysed as a general linear model with a binomial distribution and a probit link function. This provides a measure of the deviance for each added effect in the model and a deviance ratio, which is related to the variance ratio of the standard analysis of variance. The significance of individual effects within the analysis can be noted from the associated *t* value.

For the yield data means we need an analysis of variance. The model was planned as a balanced design with no replicates (the replicate years being hidden from the analysis, but necessary to get both stable yield estimates and the variance between years for the reliability analysis). The sources of error in the analysis are the uncertainties due to the outcomes of the GCM models and the emissions scenarios used. With 12 sites, four climate models and three scenarios at two simulation years (which give us the effect of climate change) in addition to agronomic factors (two fertilizer treatments and two harvest dates in the case of cassava and merely three fertilizer treatments for the grain crops) this gives plenty of degrees of freedom for the error term.

In the first analysis all of the degrees of freedom with anything to do with climate model or scenario were combined into the error term. If any effect is due to climate change based on this test it is judged to be robustly independent of the climate model used or the scenario it was run under. Nevertheless, we do expect some effects of climate model and scenario because they represent different views of the possible future, and these are interesting from the perspective of seeing how different climate projections translate into crop growth in realistic scenarios. We would also like a general idea of how different the outcomes would have been under different climate models or scenarios. A second analysis was carried out for each of the crops with some of these affects added in to the analysis of variance. Where reasonable significance was achieved the resultant means were tabulated.

Detailed results of the crop model runs are presented in Appendix A. Table 23 and Table 24 summarise the mean simulated yields per ha and the percentage of years in which yields fall below a certain threshold. These tables show clearly that the effects of climate change are dependent on crop and on location. Despite the considerable uncertainties, the IPCC (2007) noted reasonable consistency between different climate models in projecting 5-20% increases in rainfall amounts for the June-August period in East Africa (changes in rainfall amounts for the December-January period are inconsistent). By the 2090s, average temperatures over the whole region are projected to increase, the degree of warming dependent on the emissions scenario used. Rainfall in some of the sample pixels is projected to increase also, but not in all. The impacts on crop yields are similarly variable, and these results are broadly in line with other work carried out in the region (e.g., Thornton et al., 2009).

An interesting observation from Table 23 and Table 24 is that in these sample pixels, the preferred crop (maize) does not in general do very well under current conditions, in terms of yield, nor does it seem well-suited to the future conditions of the 2090s, in that yields decline in most pixels and the probability of crop failure increases in two-thirds of pixels. In terms of yield, cassava (and even sorghum and cowpea) show higher and more resilient yields into the future.

It should be noted that recent work has suggested that the IPCC AR4 climate models are missing some key physical processes for East Africa, and that the region may in fact be drying up, a trend that could continue into the future (Williams and Funk, 2011).

Impacts at the household level

We explored alternative scenarios using households' options for cropping and livestock keeping in a future that might get drier. The scenarios were compared to a baseline which represents the current situation of the farm households across sites.

We used a simple linear programming household model that optimizes the use of the land to allocate crops that meet the household demands for food (current food self-sufficiency) while it maximizes income. For each simulation, the model keeps track of food self-sufficiency and food security, and farm emissions due to crop and livestock production. We report farm profit per capita, after meeting the consumption demands reported by the households. The model is parameterized using technical coefficients derived from the household survey (i.e. crop yields and livestock production, food consumption, prices of inputs and outputs), and simulated data for crop yields and emission coefficients. Emission coefficients were derived from Herrero et al. (2011). Household model parameters are included in Appendix B.

Scenarios

The scenarios investigated include several variants of the baseline with stepwise explorations, using current climate and yields. The future scenarios use simulated yields reported in the previous sections. We did not include expenses other than those in agricultural inputs to calculate farm profits.

Scenario 1: Households maximize profit (Profit maximisation)

Allocation of land to different crops maximizes profit and there is no consumption of home-grown products. Livestock numbers are constrained to the maximum herd size observed in the sample, and sales are determined by off-take rates from the survey. We estimate profit on the basis of the households´ resources, current prices and costs. Here we assumed that households have the investment capacity to grow the most profitable crops.

Scenario 2: Households maximize profit meeting goals of food self-sufficiency (Food for home)

Allocation of land to different crops is constrained by current food self-sufficiency of crops determined by current diet and consumption patterns. The cropping portfolio is that observed on farm, and areas are adjusted to meet the goals.

Scenario 3: Households adapt by growing drought tolerant crops (Adapt cropping)

In this scenario households are assumed to modify their diets and therefore allocation of land is constrained for maize and beans. Crops for home consumption are those mentioned by the households as drought tolerant. Households grow a minimum of millet, sorghum and cassava, cow peas and pigeon peas using current yields, costs and prices. Households are assumed not to modify livestock numbers.

Scenario 4: Households increase herd sizes (More livestock)

This scenario uses the same land allocation as *Food for home*. Households are assumed to purchase more animals of the species and breeds they indicated. Recruitment rates were estimated from the baseline survey, and increased by 10-20%. We estimate here the investment needed and the feeds and areas that will be required to sustain the increased herd and flock sizes.

For each of these scenarios we calculated the areas under grassland needed and resulting food security and food self-sufficiency indices, and emissions using simulated emission coefficients per livestock head and per ha of cropped land. Food security was calculated as the ratio of the farm profit and the expenditure on food for each scenario. In the case of the profit maximization scenarios, households would have to purchase all their food. For the other scenarios, households would only purchase the additional food items that complement their diets – derived from the survey data. Subsequently, we tested the same scenarios including the effects of climate change on yields as simulated by the crop simulation models.

Results are presented in Table 25 and Table 26.

Household impacts in Kajiado

Households utilise some of the crop and livestock production for home consumption (*Food for home*). That covers about half of their energy needs. If households would meet that demand and still maximize profit, most cropland would be cultivated with beans and cowpeas (60%), and the rest planted to maize (22%), cassava (12%), and green grams (6%). They purchase the rest of the food for consumption mostly with income generated from the sale of livestock products and the rest of the crop products. They would be most of the time food secure.

If households would be maximizing income without producing food for home consumption, they would most likely produce mono-crops of legumes (common beans, cowpeas, or green grams) or a combination of these. These crops do relatively well in the soils and climate of the region, and have lower costs and higher market prices for the outputs than cereals. Following this strategy would allow households to be food secure, if there is no drought. It is unlikely though that they would sell all the food they produce.

If households were to implement their own plans to adapt, change their diets, plant more drought-tolerant crops and limit the amount of land allocated to beans to a maximum of 30%, profit drops by about 26% compared with the *Food for home* scenario. The cropping portfolio would be diversified, and food self-sufficiency would rise to about 60%. Most land would be allocated to sorghum (29%), followed by cassava (19%), millet (12%), green grams (12%) and cowpea (11%), all mentioned by the households to be dryland crops.

Most livestock owners in Kajiado wanted to increase cattle and small ruminant numbers (see Figure 20). For the explorations, we assumed that recruitment rates were increased to 20-30%, which represented purchasing 8 cattle, 3 goats, and 11 sheep. We assumed that ther increase in herd size results in increased income and not in increased consumption of animal products. The investment needed would be about USD 2700, 134% of the annual farm profit without considering returns to family labour. This scenario would also imply an increase of about 50% in the grazing land required to feed the additional livestock.

The climate of the 2090s is projected to become more favourable for cropping in Kajiado. So for all four scenarios, assuming no other changes are introduced and that higher yields do not imply higher costs, it appears that households would benefit from the effects of climate change in cropping. Because climate would more favourable for maize than other crops, in the *Food for home* scenario households might be allocating larger areas to maize (28% of the land) for producing grain for the market, and smaller areas to cassava and cowpea. Households might also choose to increase food self-sufficiency using the additional grain produced. In the profit maximization scenario, households would benefit from growing legumes (i.e. beans or cowpeas) as a monocrop, although combinations with maize are more likely. A scenario of adapting cropping would make sense from a risk management perspective, but not from a profit maximization perspective. A shift of diets towards sorghum, millet and cassava, that would meet a 60% food self-sufficiency target of the adapt scenario with current climate, would lead to a lower farm profit (34%) than cultivating maize and beans to satisfy food consumption. Increasing livestock numbers might be possible, if the future climate is also favourable for rangeland production.

Household impacts in Machakos

In Machakos, households would be food secure under all scenarios farming with their current resources (3.5 ha of land and 16 animals) and under current prices for inputs and outputs. They can also meet food self-sufficiency of current diets, cropping their land with maize (67%), beans (25%), pigeon peas (5%), and cassava (3%), which includes a consumption of 28 g of animal protein per capita per day.

Most households in Machakos mentioned cassava, millet, sorghum and pigeon pea as drought-tolerant crops and recognized water shortages as an important constraint for farming. If the households would shift their diets to consume more cassava and small amounts of maize, millet, sorghum, beans and pigeon peas, farm profit would increase. That would imply cropping 60% of the land split equally among cassava, millet and sorghum to meet dietary requirements, and the rest to beans (7%), maize (3%), and pigeon peas (27%) to generate profit.

Projected changes in climate to the 2090s would increase the yields of most crops cultivated in Machakos. So under all scenarios households would benefit from more productive croplands. In particular, a diverse cropping portfolio would increase profit at the farm level. Increasing livestock numbers appears profitable too. However, increases in numbers would increase the need for feeds, an equivalent of an additional 2-4 ha of grasslands or land being allocated to feed crops. This could create strong competition for land, especially in the future with higher population densities at this site.

Household impacts in Samburu

Explorations in Samburu were simpler than in the other sites because the households do not practise cropping, and depend largely on off-farm income and food aid. We first determined for the profit maximization scenario the minimum herd and flock sizes that would allow households to be food secure with current costs and prices for livestock products. Selling the products of the actual herd size of 20 animals would allow household to achieve about 80% food security (i.e., generating 80% of the income needed for purchasing the products that make up the current meagre diet, see Figure 8).

Subsequently, for the *Food for home* scenario we introduced as a constraint for profit maximization the current consumption of animal products and calculated the livestock numbers and resources needed to feed the animals. The households would need 56 animals (4 cattle, 34 goats, and 18 sheep) to make some profit and at the same time meet the actual consumption of animal products of 8 g of animal protein per capita per day. Households in Samburu purchase relatively small amounts of grain legumes, adding about 3-4 g of plant protein to their diet. So these households are most likely far below the 40-50 g protein recommended by WHO (2002). We then explored the herd and flock sizes that would allow households to double protein intake and make them more food secure. The profitability of such a scenario is low, with 102 head of livestock, which require about 65-93 ha of grazing land, and even then food consumption is still far from adequate. The investment required for increasing animal numbers from 20 to 106 (mostly small ruminants) would be about USD

2600 per household.

Finally, we evaluated the profitability of having larger herds for marketing products (*Profit maximization* scenario) without meeting food consumption goals. This would create a profit of about USD 0.2 per capita per day, which would allow households to purchase the food items people consume under current diets. It will not, though, improve food intake significantly. For Samburu, we have not explored the effects of climate change, since this will most likely affect grassland production for which we do not yet have robust information available.

Household impacts in Mbarara

In the *Food for home* scenario only about 50% of the land is allocated to crops to meet the household's food consumption and make a little profit with the surplus. These households can achieve food security and food self-sufficiency. They have pieces of private land allocated to grazing – a median of 180 ha. So in principle, with this amount of land they could feed their own livestock.

In a *Profit maximization* scenario, households would allocate all their land (2.6 ha) to cooking banana production, increasing profit three-fold. In the *Adapt cropping* scenario, households would choose to crop more cassava and plant a small area to millet, to minimize the effect of drought on crop yields and diversify cropping. They would also cultivate all the cropland to increase farm income. After meeting the home consumption of food target, households would allocate a large share to cooking bananas for the market (60% of the land), and the rest would be allocated to cassava, millet, maize, and beans. Most households in Mbarara would like to increase both cattle and goat numbers. For the *More livestock* scenario, we assumed a recruitment rate of 20% for both species, and assumed that 20% of the purchased goats produce milk. These changes all result in an increase of farm profit of 20%, an increase in the requirement of grazing land of 20-40%, and an investment of USD 3400 per household.

The climate of the 2090s would mostly benefit crop production in Mbarara. We assumed a similar effect of climate on bananas as that on cassava, with an increase of about 30% in yields. Under these circumstances, and in the *Profit maximization* scenario, households would still plant monocrops of cooking bananas, increasing profit three-fold compared with the *Food for home* scenario. In the *Food for home* scenario – keeping constant the land allocated to crops – households would also benefit in the climate of the 2090s. Profit would increase about 20% and food security would be higher. A change in climate and yields would also be favourable for the *Adapt cropping* scenario. The choice of a more diverse cropping portfolio would increase farm profit by 17%. Changes in yields do not have an effect in the *More livestock* scenario, unless of course there is competition for resources (e.g. labour or cash) to be invested in crop or livestock production.

Household impacts in Baringo

Householders in Baringo are traditional pastoralists. Cropping is relatively new in the area, and the cropland is communally owned. Land parcels allocated to each household are small (around 0.25 ha), although some expansion could be possible into the river banks. Household purchase most of the crop products of their diet, with home production contributing about 2 MJ per day to the total energy intake. The rest of the food must be either purchased or provided as food aid. In the *Food for home* scenario therefore, households achieve about 20% of food self-sufficiency and about 80% of food security with some 57 head of livestock. Farm profit is not enough to make these people food secure.

Under the *Profit maximisation* scenario, and given current resources, households would achieve food security in relation to current diets. In the *More livestock* scenario, households have to increase their herd size to about 85 animals to be food secure (i.e., they purchase food items to make a diet of 10 MJ per day per capita, comparable to that of Machakos). Increasing the livestock numbers from 57 to 85 would require an investment of about USD 1300 per household, to purchase mainly goats and sheep. An expansion of the cropping area to 0.6 ha per household in the *Adapt cropping* scenario would allow households to improve food self-sufficiency to 33% in the area. However, increasing the low yields of maize, beans and cowpeas would be certainly more effective, provided that farm inputs and extension services become available to reduce production costs.

Current livestock populations in Baringo require that each household has on average 42-84 ha of grazing land, given the poor quality of the feeds in the region. Increasing herd sizes to achieve food security would stress the environment even more, requiring 54-126 ha per household, without mentioning conflicts for water and pastures with other pastoralist communities.

Crop yields would be affected by climate to the 2090s. Crop model simulations indicate a reduction of 20-34% in the yields of maize and beans in the area. That would most likely also affect rangeland productivity and therefore increase the amount of land each household would need for survival. We have not estimated the impacts of climate change on rangeland productivity.

Household impacts in West Pokot

Households grow maize and cowpea on relatively small areas of cropland. Farm production satisfies only about 35% of food requirements and about 80% of the food security index, and households have to purchase food with the income from livestock. To feed the 64 livestock that households own on average, requires 50-100 ha of rangeland with a productivity of 1-2 tonnes of biomass per ha. In the *Profit maximisation* scenario households would be food secure, being able to purchase the food items of the current diet.

Following households' intention to increase livestock numbers, we explore in the *More livestock* scenario the consequences of having 30% more goats and 10% more sheep. Food security would increase 20%, and the land required to feed the livestock would increase to 60-118 ha per household, depending on the quality of the feed. The investment required to purchase the additional goats and sheep would be about USD 350 per household.

The *Adapting cropping* scenario in West Pokot tested a change in diets from one that is maize-cow pea based to a mixture of maize, cassava, sorghum, millet and cow pea; this was suggested by the households themselves as an adaptation to drought. Achieving 70% of food self-sufficiency, and a contribution of about 6 MJ per day to people´s diet, would require an expansion of cropland from 0.7 to 1.2 ha, or an increase in yields due to better management and input use.

According to the model simulations, climate change to the 2090s would have a positive effect, almost doubling yields of maize and cowpea. Under these circumstances, in the *Food for home* scenario, households would achieve 100% food security with their current poor diets, and would be able to improve diets in a *Profit maximisation* scenario without achieving food self-sufficiency, and cropping only maize. Increasing livestock numbers has a similar effect, increasing food security 20% compared with *More livestock* with current climate and assuming no increases in food self-sufficiency and animal protein intake. In the *Adapt cropping* scenario and because of the yield increases, food security could increase almost four-fold, keeping food self-sufficiency constant. Much of the additional income would be provided by the cropping, contributing to about 44% of the farm profit compared with no contribution in the *Adapt cropping* scenario with current climate.

Household impacts in North Pokot

With current farm production structure and resources, households from North Pokot achieve about 65% food self-sufficiency by cropping 1 ha of land with only maize and beans in the *Food for home* scenario. They achieve food security with current diets, thanks to the livestock production with 62 head of livestock. This requires the use of about 30-50 ha of rangeland per household to provide the feed.

In the *Profit maximisation* scenario, assuming households purchase all the food items needed for home consumption, they would be food secure with current diets, and would make some farm profit cultivating monocrops of cassava. However, it seems that it would be better to rely on on-farm produce for consumption due to the prices of food products that make up the diet in the region.

In the *More livestock* scenario, households would increase recruitment rate by 20% for cattle and goats, and by 10% for sheep. They would increase food security, but would need an additional 10-15 ha of rangeland per household to sustain the additional 10 animals and an investment of about USD 750 per household to purchase them.

A change in diets to include millet, sorghum and cassava in the *Adapt cropping* scenario, aiming at increasing food self-sufficiency to 90%, would not be profitable with current yields and areas allocated to cropping. Such a scenario would be possible only by reducing farm profit about 30%.

Model projections indicate that maize and beans yields would be reduced by about 30-50% under the climate of the 2090s. To achieve comparable levels of food security and food self-sufficiency to the *Food for home* scenario, households would need to crop 50% more land. In the *More livestock* scenario, impact of climate change on rangeland productivity might compromise the feasibility of households being able to increase herd sizes due to competition. In the *Profit maximisation* scenario, and assuming that households would need to expand cropland to compensate for yield declines due to climate change, a monocrop of cassava would still make the most profit. The *Adapt cropping* scenario with expansion of cropland would result in no changes in farm profit compared with *Food for home*. However, including a more diversified cropping portfolio with millet, sorghum, cassava and beans would be an advantage to deal with climate variability.

Household impacts in Kwale

Cropland areas per household (5.8 ha) are much larger in Kwale than at other sites. However, households cultivate few crops, and these at low intensity, resulting in low yields (less than 500 kg per ha). Main sources of income for these household are off-farm, and household use few inputs in crop and livestock production besides their own labour.

In the *Food for home* scenario, households cultivate all the land with maize, cowpeas and green grams. They meet 50% food self-sufficiency and would not be food secure, given current farm incomes.

An increase of 10 head of livestock in the *More livestock* scenario would require an additional 10-15 ha of rangeland and an investment of about USD 800 per household. This would increase food security with current diets. In *Adapt cropping*, households would consume more cassava, millet and sorghum – crops they indicated as drought tolerant. Having a diversified cropping portfolio with five crops would increase farm profit by 33%, and would allow households to achieve both food security and food self-sufficiency.

In the *Profit maximisation* scenario, households would cultivate monocrops of cowpea or green grams even at low yields because of the high market prices for the grain and the low input costs associated with production.

Climate change is expected to reduce the yields of the main cereals and legumes cultivated in the region of Kwale. Because households have relatively large areas of cropland they could still be food secure growing a combination of maize, cow pea and green grams. Climate change reduces food security and reduces farm profit in *Food for home*, *Profit maximisation* and *Adapt cropping* scenarios. The effect of climate change on crop yields is large enough for the main crops that diversification with the current crops and varieties would probably not be enough to overcome the effects. Methods to intensify crop production (e.g. fertilisers and spreading planting dates) could help to offset the effects of climate change on productivity and release land for other uses.

Household impacts in Singida

Most income (about 70%) is made off-farm in Singida. As in Kwale, where most income comes from off-farm, few inputs are used in crop and livestock production, resulting in relatively low costs for crop and livestock products. Relatively large areas of land are cropped mainly to millet with smaller portions cropped to green grams, sorghum and maize (which makes up the main diet).

In *Food for home*, households achieve about 60% food self-sufficiency and are food secure. They would crop large pieces of land to millet, sorghum and green grams to meet home consumption because of the low yields.

More livestock would increase food security slightly, while requiring 3-5 ha of rangeland and an investment of USD 260 per household to purchase one local (zebu) cow and three goats.

In the *Profit maximisation* scenario households would cultivate monocrops of millet, because of both the low input costs and relatively high market price for the grain. Farm profit would increase four-fold compared with *Food for home*. Yet, households would not be able to purchase the food items of their diet, with food security dropping to about 50%.

Households in Singida showed interest in cassava as an adaptation strategy against drought. Making cassava an important ingredient of the diet in the *Adapt cropping* scenario would make household food self-sufficient and food secure because it is expected that this crop would do well in the climate and soils of the region.

Model projections indicate that yields of the cereals cultivated in the region of Singida would increase 10-40% under the climate of the 2090s. That is why the farm profit with *Food for home* increases about 50%. This positive effect is even greater for the *Adapt cropping* scenario, in which cassava is introduced into the diet and occupies 23% of the cropland. The *Profit maximisation* scenario does not do much better under climate change. The best option to maximise profit is still a monocrop of cassava, whose profit is not enough to make households food secure.

Household impacts in Nebbi

Households in Nebbi make most of their income from cropping. Less than 30% comes from off-farm activities. In the *Food for home* scenario, households have relatively large farms (4.5 ha), mostly cropped to cassava (50%), with smaller areas cultivated with sorghum, millet, sesame and cotton. They achieve 100% food self-sufficiency, and make a profit from cropping. Having more livestock (20% more goats and cattle) does not modify food security much. The investment required would be about USD 230 per household. It could, however, help increase animal protein intake, but households usually prefer to keep their animals as savings and not as a means to increase consumption.

In *Profit maximisation*, households would cultivate monocrops of cassava. Although farm profit would be 2.5 times higher, food security would be lower than *Food for home*. In the *Adapt cropping* scenario households would first attain food self-sufficiency and then crop the rest of their land to market the surplus. That would result in a similar cropping pattern, but would increase the areas allocated to cassava to about 70%, increasing farm profit by 50%.

Yields to the 2090s would be reduced by the effect of climate change. That would have a direct negative impact on farm profit and food security under all scenarios. In Nebbi, household already cultivate the crops mentioned for their drought tolerance at all sites. They may adapt by choosing varieties of those crops that are more drought tolerant and that satisfy the standards for being used as food.

Household impacts in Kishapu

Households in Kishapu make most of their income on-farm. They cultivate relatively small areas (2.2 ha), most of it to maize (50%) followed by cowpeas, green grams, and sorghum. They own about 18 head of livestock, half cattle and half goats. In the *Food for home* scenario they produce most of the food (70% self-sufficiency) and are food secure thanks to the profits generated by the farm.

Increasing livestock numbers - 20% more cattle and 30% more goats - would increase food security, but would require 3-4 more ha of grazing land and an investment of USD 290 per household. It would be possible in *Adapt cropping* to achieve food self-sufficiency with the resources of the farm household. That would imply cropping more land to maize and millet, and reducing sales. Cassava would be incorporated in the cropping portfolio, occupying 50% of the area after meeting food self-sufficiency. In *Profit maximisation*, households would cultivate monocrops of maize, because it attains higher yields than the other crops.

Model projections to the 2090s indicate a 10-20% yield reduction for the main crops cultivated in the region of Kishapu. That would affect food security for all scenarios. However, the most sensible scenario appears to be *Adapt cropping*, in which households would be food self-sufficient and would generate farm profit from cultivating a number of crops. That should make households less vulnerable than planting monocrops of maize to maximise profit.

Household impacts in Masaka

In Masaka households also rely mostly on the farm for their livelihood. About 70% of their income comes from farm production, most of it from cropping cooking bananas, beans, maize, and cassava . Households achieve food self-sufficiency and generate farm profit in the *Food for home* scenario, cultivating 40% of the land with cooking bananas, another 40% with beans, and the rest with maize and cassava.

Having more livestock (20% more) would improve food security a little, but would require an investment of USD 320 per household - most likely taken from the profits from cropping - to purchase two head of cattle.

In the *Profit maximisation* scenario, households would cultivate monocrops of bananas, increasing farm profits, but this would compromise food self-sufficiency and diet diversity. In *Adapt cropping*, households would probably diversify to minimise the risks of crop failure. They already cultivate cassava, so they might allocate larger areas to millet and sorghum and smaller areas to bananas and maize. Having a diversified cropping portfolio reduces farm profit, but without compromising food self-sufficiency. This scenario might however be more climate proof than *Food for home* and *Profit maximisation*.

The climate of the 2090s would reduce the yields of the cereals by 15-20% but would increase yields of cassava and cooking bananas by 10-20%. Under all scenarios, farm profit decreases compared with current climate. However, households in Masaka might be food secure and food self-sufficient using a broad range of strategies.

Synthesis of impacts at the household level

1. Expected effects of climate change in the region are diverse. Several of the sites might benefit from the effects of climate change to the 2090s and so may not need a shift from being maize-based to including cassava and sorghum in the cropping portfolio. The cropping

of dryland crops, with their associated yields and production costs, would have negative impacts on farm profit, although diversification may help smooth the inter-annual income variability that can arise because of market price variability.

2. The model experiments presented here could not capture the effect of climate change on livestock through the production of feeds because in the study sites most livestock graze on rangeland and supplementation is not yet economically important. There was free grazing in cropland, which we also could not capture quantitatively with the methods used in this study. In 2012 we will be able to evaluate the impacts of climate change on rangelands in East Africa, with a newly-developed model, G-Range.

3. It is very likely that we have substantially underestimated the impacts of climate change on crop yields to the 2090s. The impacts of changes in climate variability have not been accounted for, although it is known that climate variability will increase in the future and these changes may have even greater impacts on households' agricultural production than changes in climate means (IPCC, 2007). In addition, changes in pest, weed and crop and livestock disease burdens into the future have not been accounted for.

4. Most people, except in the extreme cases of Samburu and Baringo, manage to generate the income needed to purchase the food items of their diet that are not produced on-farm. This does not mean that current diets are good and nutritious; on the contrary, people may just be attaining the food intake that is needed to survive. It is likely that the households identified as food secure may not be so food secure after all, as in several of the sites households depend heavily on food aid.

5. The *Profit maximization* scenario shows that there is room to increase profits, with current costs and prices. That often implies going for monocropping, even when farmers would get one good harvest only in every three years, especially in the higher rainfall sites. It is, however, very unlikely that farmers would practise monocropping as they are all interested in diversifying, trying different crops, and increasing livestock numbers. This shows that food self-sufficiency is a very important indicator for assessing any scenario. We suspect that farmers would not adopt options that would result in less food being produced for home

consumption. In all sites, household allocate much of what they produce to self-consumption.

6. Labour is the main ingredient of production costs everywhere. Intensification pathways need to consider that households may often be labour constrained: we may be wrong when we assume that adding inputs will result in direct increases in farm productivity. We have to bear in mind that there is often competition for labour within the farm and with all the other things that farmers do off-farm.

7. The market orientation implied in the *Profit maximization* scenario may make households vulnerable, as they would be dependent on buyers, prices and markets that they cannot influence. We demonstrate above, with a simple household model, the inappropriateness of profit maximization as a mode of production within the context of subsistence farming.

8. Increasing livestock numbers might be good for food security, if households would treat livestock as an enterprise, as they do crops. The problem arises when livestock enter the farm because farmers have difficulties selling animals or managing them to make a profit. That can be seen in disparate recruitment and offtake rates, and in the low livestock productivity indicators, such as milk production and number of milking animals.

9. Increasing livestock numbers requires a capital investment, may induce competition for resources, and may render households more vulnerable in the end because they may lose their capital due to drought or disease.

10. Climate change may create opportunities for diversifying cropping, and in some regions it may allow households to diversify their livelihoods by allowing cropping to start and/or become more intensive.

8 Scaling up the household model results

9 Discussion and next steps

The discussion below is structured under broad headings related to the five study questions set out in Section 2 of the report. We conclude with a brief discussion of next steps.

Evolving production systems

The work reported here indicates that there have been considerable changes in farming system at the sites studied over the last few decades. Livestock keeping has historically been the main activity of these households, generally in the form of nomadic pastoralism. Cropping in all but four of these sites has been introduced only in the last 50 years, and in the driest site (Samburu), cropping still does not occur at all (Figure 3). The drivers of the system changes observed are likely to be several and varied, and probably include socio-cultural shifts in attitudes and objectives as well as an increasing human population. A changing climate is also likely to be one such driver: Hulme et al. (2001) document the shifts in Africa's climate during the twentieth century. Whether anthropogenic global warming is causing further changes to the climate in East Africa is not known with any certainty at this time, although the perceptions of many householders are that the climate is now changing more quickly than in the recent past (Silvestri et al., 2011; Bryan et al., 2011).

Householders' farming systems are still evolving, and will continue to do so. Nearly all households are trying to diversify their farming systems, and in the future, most households want to increase their holdings of livestock. The major reason for this is that households want to increase sales and generate more income, although the desire for increased consumption of livestock products was also widely expressed. Increased incomes will also allow for more diverse household diets, even where crop diversity cannot be increased much because of climatic conditions, to supplement the current dietary dependence on maize.

There is little doubt that crop suitability for current staples in East Africa will continue to change, perhaps dramatically, towards the end of the century. Other studies of sub-Saharan Africa have indicated sometimes severe reductions in crop yields and suitability to mid-century, particularly for the cereals (Schlenker and Lobell, 2010), trends broadly in agreement with what we found here. At the same time, the impacts of climate change on cassava productivity in our sample locations are broadly positive, as found also by Jarvis et al. (2011) for sub-Saharan Africa in general. Although not widely grown at our study sites, pigeonpea is another crop that may be relatively resilient to projected climate change in the coming years (Dimes et al., 2009). Shifts in crop prevalence may come about not just because of the widely-recognised importance of crop diversity on household incomes, but because of improving suitability for particular crops. Considerably more work is warranted on the prospects of key crops such as cassava and pigeonpea that appear to be highly resilient to climate change and could thus provide important adaptation options for households struggling to become or remain food secure.

Similarly, there may be important adaptation potential in relation to shifts in livestock species and breeds. While this is not something that we investigated here, we are starting to investigate the impacts of such shifts on incomes and food security at the household level using models similar to those used in this study.

Transformational change?

The work reported on here arose in response to the notion that households might be forced to revert to nomadic pastoralism as climatic conditions deteriorate for cropping. To date we have found no evidence, in relation either to households' recent systems changes or to their expressed preferences for the future, to suggest that this may occur. It may be that the East African region has simply not seen adequate levels of climate change to enforce such system transformations. At the same time, several respondents to the survey indicated that they thought a return to nomadic pastoralism was not possible in the future anyway.

On the other hand, it may be that systems' evolution in the region is driven by additional factors that tend to militate against system extensification. The survey results shown in Figure 11 and Figure 16 indicate that there are very strong socio-cultural drivers operating in these systems. Even allowing for the uncertainty associated with survey questions that seek information about household income, most of the households surveyed are poor. For poor households in dry locations, livestock will be owned largely for cultural reasons; net household incomes are driven largely by cropping activities (see Figure 16 A) and by the diversity of activities that households engage in (Figure 16 D), and in the drier areas, householders will trade and work off-farm to make ends meet, and they will do what cropping is possible. In the wetter areas, households still keep livestock for cultural reasons, but more cropping can be done, and households may then be less dependent on off-farm income.

Survey results indicate quite clearly why we have seen no evidence of "reverse genesis" in East Africa: households want to keep livestock, and the great majority of households want more of them, not fewer; but at the same time, households want to grow crops for reasons of both attaining some self-sufficiency target and to generate income, as far as they can, and households are going to considerable lengths to do this. The taking on board of cropping activities in some of these environments is clearly not about systems integration, but it is about diversification of livelihoods in the face of highly variable, and probably increasingly variable, climate (opportunistic income generation). Whether some threshold will be reached in the future at some of these sites such that cropping has to be abandoned entirely is not known. Our crop and household modelling results, even though imperfect and in some important respects incomplete, suggest that this is not likely to happen any time soon, from a climatic perspective. Even if such thresholds were reached at some stage in the future, nomadic pastoralism might not actually be a viable livelihood strategy for several reasons, a point we return to below.

Poverty and food security

Survey results highlight again, if any reminder is needed, that rainfall is a key determining factor that affects household incomes and food shortages (see Figure 8 A, B). Almost all households surveyed are poor, and many are very poor. The average household in all sites bar one is below, and sometimes far below, the poverty line (the exception is Mbarara, with relatively higher rainfall and widespread dairy production) (Figure 11 A). Most households suffer food deficits at some stage during the year, whatever the rainfall, but the length of time that households suffer them increases markedly as rainfall decreases (Figure 7 and Figure 8). The survey data show this obvious point very clearly, and for many of these sites, there is little climate proofing that can be done for households that have such a reliance on natural resources in what are often highly marginal environments.

In addition to the considerable variability in household conditions between sites, there is enormous variability between households within sites in income, food security and self-sufficiency metrics, even in the wetter locations (see Figure 8 B, for example). Given the importance of rainfall and rainfall variability as a driving factor in these locations, the increases in climate variability projected for the future are likely to result in increases in between-household variability also. Some households may be successful in the future in adapting to climate change and taking advantage of the new opportunities that may exist in some places. But in many other places, as climate variability increases, the number of households below the poverty line is likely to increase (households shifting leftwards in Figure 8 A). A factor that will exacerbate this tendency is increasing competition for natural resources, particularly water, an issue that the survey highlighted as already being critical in many places, even (particularly) in the higher rainfall sites.

Many households in these sites are likely to see increases in food insecurity and poverty in the future as a result of increasing climate variability. Households are already vulnerable to drought, and questions need to be asked as to how existing coping mechanisms (see Table 19) will be effective in the future. Grain storage is one such mechanism, mentioned by respondents at nearly all sites across the rainfall gradient; but grain sales already largely drive household incomes, and in the same way as for saving cash, it is difficult to see such mechanisms being effective or even possible for many households.

The model results indicate that there may be ways of increasing incomes and decreasing household vulnerability with current resources, but that these have to be weighted up carefully in relation to households' requirements. As noted above, from a socio-cultural perspective, the livestock enterprise in the study sites can be seen almost as "background radiation" - they are ever-present, but livestock production *per se* contributes little to the household economy, compared with trading, off-farm activity and cropping. It is cropping that offers households the most opportunity for on-farm income generation, and the more crop diversity that is possible, the better, although high levels of cropping diversity are only really possible in the wetter areas.

Effects of system transitions

Perhaps the most remarkable preference for the future expressed by household respondents is the planned increase in the number of livestock in the future (Figure 20). This preference may be culturally conditioned, and for many households the prospects may be remote of finding the capital needed to invest in livestock, but the implications of this could be considerable. In a sense, it is one piece of the "reverse genesis" idea, perhaps: more dependence on livestock, but not at the expense of cropping activities.

A widespread transition to agriculture dominated by mobility, regardless of what happens to household cropping activities, would be a relatively extreme adaptation pathway in marginal environments. The modelling work indicates that increasing livestock numbers could in fact reduce household vulnerability. At the same time, there are certainly other possible options for these regions that we have not explored here, including using the land for biofuel production, for more commercially-orientated farming, and for large-scale carbon sequestration as a contribution to climate change mitigation, for example. Whether such land-use transitions could be managed equitably and efficiently, even if seen as desirable, is an open question. For instance, the implications of widespread nomadic pastoralism would doubtless be profound, socially, environmentally, economically and politically. But there would still be important implications of essentially sedentary households increasing livestock numbers. First, this would have impacts on natural resources and the environment. Livestock feed deficits are already a major concern among households, as is the availability of water for both human and livestock use. Substantial increases in livestock numbers could exacerbate the degradation of rangelands in some places, and large-scale development of groundwater resources in strategic places might be the only way in which livestock could be adequately watered. Second, increases in livestock numbers are very likely to lead to increasing conflicts over natural resources, particularly land and water. Insecurity, violence and theft are already mentioned as concerns by households in five of the 12 sites surveyed. Although the relationship between climate change and conflict is complex and a subject of much current debate, there is little doubt that increases in climate variability will tend to increase the probability of conflicts over natural resources (Barnett and Adger, 2007), particularly in more marginal environments. Third, many pastoralists themselves already feel excluded and marginalised from national democratic and political processes (BurnSilver et al., 2008). Substantial increases in livestock populations in the rangeland and mixed systems in East Africa are likely to do nothing to assist in the integration of pastoralist communities into national policy processes. This is particularly so in view of the fact that movement of livestock in search of feed resources would remain the key management strategy for pastoralists, even if not fully nomadic. And in any case, this movement within landscapes is becoming increasingly difficult in East Africa, for several reasons (BurnSilver et al., 2008). To bring the socio-cultural expectations of different groups in society together requires serious political will at the national level, and this does not yet exist.

Policy and institutional implications

The work described here suggests several policy implications. First, something can be said with regard to human nutrition and what some call the maize dependence of the region. It is true that in terms of its nutritive value, maize is similar to other cereals (slightly superior to wheat, slightly inferior to rice). At the same time, the diets of many people in the region that are built around maize are largely protein deficient, and reliance on maize as a regional food security strategy may be increasingly risky in view of its susceptibility to climate change impacts. Some policy measures to increase the consumption of cassava, sorghum, millet and legumes such as pigeonpea could be highly beneficial for future food security in the region. Encouraging people to modify their diets, thereby creating a demand pull, is not easy, but it might be possible to develop marketing strategies and school programmes (or even consider price incentives) that could help in this regard.

Households at the drier end of the rainfall spectrum may well in the future be beyond any conceivable tipping points for self-sufficiency and food security. The numbers of such households may be relatively low, but their vulnerability will be very high, and policies will be needed to support them with safety nets and through market and infrastructure (roads, water, crop and livestock input services) development. These households are not likely to move, and they are not going to stop keeping livestock. For households in the wetter areas, what would seem to be needed is a concentration on risk management through crop diversification or dairy development, where that may be possible, again in concert with market development for reaching the growing populations in the urban and peri-urban areas of the region. Other ways of managing risk would be worth exploring, such as the development and dissemination of better short- and medium-term weather forecasting, so that cropping becomes somewhat less opportunistic in the drier areas. Expansion of existing crop and livestock insurance schemes might also be feasible in places.

In general, the Boserupian processes of farming systems evolution, whether forwards or in reverse, do not appear to be operating in East Africa but are largely overshadowed by enormously powerful socio-cultural processes. The work has highlighted the need for some agricultural technology development, nonetheless. The diversity of activities in general that households undertake, and the diversity of crops grown in particular, are strongly and positively related to household income. Indeed, households themselves identified the need for greater diversity of crops that are able to function in these environments, and this warrants development of a clear research agenda. Households also outlined their need, and preferences, for improved drought-tolerant crops, particularly sorghum, millet, cassava, and cowpeas. In addition to the associated crop breeding agenda, addressing seed distribution systems would be important, together with knowledge transfer on what can be done with these somewhat non-traditional food crops in relation to cooking, processing, and value addition.

Many of the households in the study sites described in this report face a wide array of problems, including poverty, food insecurity, and grossly inadequate diets if household members are to reach their full human potential. The future is highly uncertain, but the outlook is not good. At a minimum, these areas will need highly targeted schemes that promote livestock ownership, extend knowledge about cropping and crop diversification, and facilitate risk management where this is appropriate, as well as efforts to broaden income-generating opportunities both on-farm and off-farm, where this is feasible. A prerequisite for such efforts is physical security, without which any coordinated facilitation of systems change is increasingly likely to be impossible.

Next steps

There is astonishing dynamism in these farming systems, much of which seems to be driven as much by socio-cultural factors as by agro-ecological factors. Most of these households are already on the margin, and many are facing the prospect of increased food insecurity and more variable income in the coming decades. There is considerably more to be learned from further analyses of this data set, including the relationship between incomes and distances to markets, and the identification and evaluation of new and different options for increasing both household income and food security, for example.

Further study of households in these types of systems in East Africa and in other regions is also warranted: better understanding of these dynamic systems, what drives them, what are the options and (especially) the trade-offs. The household modelling work outlined in Section 7 above could usefully be extended to include the running of scenarios that look at higher-input cropping and improved diets for animals, where this is feasible. Quantifying the impacts of species shifts of livestock would also be useful, as would investigating the impacts of possible changes in climate variability in the coming decades at these sites.

As agricultural systems continue to change, one way to connect farmers to their possible future climates is via farm visits. Farmer-to-farmer exchanges between homologous sites (a location that experiences climatic conditions now that are characteristic of how the climate will be in another location the future) have the potential to integrate participatory learning principles, in order to promote knowledge sharing between producer communities. This approach is being tested elsewhere (see "Farms of the Future", ccafs.cgiar.org/our-work/research-themes/progressive-adaptation/farms-future) and could be used to identify high-potential adaptation pathways in target communities.

References

Baltenweck I, Staal S J, Ibrahim M N M, Manyong V, Williams T O, Jabbar M, Holmann F, Patil B R, Herrero M, Thornton P K, de Wolff T, 2003. SLP Project on Transregional Analysis of Crop-Livestock Systems. Level 1 Report: Broad dimensions of crop-livestock intensification and interaction across three continents. International Livestock Research Institute (ILRI), Nairobi, Kenya.

Barnett J, Adger W N, 2007. Climate change, human security and violent conflict. Political Geography 26, 639-655.

Boserup E, 1965. The condition of agricultural growth: the economics of agrarian change under population pressure. Aldine Publishing Company, London.

Bryan E, Ringler C, Okoba B, Koo J, Herrero M, Silvestri S, 2011. Agricultural Management for Climate Change Adaptation, Greenhouse Gas Mitigation, and Agricultural Productivity: Insights from Kenya. IFPRI Discussion Paper 01098, 42 pp.

BurnSilver S B, Worden J, Boone R B, 2008. Processes of fragmentation in the Amboseli ecosystem, southern Kajiado District, Kenya. In: K A Galvin et al. (eds), Fragmentation in Semi-Arid and Arid Landscapes: Consequences for Human and Natural Systems, pp 225-253. Springer, Dordrecht.

Center for International Earth Science Information Network (CIESIN), Columbia University; and Centro Internacional de Agricultura Tropical (CIAT), 2005.Gridded Population of the World Version 3 (GPWv3): Population Density Grids. Palisades, NY: Socioeconomic Data and Applications Center (SEDAC), Columbia University. Available at http://sedac.ciesin.columbia.edu/gpw.

Challinor A J, Wheeler T, Garforth C, Craufurd P, Kassam A, 2007. Assessing the vulnerability of food crop systems in Africa to climate change. Climatic Change 83, 381-399.

Challinor A J, Ewert F, Arnold S, Simelton E, Fraser E, 2009. Crops and climate change: progress, trends, and challenges in simulating impacts and informing adaptation. Journal of Experimental Botany 60 (10), 2775–2789.

Dimes J, Cooper P, Rao K P C, 2009. Climate change impact on crop productivity in the semi-arid tropics of Zimbabwe in the 21st century. In: L Humphreys(ed), Proceedings of the Workshop on Increasing the Productivity and Sustainability of Rainfed Cropping Systems of Poor, Smallholder Farmers, Tamale, Ghana, 22-25 September 2008. The CGIAR Challenge Program on Water and Food, Colombo.

Dixon J, Gulliver A (with Gibbon D), 2001. Farming systems and poverty: Improving farmers' livelihoods in a changing world. FAO and World Bank, Rome and Washington, DC.

FAO, 1998. Digital Soil Map of the World and Derived Soil Properties, Original scale 1:5.000.000. FAO/UNESCO. FAO 1998. Rome, Italy.

FAO/IIASA/ISRIC/ISS-CAS/JRC, 2009. Harmonized World Soil Database (version 1.1). FAO, Rome, Italy and IIASA, Laxenburg, Austria. http://www.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/index.html

Gijsman A J, Thornton P K, Hoogenboom G, 2007. Using the WISE database to parameterise soil inputs for crop simulation models. Computers and Electronics in Agriculture 56, 85-100.

Herrero M, Thornton P K, Havlík P, Rufino M, 2011. Livestock and greenhouse gas emissions: mitigation options and trade-offs. In: E Wollenberg, A Nihart, M L Tapio-Bistrom, C Seeberg-Elverfeldt (eds), Climate Change Mitigation and Agriculture, Earthscan, London (in press).

Hijmans R J, Cameron S E, Parra J L, Jones P G, Jarvis A, 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25, 1965-1978.

Hulme M, Doherty R, Ngara T, New M, Lister D, 2001. African climate change: 1900–2100. Climate Research 17, 145-168.

ICASA, 2011. The International Consortium for Agricultural Systems Applications website, www.icasa.net/index.html

IPCC (Intergovernmental Panel on Climate Change), 2007. Climate Change 2007: Impacts, Adaptation and Vulnerability. Summary for policy makers. Online at http://www.ipcc.cg/ SPM13apr07.pdf

ILRI, 2006. Shapefile of ward level (4th admin unit) census data from Tanzania National Census

Bureau 2002 population census. From the ILRI Spatial Database. International Livestock Research Institute (ILRI), Nairobi, Kenya.

Jarvis A, Reuter H I, Nelson A, Guevara E, 2008. Hole-filled seamless SRTM data V4, International Centre for Tropical Agriculture (CIAT), available at http://srtm.csi.cgiar.org

Jarvis A, Ramirez-Villegas J, Herrera B V, Navarro C, 2011. Is cassava the answer to African climate change adaptation? Tropical Plant Biology (submitted).

Jones P G, Thornton P K, Diaz W, Wilkens P W, 2002. MarkSim: A computer tool that generates simulated weather data for crop modeling and risk assessment. CD-ROM Series, CIAT, Cali, Colombia, 88 pp.

Jones P G, Thornton P K, 2009. Croppers to livestock keepers: livelihood transitions to 2050 in Africa due to climate change. Environmental Science and Policy 12 (4), 427-437.

Jones P G, Thornton P K, Heinke J, 2009. Software to generate characteristic daily weather data at any resolution using downscaled climate model data from the IPCC's Fourth Assessment. Online at https://hc.box.net/shared/f2gk053td8

Karanja N K, Ayuke F O, Swift M J, 2006. Organic resources quality and soil fauna: their role on the microbial biomass, decomposition and nutrient release patterns in Kenyan soils. Tropical and Subtropical Agroecosystems 6, 73-86.

McIntire J, Bourzat D, Pingali P, 1992. Crop-livestock interaction in Sub-Saharan Africa. World bank, Washington DC, 246 pp.

Monfreda C, Ramankutty N, Foley J A, 2008. Farming the planet: 2. Geographic distribution of crop areas, yields, physiological types, and net primary production in the year 2000. Global Biogeochemical Cycles 22, GB1022, doi:10.1029/2007GB002947.

Nelson A, 2007. A global 1-km accessibility (cost distance) model using publicly available data. Dataset and notes, Joint Research Centre (JRC), Ispra, Italy.

Payne R W, Lane P W, Ainsley A E, Bicknell K E, Digby P G N, Harding S A, Leech P K, Simpson H R, Todd A D, Verrier P J, White R P, 1987. GENSTAT 5 reference manual. Clarendon Press, Oxford.

Ramankutty N, Evan A T, Monfreda C, Foley J A, 2008. Farming the planet: 1. Geographic distribution of global agricultural lands in the year 2000. Global Biogeochemical Cycles 22, GB1003, doi:10.1029/2007GB002952.

Robinson T P, Franceschini G, Wint W, 2007. The Food and Agriculture Organization's Gridded Livestock of the World. Veterinaria Italiana 43 (3), 745–751.

Schlenker W, Lobell DB, 2010. Robust negative impacts of climate change on African agriculture. Environmental Research Letters 5, 014010.

Seré C, Steinfeld, H, 1996. World livestock production systems: Current status, issues and trends. FAO Animal Production and Health Paper 127. FAO (Food and Agriculture Organization of the United Nations), Rome, Italy.

Silvestri S, Bryan E, Ringler C, Herrero M, Okoba B, 2011. Climate change perception and adaptation of agro-pastoral communities in Kenya. Regional Environmental Change (in press).

Thornton P K, Jones P G, Alagarswamy A, Andresen J, 2009. Spatial variation of crop yield responses to climate change in East Africa. Global Environmental Change 19, 54-65.

Thornton P K, Jones P G, Ericksen P J, Challinor A J, 2011. Agriculture and food systems in sub-Saharan Africa in a four-plus degree world. Philosophical Transactions of the Royal Society A 369, 117-136.

Thornton P K, Herrero M, Jones P G, 2012. Adaptation to climate change in mixed crop-livestock farming systems in developing countries. In: R Mendelsohn, A Dinar (eds), Handbook on Climate Change and Agriculture. Elgar (in press).

Wilby R L, Troni J, Biot Y, Tedd L, Hewitson B C, Smith D M, Sutton R T, 2009. A review of climate risk information for adaptation and development planning. International Journal of Climatology 29 (9), 1193-1215.

Williams A P, Funk C, 2011. A westward extension of the warm pool leads to a westward extension of the Walker circulation, drying eastern Africa. Climate Dynamics DOI: 10.1007/s00382-010-0984-y

World Health Organisation (WHO), 2002. Diet, Nutrition and the Prevention of Chronic Diseases. WHO Technical Report Series 916, Geneva.

Table 1: Original variates used in setting up the sampling frame

Variate	Units	Mean	Standard Deviation	Standardized Variate
Bean	% area	15.80	18.89	p1
Cassava	% area	2.597	5.887	p2
Cowpea	% area	2.769	2.186	p3
Maize	% area	35.57	34.62	p4
Pigeonpea	% area	3.103	2.863	p5
Sorghum	% area	5.527	8.659	p6
Cropland	% area*10	150.1	166.3	p7
Cattle	head per $10km^2$	23.7	38.79	p8
Goats	head per $10km^2$	12.8	21.85	p9
Sheep	head per $10km^2$	21.28	33.84	p10
Pasture	% area*10	455.9	282.5	p11
CEC [a]	meq per 100 g	13.79	14.32	p12
Clay	%	31.04	17.52	p13
pH	*10	61.91	8.841	p14
Silt	%	19.10	8.044	p15
SWHC [b]	mm	111.5	29.61	p16
Plus5 [c]	% failure	35.07	25.72	p17
Elevation	m	862.0	520.3	p18
Slope	degrees*10	29.61	34.10	p19
Population	persons per km^2	24.37	56.78	p20

[a] Cation Exchange Capacity
[b] Soil Water Holding Capacity
[c] Season failure rate in a putative +5 °C warmer world

Table 2: Results of the Principal Components Analysis: eigenvalues with percentage variance and cumulative variance

Order	Eigenvalue	Variance explained (%)	Cumulative variance (%)
1	16189	22.19	22.19
2	10227	14.02	36.21
3	8451	11.59	47.80
4	6042	8.28	56.08
5	4783	6.56	62.64
6	4140	5.68	68.32
7	3778	5.18	73.50
8	2796	3.83	77.33
9	2668	3.66	80.99
10	2535	3.48	84.47
11	2346	3.22	87.69
12	1842	2.53	90.22
13	1764	2.42	92.64
14	1509	2.07	94.71
15	1176	1.61	96.32
16	936	1.28	97.55
17	712	0.98	98.53
18	490	0.67	99.20
19	438	0.60	99.80
20	119	0.16	100.00

Table 3: The first eight eigenvectors. Important variates are highlighted, blue for positive, yellow for negative.

Variate	Eigenvector							
	1	2	3	4	5	6	7	8
p1	-0.3986	0.1688	0.0569	-0.0613	-0.0840	0.0888	0.0208	0.1363
p2	-0.1954	-0.0074	-0.1016	0.3254	0.3386	-0.1198	0.2607	0.4260
p3	-0.4161	0.1524	-0.0437	0.0146	-0.0695	-0.0244	-0.1088	-0.0986
p4	-0.3913	0.1713	-0.0373	-0.0441	-0.0041	-0.0649	-0.0508	-0.0325
p5	-0.4103	0.1781	0.0417	-0.0814	-0.1447	0.0803	-0.1026	-0.0432
p6	-0.1998	-0.0358	-0.1766	0.2904	0.4453	-0.2251	0.0853	-0.1950
p7	-0.3878	0.0475	0.0039	0.1728	-0.0353	0.0316	0.0453	-0.1183
p8	-0.0374	-0.2343	-0.3122	0.0447	0.2862	0.1414	-0.2141	-0.2999
p9	-0.1189	-0.2008	-0.2626	-0.3267	-0.0197	0.1087	-0.3498	0.0723
p10	-0.0848	-0.2553	-0.2480	-0.2126	0.1982	0.2418	-0.3679	0.1281
p11	0.0818	0.0674	0.0142	-0.1828	0.3826	-0.5617	-0.1885	0.0769
p12	0.0048	0.0520	-0.4466	-0.1027	-0.2931	-0.4406	0.0042	0.2416
p13	0.0722	0.3540	-0.2823	-0.3395	0.1310	-0.0488	0.1777	0.0779
p14	0.1052	0.1157	-0.3660	0.2933	-0.4481	-0.1383	-0.1806	0.0826
p15	0.1196	0.3245	-0.3248	-0.0345	0.1502	0.2874	0.2162	-0.1971
p16	0.1591	0.3582	-0.3092	0.0899	0.0543	0.2587	0.1056	-0.1457
p17	-0.0172	0.2717	0.1917	-0.4599	0.1602	0.0542	0.0415	0.2083
p18	0.1266	-0.3565	-0.2034	-0.1820	-0.1258	-0.1558	0.3261	-0.2727
p19	0.1117	-0.2652	-0.0393	-0.3306	-0.1157	-0.0735	0.5154	-0.1799
p20	0.0630	-0.2693	-0.1681	0.0718	0.0270	0.3336	0.2500	0.5800

Table 4: Some characteristics of the sample pixels.

Cluster	1	2	3	4	5	6
Country	KY	TZ	KY	KY	UG	KY
Pixels in cluster	961	99	480	299	294	137
Location	Taru	Kolandoto	Nginyang	Seredupi	Chiruhura	Mua Hills
District	Kwale	Kishapu	Baringo	Samburu	Mbarara	Machakos
Main tribe	Duruma	Sukuma	Kalenjin	Samburu	Banyankole	Kamba
Lat	-3.708	-3.458	0.958	1.125	-0.458	-1.458
Long	39.125	33.542	35.958	37.625	31.042	37.208
System [a]	LGA	MRA	MRA	LGA	MRA	MRT
System 2 [b]	MBM	MBM	APMSB	MBM	HP	MBM
Access index [c]	104	350	592	516	243	160
Population km^{-2}	19	24	15	1	15	498
LGP days	179	168	134	85	211	159
Av rainfall mm	787	875	658	523	898	1205
Rainfall CV %	28	23	28	26	22	29
Elevation m	372	1187	906	724	1305	1923
Cattle *10 km^{-2}	445.74	1259.97	134.35	6.17	0	478.28
Chicken *10 km^{-2}	665.06	1167.06	297.89	4.64	0	920.42
Goats *10 km^{-2}	156.33	647.97	253.53	168.06	0	436.56
Sheep *10 km^{-2}	66.15	337.4	45.15	139.27	0	169.17
Pigs *10 km^{-2}	0.04	0.98	0	0	0	0
Cropland %	15	19	10	18	67	13
Pasture %	48	35	85	57	0	49

[a] Sere and Steinfeld (1996) classification: LGA arid-semiarid rangeland; LGT tropical highland rangeland; MRA mixed rainfed arid-semiarid; MRT mixed rainfed tropical highland.
[b] Dixon et al. (2001) classification: HP highland perennial; MBM maize-based mixed; APMSB agro-pastoral millet/sorghum based.
[c] Accessibility index: time in minutes to travel to a town of >250,000 people (Nelson, 2007).

(Table 4 continued)

Cluster	**7**	**8**	**9**	**10**	**11**	**12**
Country	UG	TZ	KY	UG	KY	KY
Pixels in cluster	5	871	312	46	102	42
Location	Pakwach	Singida	Kisanyu	Lwengo	Sigor	Lokichar
District	Nebbi	Singida	Kajiado	Masaka	West Pokot	North Pokot
Main tribe	Acholi	Wanyaturu	Maasai	Bunyore	Pokot	Pokot
Lat	2.458	-4.792	-1.625	-0.375	1.458	1.542
Long	31.458	34.708	36.875	31.542	35.542	35.042
System [a]	MRA	MRA	LGT	MRA	MRA	MRA
System 2 [b]	MBM	MBM	MBM	HP	MBM	MBM
Access index [c]	395	414	48	254	594	493
Population km^{-2}	55	28	21	294	17	22
LGP days	210	139	146	217	139	196
Av rainfall mm	1058	827	655	1061	717	935
Rainfall CV %	26	32	29	21	27	26
Elevation m	652	1505	1619	1218	939	1275
Cattle *10 km^{-2}	132.75	741.82	116.63	2.48	229.6	204.88
Chicken *10 km^{-2}	700.92	784.12	1.04	1548.21	298.33	366.31
Goats *10 km^{-2}	429.12	455.78	30.64	23.33	698.65	131.22
Sheep *10 km^{-2}	40.56	276.53	230.16	490.51	447.06	753.59
Pigs *10 km^{-2}	62.37	0.52	4.17	53.65	0.09	0
Cropland %	64	2	24	88	34	74
Pasture %	36	98	0	0	65	26

[a] Sere and Steinfeld (1996) classification: LGA arid-semiarid rangeland; LGT tropical highland rangeland; MRA mixed rainfed arid-semiarid; MRT mixed rainfed tropical highland.
[b] Dixon et al. (2001) classification: HP highland perennial; MBM maize-based mixed; APMSB agro-pastoral millet/sorghum based.
[c] Accessibility index: time in minutes to travel to a town of >250,000 people (Nelson, 2007).

Table 5: Percentage of households accessing different sources of water for human and livestock consumption. The numbers between parentheses represent the average time (in hours) taken to fetch water by the households or for watering the livestock.

	River		Shallow well		Borehole		Dam	
	Households (%)	Time (h)	Households (%)	Time (h)	Households (%)	Time (h)	Households (%)	Time (h)
Human consumption								
Samburu	90	(4)	10	(1)				
Kajiado					100	(0.4)		
Baringo	70	(0.5)			30	(0.4)		
West Pokot	70	(1)	10	(0.5)	20	(0.5)		
Kwale			10	(0.3)	90	(0.5)		
Singinda			100	(0.5)				
Kishapu	70	(0.7)	10	(0.3)	20	(1)		
Mabarara			100	(0.7)				
North Pokot	100	(0.7)						
Nebbi	70	(4.8)			30	(0.2)		
Masaka			10	(0.1)	90	(0.3)		
Machakos			90	(0.2)	10	(0.5)		
Livestock consumption								
Samburu	90	(4)	10	(1)				
Kajiado	20	(1)			50	(0.7)	30	(1.8)
Baringo	60	(0.4)			30	(0.4)	10	(0.5)
West Pokot	70	(1)	30	(0.5)				
Kwale					30	(0.3)	60	(2)
Singinda			30	(2)				
Kishapu	40	(0.4)						
Mabarara			100	(0.7)				
North Pokot	100	(0.7)						
Nebbi	40	(6.3)						
Masaka					50	0.7		
Machakos					90	0.6		

Table 6a: Livestock mortality reported for a normal year

	Indigenous								Crossbred				Exotic	
Sites	Cattle	*n*	Sheep	*n*	Goats	*n*	Camel		Cattle	n	Sheep	n	Cattle	n
Samburu	43	*(1)*					50	*(1)*						
Kajiado	5	*(3)*	7.2	*(2)*					16	*(3)*	4	*(1)*		
Baringo														
West Pokot														
Kwale					51	*(2)*								
Singida					100	*(2)*								
Kishapu					34	*(2)*								
Mbarara	15	*(7)*			28	*(5)*			28	*(2)*				
North Pokot														
Nebbi														
Masaka	10	*(1)*												
Machakos	16	*(1)*			8	*(1)*							20	*(1)*

6b: Livestock mortality for a bad year

	Indigenous						Crossbred				Exotic			
Sites	Cattle	*n*	Sheep	*n*	Goat	*n*	Cattle	*n*	Sheep	*n*	Cattle	*n*	Goat	*n*
Samburu	83	*(10)*	75	*(1)*	81	*(10)*								
Kajiado	53	*(3)*	22	*(5)*	71	*(1)*	39	*(5)*	37	*(3)*			63	*(1)*
Baringo			8	*(1)*	60	*(10)*								
West Pokot	78	*(4)*	76	*(2)*	49	*(8)*	57	*(1)*						
Kwale	66	*(7)*			86	*(7)*								
Singida					100	*(1)*								
Kishapu	25	*(2)*			48	*(3)*								
Mbarara							25	*(2)*						
North Pokot	47	*(6)*	39	*(8)*	45	*(8)*								
Nebbi	43	*(3)*			54	*(8)*								
Masaka														
Machakos	16	*(1)*	100	*(1)*	51	*(1)*					42	*(1)*		

NB: Values between parentheses(n) are the numbers of households whose response was used in computing the mortality rates

Table 7: Incidence of diseases for different livestock species across study sites: percentage of households who have treated their animal against a disease.

Sites	Cattle			Goats				Sheep
	East Coast Fever (ECF)	Food and Mouth Disease (FMD)	Caprine Bovine Pleuro-Pneumonia (CBPP)	East Coast Fever (ECF)	Food and Mouth Disease (FMD)	Diarrhea	Caprine Bovine Pleuro-Pneumonia (CBPP)	Caprine Bovine Pleuro-Pneumonia (CBPP)
Samburu						40	90	10
Kajiado	100	30	10					10
Baringo			10	10	30	10	60	10
West Pokot	10	20	10	50	10	30	80	
Kwale			30			30	50	
Singinda	10		10	20			30	
Kishapu			20					
Mabarara	100			90				
North Pokot						30	100	
Nebbi	10		10	10		30		
Masaka	20		10					
Machakos	20							

Table 8: Household main characteristics across study sites

Site	HH size (#)	Farm size (ha)	Crop land (ha)	Main crops	Livestock (TLUs)	Main livestock species	Main income sources
Samburu	7.8±2.5	0	0	No crops	3.8±3.7	Goats, sheep, cattle, camel	Livestock, employment, trade
Kajiado	7.3±2.9	2.1±3.3	1.16 ±0.7	Maize, beans, tomato	36.3±15.8	Sheep, cattle, goats	Livestock, cropping
Baringo	7.2±5.0	0.09±0.03	0.09±0.03	Maize, cowpeas, beans	4.8±3.6	Goats, sheep, camels	Livestock, employment
West Pokot	6.2±3.2	0.7±0.4	0.3±0.2	Maize, cowpeas	8.1±7.6	Goats, sheep, cattle	Livestock, cropping
Kwale	7.5±4.3	5.8±4.1	5.0±3.6	Maize, grams, cowpeas	8.0 ±7.3	Goats, cattle	Trade, employment, livestock
Singida	4.7±2.1	2.9±5.4	2.6±4.7	Millet, sorghum, maize	6.7±3.2	Goats, cattle	Employment, trade, cropping
Kishapu	5.9±2.1	1.8±1.5	1.8±1.5	Maize, cowpeas, sorghum	11.1±6.9	Cattle, goats	Cropping, employment
Mbarara	6.8±1.7	2.6±4.1	0.7±0.6	Bananas, maize, beans	62.2±51.5	Dairy cattle	Livestock, employment
North Pokot	6.9±2.5	0.5±0.3	0.5±0.3	Maize, millet, beans	14.2±12.2	Goats, sheep, Zebu cattle	Livestock, cropping,
Nebbi	8.6±5.0	4.4±3.9	4.1±4.0	Cassava, sorghum, cotton	4.6±4.4	Cattle and goats	Cropping, employment
Masaka	7.3±2.6	1.5±1	1.5±1	Maize, cassava, bananas	5.9±4.1	Zebu cattle	Cropping, employment
Machakos	5.7±2.8	3.6±4.3	2.7±2.1	Maize, beans	14.1 ±12	Dairy, Zebu cattle, goats	Cropping, livestock

Table 9: Household assets; characteristics of the housing across sites

District	House owned	Roof type		Walls type					Rooms		
	(%)	Thatch (%)	Iron (%)	Poles and mud (%)	Bricks and mud (%)	Unburnt bricks (%)	Bricks plastered (%)	Stone (%)	1-2 (%)	3-4 (%)	> 4 (%)
Samburu	100	90	10	100	0	0	0	0	70	30	0
Kajiado	70	0	100	80	0	0	20	0	0	0	100
Baringo	100	40	60	90	0	0	0	10	90	10	0
West Pokot	100	50	40	100	0	0	0	0	50	40	10
Kwale	100	40	60	90	10	0	0	0	30	30	40
Singida	90	30	30	100	0	0	0	0	20	50	30
Kishapu	100	80	20	0	10	90	0	0	30	50	20
Mbarara	90	40	60	30	0	0	70	0	20	30	50
North Pokot	90	60	40	90	10	0	0	0	70	30	0
Nebbi	100	0	100	100	0	0	0	0	40	50	10
Masaka	100	20	80	10	0	0	90	0	10	20	70
Machakos	100	10	90	30	70	0	0	0	0	25	75

Table 10: Percentage of households involved in different activities and access to services at each of the study sites, ordered according to increasing average annual rainfall

Site	Practising cropping (% households)	Owing livestock (% households)	Accessing off-farm income (% households)	Accessing electricity (% households)	Accessing mobile phone (% households)	Accessing mobile banking (% households)
Samburu	0	100	90	0	0	0
Kajiado	100	100	100	0	100	100
Baringo	30	100	100	0	30	30
West Pokot	60	100	40	10	20	20
Kwale	100	90	100	10	60	60
Singida	100	30	100	0	30	10
Kishapu	100	40	50	0	60	30
Mbarara	90	100	100	0	90	0
North Pokot	100	100	60	0	60	60
Nebbi	100	80	50	0	50	0
Masaka	100	50	30	0	50	0
Machakos	80	80	70	60	100	100

Table 11: Prices for the livestock categories expressed in Kenyan shillings per head across the study sites

	Females		Male			Young stock
	Breeding	Young	Breeding	Intact	Castrated	Calf/lamb/kid
Cattle						
Samburu	22000	16000	25000	14000	10000	6000
Kajiado	28166	27900	30500	19200	17900	11000
Baringo	27000	24500	30000	22000	15000	7500
West Pokot	28000	25400	30000	21000	14000	9000
Kwale	30000	27500	31000	24500	15000	8500
Singinda	18000	16000	20000	14500	12000	6500
Kishapu	22000	19500	24000	17000	14000	7000
Mbarara	24500	24000	20950	20000	16500	8000
North Pokot	20000	16000	25000	14000	12000	9000
Nebbi	17500	16000	19000	14000	12500	5500
Masaka	16000	15500	17500	13000	11500	5000
Machakos	24000	21000	27500	18000	14500	7000
Sheep						
Samburu	2750	2500	2800	2000	1750	750
Kajiado	4000	3000	4500	2700	2250	1500
Baringo	3750	2800	4000	2400	2000	1250
West Pokot	3200	2800	3500	2750	2500	1200
Kwale	-	-	-	-	-	-
Singinda	-	-	-	-	-	-
Kishapu	2700	2450	2800	2000	1800	900
Mbarara	-	-	-	-	-	-
North Pokot	2900	2700	3200	2500	1800	1100
Nebbi	-	-	-	-	-	-
Masaka	-	-	-	-	-	-
Machakos	-	-	-	-	-	-
Goats						
Samburu	2500	2250	2650	1800	1600	750
Kajiado	3500	2800	4000	2500	2000	1100
Baringo	3450	3000	3750	2800	2500	1000
West Pokot	2800	2750	3000	2500	1800	900
Kwale	3500	3250	4000	2900	2500	1350
Singinda	2350	2950	2500	1800	1450	850
Kishapu	2300	2000	2500	1750	1500	750
Mbarara	2750	2500	2800	2350	1850	1000
North Pokot	2750	2500	3150	2350	1750	900
Nebbi	2350	2000	2500	1850	1450	750
Masaka	-	-	-	-	-	-
Machakos	2750	2450	2800	2250	1750	1000

Table 12: Livestock population composition at each of the study sites. Means and standard deviations are included for each livestock species

		Herd/flock sizes				Cross bred			Indigenous			Exotic	
Cattle	HH (%)	Total	Females	Males	n	Females	Males	n	Females	Males	n	Females	Males
Samburu	50	3±2	2±2	1±2		0	0		2±2	1±2		0	0
Kajiado	100	28±15	17±8	5±5	4	18±10	5±5	6	17±8	5±5		0	0
Baringo	0	0	0	0		0	0		0	0		0	0
West Pokot	40	6±3	4±2	1±1		0	0		4±2	1±1		0	0
Kwale	60	8±5	5±3	2±2		0	0		5±3	2±2		0	0
Singida	20	6±2	3±4	3±2		0	0		3±4	3±2		0	0
Kishapu	30	9±2	3±0	6±3		0	0		3±0	6±2		0	0
Mbarara	90	65±48	37±27	14±14	2	71±2	21±26	7	26±21	12±11		0	0
North Pokot	100	7±7	4±3	2±3		0	0		4±3	2±3		0	0
Nebbi	40	5±3	3±2	2±1		0	0		3±2	2±1		0	0
Masaka	50	4±3	3±3	1±0		0	0		3±3	1±0		0	0
Machakos	90	6±5	3±3	1±2		0	0	5	2±2	3±2	5	4±3	0
Goats													
Samburu	100	13±12	11±10	2±3		0	0		11±10	2±3		0	0
Kajiado	60	14±11	9±7	3±3		0	0		9±7	3±3		0	0
Baringo	100	29±19	12±11	7±4		0	0		12±10	7±4		0	0
West Pokot	100	32±26	16±14	6±6		0	0		16±14	6±6		0	0
Kwale	80	15±15	11±14	3±2		0	0		11±14	3±2		0	0
Singida	20	13±6	12±6	1±0		0	0		12±6	1±0		0	0
Kishapu	30	8±7	7±6	1±1		0	0		7±6	1±1		0	0
Mbarara	90	30±31	16±15	8±11		0	0		16±15	8±11		0	0
North Pokot	100	25±22	15±14	5±4		0	0		15±14	5±4		0	0
Nebbi	60	6±2	3±2	2±1		0	0		3±2	2±1		0	0
Masaka	0	0	0	0		0	0		0	0		0	0
Machakos	60	7±5	5±3	1±2		0	0	5	6±3	1±2	2	3±4	1±1
Sheep													
Samburu	10	6±0	5±0	1±0		0	0		5±0	1±0		0	0
Kajiado	100	53±41	40±40	7±4	1	40±0	15±0	9	40±42	6±3		0	0
Baringo	20	2±0	2±0	0		0	0		2±0	0		0	0
West Pokot	20	27±13	24±11	2±0		0	0		24±11	2±0		0	0
Kwale	0	0	0	0		0	0		0	0		0	0
Singida	0	0	0	0		0	0		0	0		0	0
Kishapu	0	0	0	0		0	0		0	0		0	0
Mbarara	0	0	0	0		0	0		0	0		0	0
North Pokot	60	16±11	9±6	3±3		0	0		9±6	3±3		0	0
Nebbi	0	0	0	0		0	0		0	0		0	0
Masaka	0	0	0	0		0	0		0	0		0	0
Machakos	0	0	0	0		0	0		0	0		0	0

Table 13: Percentage of household selling different livestock products

	Cattle			Goats		Sheep			Camel
Sites	Milk	Hides	Manure	Milk	Skins	Skins	Manure	Wool	Milk
Samburu	0	10	0	0	70	10	0	0	0
Kajiado	50	30	10	10	0	0	10	10	0
Baringo	0	0	0	20	80	10	0	0	0
West Pokot	10	0	0	10	0	0	0	0	0
Kwale	0	0	0	0	0	0	0	0	0
Singinda	10	0	0	0	0	0	0	0	0
Kishapu	10	0	0	10	0	0	0	0	0
Mbarara	80	0	0	0	0	0	0	0	0
North Pokot	10	0	0	0	0	0	0	0	10
Nebbi	0	0	0	0	0	0	0	0	0
Masaka	20	0	10	0	0	0	0	0	0
Machakos	40	0	0	0	0	0	0	0	0

Table 14: Production indicators for lactating cows and goats. Numbers in the parenthesis represent the households owning lactating cattle and goats across the study sites.

	Cows				Goats			
Sites	Lactating (%)	n	Lactation length (months)	Milk yield (kg cow^{-1} yr^{-1})	Lactating (%)	n	Lactation length (months)	Milk yield (kg $goat^{-1}$ yr^{-1})
Samburu								
Kajiado	23	(9)	9	300	24	(2)	3	67
Baringo					84	(6)	3	26
West Pokot	39	(2)	11	275	45	(10)	3	29
Kwale	47	(4)	7	385	13	(1)	3	40
Singida	50	(1)	8	136				
Kishapu	83	(2)	8	223	25	(1)	2	61
Mbarara	50	(9)	7	291				
North Pokot	53	(9)	11	341	53	(8)	3	40
Nebbi	100	(2)	3	60				
Masaka	29	(2)	9	364				
Machakos	67	(5)	8	1497				

Table 15: Recruitment and off-take rates (expressed as %) for different species of livestock across the twelve sites. The numbers in parenthesis represent the number of households who recruited or sold animal across the different sites

	Cattle				Goats				Sheep			
sites	Recruitment rate	n	Off-take rate	n	Recruitment rate	n	Off-take rate	n	Recruitment rate	n	Off-take rate	n
Samburu	0		0		0		60	(6)	0		0	
Kajiado	60	(7)	20	(4)	0		0		10	(1)	0	
Baringo	0		0				40	(7)	0		0	
West Pokot	10	(1)	0				40	(9)	0		0	
Kwale	30	(1)	10	(1)	40	(2)	30	(3)	0		0	
Kishapu	0		10	(2)	0		90	(1)	0		0	
Singinda	0		10	(1)	0		30	(1)	0		0	
Mbarara	10	(1)	10	(9)	0		60	(2)	0		0	
North Pokot	30	(2)	30	(5)	10	(2)	20	(8)	20	(5)	0	
Nebbi	0		40	(4)	0		50	(2)	0		0	
Masaka	20	(1)	30	(2)	0		0	(1)	0		0	
Machakos	10	(2)	10	(1)	0		0	(4)	0		0	

	Camel				Pigs			
	Recruitment rate	n	Off-take rate	n	Recruitment rate	n	Off-take rate	n
Samburu	0		0		0		0	
Kajiado	0		0		0		0	
Baringo	0		10	(1)	0		0	
West Pokot	0		0		0		0	
Kwale	0		0		0		0	
Kishapu	0		0		0		0	
Singinda	0		0		0		0	
Mbarara	0		0		0		0	
North Pokot	0		0		0		0	
Nebbi	0		0		0		0	
Masaka	0		0		30	(1)	60	(2)
Machakos	0		0		0		0	

Table 16: Costs of production for the main crops expressed in Kenyan shillings per hectare across study sites

	Beans	Maize	Black beans	Cassava	Green grams	Millet	Sorghum	Pigeon peas	Cow peas	Bananas
Samburu										
Kajiado	8613 (8074)	12294 (6851)	3861 (0)	7814 (0)	5708 (0)	10710 (0)	9381 (3298)		5182 (0)	
Baringo	12865 (0)	16389 (16676)							11668 (8017)	
West Pokot		9635 (10301)							0	
Kwale		2333 (3100)			696 (784)	0			564 (829)	
Kishapu		2023 (1324)				11 (0)	425 (436)		219 (116)	
Singinda		105 (0)		692 (0)	150 (0)		522 (404)			
Mbarara	5620 (11129)	4710 (6761)		219 (132)						180 (101)
North Pokot	1300 (0)	2047 (1824)				2635 (0)	1969 (0)			
Masaka	2894 (3397)	971 (1194)		0						1324 (0)
Nebbi	0	100 (13)		1010 (1397)		186 (218)	2707 (5485)			0
Machakos	9227 (6327)	4317 (2846)						4354 (0)		

Table 17: Costs of production for different livestock species across study sites

Sites	Cattle (Ksh head^{-1})	sd	Goats (Ksh head^{-1})	sd	Sheep (Ksh head^{-1})	sd
Samburu	684	(0)	222	(143)	300	(0)
Kajiado	662	(1199)	34	(0)	34	(32)
Baringo	0		123	(107)	0	
West Pokot	1100	(1723)	134	(161)	0	
Kwale	62	(0)	17	(2)		
Singida	68	(0)	18	(18)		
Kishapu	1090	(0)	200	(50)	90	(0)
Mbarara	595	(789)	268	(359)		
North Pokot	417	(409)	86	(74)	133	(142)
Nebbi	1370	(0)	134	(4)		
Masaka	1115	(356)				
Machakos	3700	(3717)	215	(244)		

Table 18: Ranked main concerns about future problems and measures taken to prevent their occurrence

Site	n	Main concerns	Frequency	Coping	Adaptation
Samburu (Ke)	8	Not enough food for people	Twice a year	Buy food	Generate more income – diversify incomes
	7	Insecurity and violence	During drought	None	Obtain guns
	5	Not enough pastures for livestock	Twice a year	Move livestock to other areas	-
	7	Not enough drinking water	Twice a year	Walk longer distances in search for water	-
	2	Not enough water for livestock	Twice a year	Move livestock to other areas	-
	3	Livestock theft-raiding	Often	None	Obtain guns
	1	Livestock diseases	Often	None	Preventive health care
Kajiado (Ke)	10	Not enough pastures for livestock	During drought	Move livestock; buy feeds	Conserve feeds, reduce animal numbers, use irrigation
	10	Not enough water for livestock	During drought	Buy water, go to the dam	Water storage, drill boreholes, dig wells, reduce animal numbers
	6	Not enough drinking water	During drought	Buy water, use a borehole from neighbor	Drill a borehole to be managed by the community
	5	Not enough food for people	Once a year	Buy food	Crop more land, irrigate, plant other crops
	4	Livestock diseases	2-3 times a year	Use drugs	Prevent animal mixing, avoid ECF prone areas
	2	Crop failure	During drought	Buy food	Irrigation
	2	High prices of food and inputs	Often	Reduce consumption	Grow more crops
	1	Low produce prices	Often	Random marketing	Obtain market information
	1	Livestock theft	>3 times a year	-	-
Baringo (Ke)	9	Not enough pastures for livestock	Twice a year	Move livestock to other areas, buy feeds	Drought tolerant grasses, irrigation
	7	Not enough food for people	>3 times a year	Food aid, collect wild fruits, reduce consumption	Generate additional income, grow crops, sell livestock
	8	Not enough water for livestock	Twice a year	Buy water	Drill well distributed boreholes
	8	High prices of food and inputs	Twice a year	Reduce consumption, sell livestock, food aid	Crop production, store food, price policies, save cash
	6	Livestock diseases	>3 times a year	Use traditional medicines	Veterinary extension services for prevention
	6	Not enough drinking water	Twice a year	Buy water	Water storage, drill boreholes
	1	Crop failure	Twice a year	-	Irrigation
	1	Low prices of produce	Often	-	Government subsidies
West Pokot (Ke)	10	Not enough water for livestock	> once a year	Move livestock to river	Dig shallow wells
	6	Not enough drinking water	During drought	Obtain water from river	-
	7	Not enough food for people	Every year	Buy food, sell livestock	Increase herd sizes, expand cropland, save cash, store food
	6	Livestock diseases	Often	Use drugs	Preventive health care (dip wash)
	4	Not enough pastures for livestock	During drought	Move livestock, cut and carry feeds	Increase livestock mobility
	3	High prices for food and inputs	During drought	-	Store food
	2	Human diseases	Often	Use traditional medicine	-
	2	Crop failure	During drought	Use stored food	Dig shallow wells, crop in river banks
Kwale (Ke)	9	Not enough food for people	2-3 times a year	Buy food	Plant more crops
	8	Not enough drinking water	2-3 times a year	Walk longer distances in search for water	Drill boreholes
	7	Not enough water for livestock	> once a year	Move livestock in search for water	Drill boreholes, take animals to dam
	2	Livestock diseases	2-3 times a year	Use drugs	Preventive health care
	2	Insecurity and violence	Twice a year	Report to police	-
	1	Poor rainfall	Once in two years	-	-
	1	Loss of off-farm employment	Often	-	-

Singida (Tz)	7	Not enough food for people	2-3 times a year	Buy food	Generate income to purchase food
	4	Not enough drinking water	Often	Walk longer distances in search for water	Dig shallow well
	5	High incidence of human diseases	Often	Go to hospital	Search for preventive health care (mosquito nets)
	4	Lack of off-farm income	Often	Producing and selling charcoal	Look for casual employment
	2	High prices for food and inputs	Twice a year	-	Use recycled seed
	1	Water conflicts	Often	-	-
	1	Shrinkage of cropland	-	-	Migration
Kishapu (Tz)	7	Not enough drinking water	Once a year	Walk longer distances in search for water	Dig shallow wells
	6	Not enough food for people	Once a year	Buy food, obtain food aid	Generate income to purchase food
	5	High incidence of human diseases	Once a year	Use drugs	Obtain mosquito nets
	4	Loss of off-farm income	Often	Casual employment	Practise mixed crop-livestock farming
	3	Not enough water for livestock	Once a year	Obtain water from wells	Dig a shallow well
	1	Not enough land	-	Rent land	Migrate
Mbarara (Ug)	10	Conflict with wild animals	Very often	Scare them away from livestock and crops	Fencing
	10	Not enough water for livestock	1-2 times a year	Buy water, take animals to lake	Harvest water techniques, share wells and boreholes
	6	Livestock diseases	Very often	-	Practise preventive health care
	5	Low prices for produce	Often	-	-
	1	Human diseases	1-3 times a year	Use drugs	Preventive health care
	1	Not enough pastures for livestock	Twice a year	Use fiscal land	-
	1	Animal theft	Often	Use a watch dog	-
North Pokot (Ke)	10	Livestock diseases	Often	Use drugs	Practise preventive health care
	8	Not enough clean drinking water	Often	-	Dig well to obtain clean water
	6	High incidence of human diseases	Very often	-	Preventive health care (mosquito nets)
	4	Crop failure	During drought	Food aid, purchase food	Store food, save cash
	1	Not enough food for people	Sometimes	Food aid	Store food
	1	Not enough pastures for livestock	After drought	Move livestock	Increase mobility
Nebbi (Ug)	8	Not enough drinking water	Throughout year	Walk long distances to search for water	Water harvesting techniques
	9	Loss of off-farm income	Often	Sell firewood, casual employment	Diverse crop farming, get more livestock
	3	Human diseases	Often	Use drugs	Use mosquito nets
	1	Crop failure	Sometimes	-	Early planting, use drought tolerant crops
	1	Crop pests and diseases	Every year	Use pesticides	-
	1	Not enough food for people	Sometimes	Store food	Plant drought resistant crops
	1	Not enough water for animals	Often	Take animals to river	-
Masaka (Ug)	8	Loss of off-farm income	Often	Casual labour, work for food	Intercropping, rent out land
	4	Not enough water for livestock	Once a year	Fetch water from far	Boreholes
	3	High incidence of human diseases	1-2 times a year	Search for health care	Preventive care
	4	Not enough food for people	2-3 times a year	Buy food, work for food	Store food, intercropping
	2	Crop failure	Once in two years	-	Intercropping
	1	Crop diseases	Once a year	-	-
	1	Insecurity and violence	Often	-	-
	1	Lack of markets for produce	Often	-	-

	1	Loss of soil fertility	Continuous	Apply manure	-
	1	Low prices for produce	Often	-	-
	1	Not enough drinking water	Sometimes	-	-
	1	Lack of firewood	Throughout year	--	--
Machakos (Ke)	6	Not enough drinking water	Once a year	Buy water, use wells	Increase water storage
	5	Not enough water for livestock	Once a year	Buy water	Store water, reduce livestock numbers
	7	Crop failure	Once a year	Buy food;	Use irrigation, store food
	3	High prices of food and inputs	Often	Reduce consumption; Buy food in bulk	Diversify crop production
	3	Not enough pastures for livestock	Once a year	Buy feeds	Plant drought tolerant grasses, conserve feeds
	1	Human diseases	4 times a year	Go to dispensary	Preventive health care
	1	Livestock diseases	3 times a year	Administer drugs	Consult veterinarian
	1	Low prices for produce	Often	Sell at low prices	Explore new markets (further away)

Table 19: Coping mechanisms against drought

Site	n	Strategies to minimize the effect of drought	n	How to cope with the effects of the drought
Samburu (Ke)		-	9	Sell livestock
			2	Sell labour
			2	Depend on aid
Kajiado (Ke)	9	Store grain	10	Use supplementary feeding
	6	Save cash	6	Move livestock to other areas
	2	Use water harvesting and storage techniques	6	Sell livestock
	1	Plant drought resistant crops	1	Sell labour
Baringo (Ke)	3	Store grain	4	Move livestock to other areas
			3	Use supplementary feeding, including cut and curry
			2	Sell livestock
			1	Sell labour
West Pokot (Ke)	6	Store grain	9	Sell livestock
	3	Save cash	2	Sell labour
	3	Consume wild fruits		
	1	Diversify cropping		
Kwale (Ke)	10	Store grain	10	Sell livestock
	10	Save cash	3	Sell labour
			1	Sell herbal medicines
			1	Move livestock to other areas
Singida (Tz)	10	Store grain	3	Sell livestock
	9	Save cash	2	Sell labour
	3	Sell labour		
	1	Commercialize millet		
Kishapu (Tz)	10	Store grain (maize)	5	Sell labour
	5	Save cash	4	Sell livestock
Mbarara (Ug)	8	Store grain	10	Sell livestock
	6	Save cash	1	Save cash
	2	Buy food	1	Sell labour
North Pokot (Ke)	10	Store grain	10	Sell livestock
	8	Save cash	2	Sell labour
			1	Move livestock
			1	Save cash
Nebbi (Ug)	9	Store grain	7	Sell livestock
	7	Preserve cassava (in the field)	1	Sell firewood
	1	Cultivate millet		

Masaka (Ug)	10	Store grains (maize, beans, groundnuts)	3	Sell livestock
	4	Save cash	1	Sell labour
Machakos (Ke)	10	Store grain	1	Sell livestock
	8	Save cash	1	Sell labour
	1	Use irrigation		
	1	Use several planting dates		

Table 20: Households planned future changes to increase livestock populations. Percentages indicate livestock owners who gave answers

A. Reasons to increase cattle numbers and ideas on how to achieve that

	n	Households (%)	Reason for wanting to increase	How households plan to increase cattle numbers
Samburu	5	50	Milk for sale	Improve health and genetic merit
		40	Consumption	Increase reproduction rates
		30	As a form of savings	Purchase more animals
		20	Sale of animals	Improve health
Kajiado	6	40	As a form of savings	No information
		10	Milk for sale	
		10	Draught power	
Baringo	No cattle			
West Pokot	3	30	Consumption	Improve health and purchase more animals
		30	As a form of savings	Increase reproduction rates and reduce mortality
		20	Milk for sale	Improve genetic merit
Kwale	5	44	Milk for sale	Improve health and genetic merit
		44	Consumption	Purchase more animals
		44	As a form of savings	Increase reproduction rates
		11	Sale of animals	Improve health and purchase more animals
Singinda	1	33	Milk for sale	Improve genetic merit
		33	Consumption	
		33	Manure	
Kishapu	3	100	As a form of savings	Improve health
		67	Consumption	Purchase more animals
		33	Sale of animals	
		33	Milk for sale	Improve health
Mbarara	7	30	Consumption	Improve health
		20	Milk for sale	Purchase more animals
		10	To finance planned expenditure	Increase reproduction rate
		10	Sale of animals	
North Pokot	10	100	Milk for sale	Improve health and generic merit
		70	Sale of animal	Purchase more animals
		70	Consumption	Reduce mortality
		70	As a form of savings	Improve health
Masaka	4	80	Sale of animals	Improve health
		40	Milk for sale	Improve health
		40	Consumption	Purchase more animals
		40	As a form of savings	Improve health
Nebbi	4	71	To finance planned expenditure	Purchase more animals
		43	Insurance in case of emergency	
		43	Consumption	Purchase more animals
Machakos	8	75	Milk for sale	Improve genetic merit
		63	As a form of savings	Improve health and purchase more animals
		13	Consumption	Purchase more animals
		13	Upgrading animal genetic	

B. Reasons to increase goats numbers and ideas on how to achieve that

	n	Households (%)	Reason for wanting to increase	How households plan to increase their goats numbers
Samburu	10	100	Milk for sale	Improve health and genetic merit
		100	Consumption	Reduce mortality
		80	Sale of animals	Improve health
		50	As a form of savings	Purchase more animals
Kajiado	5	30	As a form of savings	
		10	To finance planned expenditure	
Baringo	9	20	Sale of animals	Improve health
		20	Consumption	Improve health
		10	Milk for sale	Improve health
		20	As a form of savings	
West Pokot	10	100	As a form of savings	Increase reproduction and purchase more animals
		40	Sale of animals	Increase reproduction and reduce mortality
		40	Milk for sale	Improve health and improve genetic merit
		10	Upgrading animal genetics	Improve the genetic merit
Kwale	8	44	Milk for sale	Improve health and improve genetic merit
		44	Consumption	Improve genetic merit and purchase more animals
		44	As a form of savings	Improve the genetic merit and purchase more animals
		11	Sale of animals	Improve health
Singida	1	33	Milk for sale	Improve genetic merit
		33	Consumption	
		33	Manure	
Kishapu	3	100	As a form of savings	Improve health and purchase more animals
		67	Consumption	Improve health
		33	Sale of animals	
		33	Milk for sale	Improve health
Mbarara	7	30	Consumption	Improve health and purchase more animals
		20	Milk for sale	Improve health and purchase more animals
		10	To finance planned expenditure	Increase reproduction
		10	Sale of animals	
North Pokot	10	100	Milk for sale	Improve health, genetic merit, reproduction, purchase more animals and reduce mortality
		70	Sale of animals	Improve health and purchase more animals
		70	Consumption	Improve health, reduce mortality and barter trade
		70	As a form of savings	Improve health and purchase more animals
Masaka	4	80	Sale of animals	Improve health
		80	Consumption	Improve health and purchase more animals
		60	Milk for sale	Improve health
		60	As a form of savings	Improve health

Nebbi	4	57	Insurance in case of emergency	
		57	To finance planned expenditure	Purchase more animals
		43	Consumption	Purchase more animals
		17	As a form of savings	
Machakos	8	75	Milk for sale	Improve genetic merit
		63	As a form of savings	Improve health and purchase more animals
		13	Consumption	Purchase more animals
		13	Upgrading animal genetic	

C. Reasons to increase sheep numbers and how to achieve that

	n	Households (%)	Reason for wanting to increase	How households plan to increase their sheep numbers
Samburu	10	10	Milk for sale	Improve health
		10	As a way to save money	Purchase more animals
Kajiado	5	50	As a form of savings	
		10	To finance planned expenditure	
Baringo	1	10	Sale of animals	
West Pokot	10	20	As a form of savings	Improve genetic merit and purchase more animals
		10	Consumption	No suggestion
		10	To finance planned expenditure	Improve health
		10	Insurance in case of emergency	Purchase more animals
Kwale	No sheep			
Singida	No sheep			
Kishapu	No sheep			
Mbarara	No sheep			
North Pokot	10	60	As a form of savings	Purchase more animals and improve health
		30	Milk for sale	Improve health, increase reproduction and improving genetic merit
		30	Consumption	Improve health, purchase more animals and reduce mortality
		20	Sale of animals	Improve health and reduce mortality
Masaka	No sheep			
Nebbi	No sheep			
Machakos	No sheep			

Table 21: Households interested in increasing livestock productivity and strategies to follow

Site	Species	n	Improved feeding	Better animal health	Increasing access to water	Improved breeding
Samburu (Ke)	Cattle	5	4	2	3	1
	Goats	10	4	2.3	2.8	1
	Sheep	1	4	2	3	1
	Camel	1	3	4	2	1
Kajiado (Ke)	Cattle	10	3	1.8	2.2	3.4
	Goats	6	3.3	1.9	2.5	3.3
	Sheep	10	3.3	1.7	2.5	3.0
Baringo (Ke)	Cattle	-				
	Goats	9	2.9	2.1	2.4	2.9
	Sheep	1	4	2.5	3	2.5
West Pokot (Ke)	Cattle	3	1.7	3	2.3	3
	Goats	9	1.8	3.2	2	3.2
	Sheep	1	2	3	4	1
Kwale (Ke)	Cattle	6	3.3	2.5	3.2	1
	Goats	8	3.5	2.1	3.1	1.1
	Sheep	-				
Singida (Tz)	Cattle	1	4	3	2	1
	Goats	2	4	3	1	2
	Sheep	-				
Kishapu (Tz)	Cattle	1	3	1	2	4
	Goats	1	3	2.5	2.5	4
	Sheep	-				
Mbarara (Ug)	Cattle	9	3.1	2.2	1.3	3.3
	Goats	3	2	3	1	4
	Sheep					
North Pokot (Ke)	Cattle	10	3.7	3.3	1.4	1.8
	Goats	10	3.5	3.3	1.3	2.0
	Sheep	6	3.7	3.2	1.4	1.9
Nebbi (Ug)	Cattle	3	2.3	1.3	2.3	4
	Goats	2	2.7	3.2	2.5	2.5
	Sheep	-				
Masaka (Ug)	Cattle	4	2.2	2.7	1	4
	Goats	-				
	Sheep	-				
Machakos (Ke)	Cattle	7	2.2	2.8	1.7	4
	Goats	6	2.2	2.7	1.7	4
	Sheep	-				

Table 22: Main agricultural soil in each cluster pixel, and the estimated start of season date.

Cluster	FAO map unit[1]	Main Agricultural Soil	Season Starting Date (day of year)
1	774	Ne (Eutric Nitosol)	260
2	417	Je (Eutric Fluvisol)	270
3	248	Fo (Orthic Ferralsol)	90
4	357	Fx (Xanthic Ferralsol)	270
5	498	Lc (Chromic Luvisol)	30
6[2]	-	Nd (Dystric Nitosol)	30
7	501	Lc (Chromic Luvisol)	60
8	407	Ge (Eutric Gleysol)	240
9	960	Nd (Dystric Nitosol)	45
10	500	Lc (Chromic Luvisol)	15
11	76	Ao (Orthic Acrisol)	45
12	498	Lc (Chromic Luvisol)	60

1 From FAO (1998)
2 The FAO soil map is in error for this pixel, so the soil type was taken from Karanja et al. (2006).

Table 23: Mean simulated unfertilised crop yields, kg per ha, by cluster pixel for current conditions (“2010”) and the 2090s (detailed results are shown in Appendix A).

Cluster	Cassava		Millet		Sorghum		Maize		Bean		Cowpea	
	2010	2090	2010	2090	2010	2090	2010	2090	2010	2090	2010	2090
1	3900	4180	583	479	948	917	679	556	560	378	369	308
2	4400	4030	339	292	386	414	229	208	1149	832	620	604
3	2490	3410	502	313	628	510	403	327	399	264	305	304
4	1580	2190	76	90	15	46	56	69	161	369	114	334
5	3650	4880	472	362	666	666	332	291	784	664	404	389
6	930	2830	142	202	141	143	166	162	1122	1231	326	515
7	6190	5150	419	328	765	729	360	279	503	311	428	412
8	2330	3140	209	236	159	235	190	188	1290	1178	575	641
9	1610	2660	210	218	135	128	140	304	650	824	186	377
10	5210	6380	365	368	592	651	342	293	1155	939	505	506
11	2950	3800	240	281	403	496	292	531	134	191	101	205
12	4300	6290	681	474	798	777	580	289	619	543	384	409
Mean	3290	4040	353	304	470	476	314	288	710	644	360	417

Table 24: Simulated percentage of harvests with less than 500 kg per ha (Cassava) and with less than 150 kg per ha (other crops) yield, by cluster pixel for current conditions (“2010”) and the 2090s (detailed results are shown in Appendix A).

Cluster	Cassava		Millet		Sorghum		Maize		Bean		Cowpea	
	2010	2090	2010	2090	2010	2090	2010	2090	2010	2090	2010	2090
1	4	3	4	10	9	11	3	8	22	35	24	33
2	1	2	2	9	4	4	9	8	3	7	2	4
3	14	8	11	16	13	9	15	16	37	53	30	36
4	18	12	97	91	40	31	41	34	65	34	74	33
5	<1	1	<1	4	1	1	2	3	11	17	18	23
6	25	1	56	30	27	22	19	23	8	7	21	10
7	1	2	1	8	1	2	1	2	19	42	15	17
8	7	6	26	22	20	13	22	17	11	10	9	7
9	11	5	23	27	27	24	24	27	26	19	49	26
10	0	<1	1	2	1	2	2	3	5	9	9	10
11	4	3	40	27	17	15	18	21	69	66	76	55
12	1	1	1	1	5	3	6	5	17	23	18	18

Table 25: Exploring the effect of future changes in farm profit, food security, and emissions with current climate

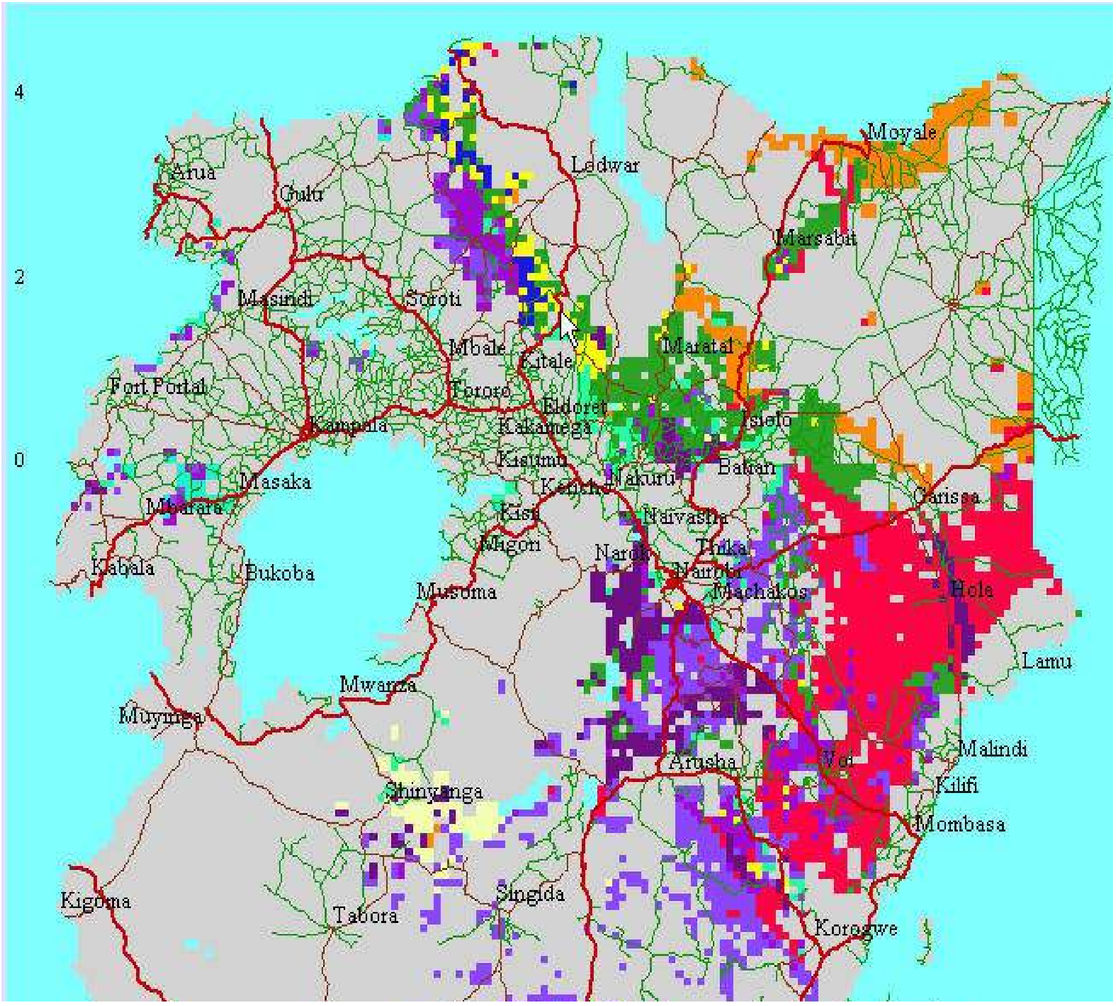
Site	Scenario	Household size #	Cropland ha	Grazing land ha	Livestock heads #	Farm profit USD (capita d)$^{-1}$	Crop profit USD (capita d)$^{-1}$	Food security -	Food self-sufficiency -	Energy from crops MJ (capita d)$^{-1}$	Energy from livestock MJ (capita d)$^{-1}$	Protein from own livestock g (capita d)$^{-1}$	Emissions Kg CO_2eq (capita d)$^{-1}$
Samburu (Ke)	Current state	8	0	14-20	20	0.05	0	0.8	0	0	0	0	1.92
	Food for home		0	30-50	56	0.09	0	1.4	0.10	0	0.6	8	4.86
	More protein		0	65-93	102	0.06	0	0.9	0.14	0	1.3	16	8.44
	Profit max		0	65-93	102	0.20	0	3.3	0	0	0	0	8.44
Kajiado (Ke)	Profit max	7	2.0	32-42	94	1.25	0.37	1.4	0	0	0	0	15.60
	Food for home		2.0	32-42	94	0.57	0.15	2.2	0.41	2.0	2.2	34	15.67
	Adapt cropping		2.0	32-42	94	0.42	0.01	1.6	0.60	3.8	2.2	34	15.67
	More livestock		2.0	50-53	116	0.81	0.15	3.2	0.41	2.0	2.2	34	19.63
Baringo (Ke)	Profit max	7	0.2	42-84	57	0.45	0.02	2.2	0	0	0	0	4.68
	Food for home		0.2	42-84	57	0.17	0.01	0.8	0.20	0.6	1.4	17	4.70
	Adapt cropping		0.6	42-84	57	0.17	0.01	1.7	0.33	1.9	1.4	17	4.84
	More livestock		0.2	54-126	85	0.36	0.01	1.7	0.20	0.6	1.4	17	7.11
West Pokot (Ke)	Profit max	6	0.7	50-100	64	0.44	0.13	1.7	0	0	0	0	7.39
	Food for home		0.7	50-100	64	0.19	0.05	0.8	0.35	2.5	1.1	12	7.37
	Adapt cropping		1.2	50-100	64	0.15	0	2.2	0.70	6.0	1.1	12	7.55
	More livestock		0.7	60-118	76	0.25	0.05	1.0	0.35	2.5	1.1	12	8.26
Kwale (Ke)	Profit max	8	5.8	34-45	32	0.64	0.26	1.6	0	0	0	0	5.89
	Food for home		5.8	34-45	32	0.21	0.08	2.0	0.47	3.6	1.1	18	6.37
	Adapt cropping		5.8	34-45	32	0.28	0.15	2.7	1.0	9.0	1.1	18	6.10
	More livestock		5.8	43-57	41	0.30	0.08	2.9	0.47	3.6	1.1	18	7.43
Singida (Tz)	Profit max	5	3.2	13-24	22	0.63	0.34	0.5	0	0	0	0	6.91
	Food for home		3.2	13-24	22	0.15	0.07	1.6	0.62	4.8	1.4	22	6.94
	Adapt cropping		3.2	13-24	22	0.16	0.09	1.8	1.0	8.3	1.4	22	6.86
	More livestock		3.2	16-29	26	0.19	0.07	2.1	0.62	4.8	1.4	22	7.65
Kishapu (Tz)	Profit max	6	2.2	13-25	18	0.75	0.37	2.4	0	0	0	0	5.90
	Food for home		2.2	13-25	18	0.19	0.10	1.0	0.68	4.8	2.0	29	5.73
	Adapt cropping		2.2	13-25	18	0.42	0.33	2.3	1.0	8.0	2.0	29	5.62
	More livestock		2.2	16-29	23	0.28	0.10	1.5	0.68	4.8	2.0	29	6.84
Mbarara (Ug)	Profit max	7	2.6	63-97	95	2.78	1.93	3.2	0	0	0	0	28.05
	Food for home		1.3	63-97	95	0.92	0.28	3.6	1.0	8.4	1.8	27	27.37
	Adapt cropping		2.6	63-97	95	1.83	1.19	8.4	1.0	8.4	1.8	27	27.93
	More livestock		1.3	88-117	114	1.11	0.28	4.4	1.0	8.4	1.8	27	32.72
North Pokot (Ke)	Profit max	7	1	29-53	62	0.87	0.26	3.1	0	0	0	0	6.99

	Food for home		1	29-53	62	0.16	0.04	3.7	0.65	4.0	2.5	30	6.92
	Adapt cropping		1	29-53	62	0.11	-0.05	2.5	0.90	6.5	2.5	30	6.92
	More livestock		1	35-62	72	0.29	0.04	6.9	0.65	4.0	2.5	30	8.19
Nebbi (Ug)	Profit max	9	4.4	8-12	15	1.46	1.29	2.0	0	0	0	0	3.31
	Food for home		4.4	8-12	15	0.55	0.54	5.3	1.0	9	1	15	3.56
	Adapt cropping		4.4	8-12	15	0.84	0.83	5.3	1.0	9	1	15	3.43
	More livestock		4.4	9-13	19	0.59	0.54	5.6	1.0	9	1	15	4.01
Masaka (Ug)	Profit max	7	1.5	5-8	6	1.92	1.78	4.3	0	0	0	0	3.00
	Food for home		1.5	5-8	6	0.57	0.55	5.9	1.0	8.4	1.1	18	2.89
	Adapt cropping		1.5	5-8	6	0.45	0.31	4.7	1.0	8.4	1.1	18	2.86
	More livestock		1.5	7-10	8	0.61	0.55	6.4	1.0	8.4	1.1	18	3.65
Machakos (Ke)	Profit max	6	3.6	9-10	16	1.97	1.02	5.9	0	0	0	0	5.44
	Food for home		3.6	9-10	16	0.97	0.28	11.1	1.0	8.2	2.0	28	5.67
	Adapt cropping		3.6	9-10	16	1.06	0.38	12.2	1.0	8.0	2.0	28	5.46
	More livestock		3.6	11-13	20	1.25	0.28	14.4	1.0	8.2	2.0	28	6.91

Table 26: Exploring the effect of future changes in farm profit, food security, and emissions with the climate of 2090

Site	Scenario	Household size \#	Cropland ha	Grazing land ha	Livestock heads \#	Farm profit USD (capita d)$^{-1}$	Crop profit USD (capita d)$^{-1}$	Food security -	Food self-sufficiency -	Energy from crops MJ (capita d)$^{-1}$	Energy from livestock MJ (capita d)$^{-1}$	Protein from own livestock g (capita d)$^{-1}$	Emissions Kg CO_2eq (capita d)$^{-1}$
Samburu (Ke)	-	-	-	-	-	-	-	-	-	-	-	-	-
Kajiado (Ke)	Profit max	7	2.0	32-42?	94	1.37	0.49	1.5	0	0	0	0	15.60
	Food for home		2.0	32-42?	94	0.78	0.36	3.0	0.41	2.0	2.2	34	15.69
	Adapt cropping		2.0	32-42?	94	0.51	0.10	2.0	0.60	3.8	2.2	34	15.67
	More livestock		2.0	50-53?	116	1.02	0.36	4.0	0.41	2.0	2.2	34	19.67
Baringo (Ke)	-	-	-	-	-	-	-	-	-	-	-	-	-
West Pokot (Ke)	Profit max		0.7	50-100?	64	0.49	0.18	0	0	0	0	0	7.27
	Food for home		0.7	50-100?	64	0.25	0.10	1.0	0.35	2.5	1.1	12	7.30
	Adapt cropping		1.2	50-100?	64	0.26	0.11	3.9	0.70	6.0	1.1	12	7.51
	More livestock		0.7	60-118?	76	0.30	0.10	1.2	0.35	2.5	1.1	12	8.19
Kwale (Ke)	Profit max	8	5.8	34-45?	32	0.59	0.21	1.5	0	0	0	0	5.89
	Food for home		5.8	34-45?	32	0.19	0.06	1.8	0.47	3.6	1.1	18	6.28
	Adapt cropping		5.8	34-45?	32	0.07	-0.05	0.7	1.0	9.0	1.1	18	6.15
	More livestock		5.8	43-57?	41	0.28	0.06	2.7	0.47	3.6	1.1	18	7.34
Singida (Tz)	Profit max	5	3.2	13-24?	22	0.67	0.38	0.5	0	0	0	0	6.91
	Food for home		3.2	13-24?	22	0.20	0.13	2.3	0.62	4.8	1.4	22	6.93
	Adapt cropping		3.2	13-24?	22	0.35	0.28	3.9	1.0	8.3	1.4	22	6.78
	More livestock		3.2	16-29?	26	0.25	0.13	2.8	0.62	4.8	1.4	22	7.73
Kishapu (Tz)	Profit max		2.2	13-25?	18	0.71	0.33	2.3	0	0	0	0	5.90
	Food for home		2.2	13-25?	18	0.17	0.08	0.9	0.68	4.8	2.0	29	5.72
	Adapt cropping		2.2	13-25?	18	0.37	0.28	2.0	1.0	8.0	2.0	29	5.63
	More livestock		2.2	16-29?	23	0.26	0.08	1.4	0.68	4.8	2.0	29	6.84
Mbarara (Ug)	Profit max	7	2.6	63-97?	95	3.44	2.60	5.7	0	0	0	0	28.05
	Food for home		1.3	63-97?	95	1.08	0.44	4.2	1.0	8.4	1.8	27	27.35
	Adapt cropping		2.6	63-97?	95	2.13	1.50	7.2	1.0	8.4	1.8	27	27.94
	More livestock		1.3	88-117?	114	1.27	0.44	5.0	1.0	8.4	1.8	27	32.72
North Pokot (Ke)	Profit max	7	1.5	29-53?	62	1.06	0.57	3.7	0.65	4.0	2.5	30	6.99
	Food for home		1.5	29-53?	62	0.19	0.03	4.3	0.65	4.0	2.5	30	7.16
	Adapt cropping		1.5	29-53?	62	0.19	0.03	4.5	0.90	6.5	2.5	30	7.09
	More livestock		1.5	35-62?	72	0.28	0.03	6.6	0.65	4.0	2.5	30	8.43
Nebbi (Ug)	Profit max	9	4.4	8-12?	15	1.24	1.07	1.7	0	0	0	0	3.31
	Food for home		4.4	8-12?	15	0.43	0.42	4.2	1.0	9.0	1.0	15	3.56

	Adapt cropping		4.4	8-12?	15	0.64	0.62	6.1	1.0	9.0	1.0	15	3.45
	More livestock		4.4	9-13?	19	0.46	0.42	4.5	1.0	9.0	1.0	15	4.01
Masaka (Ug)	Profit max	7	1.5	5-8?	6	2.33	2.19	5.2	0	0	0	0	3.0
	Food for home		1.5	5-8?	6	0.47	0.45	4.9	1.0	8.4	1.1	18	2.86
	Adapt cropping		1.5	5-8?	6	0.25	0.11	2.6	1.0	8.4	1.1	18	2.83
	More livestock		1.5	7-10?	8	0.52	0.45	5.4	1.0	8.4	1.1	18	3.63
Machakos (Ke)	Profit max	6	3.6	9-10?	16	2.44	1.49	7.3	0	0	0	0	5.33
	Food for home		3.6	9-10?	16	1.23	0.54	14.2	1.0	8.2	2.0	28	5.43
	Adapt cropping		3.6	9-10?	16	2.05	1.36	23.6	1.0	8.2	2.0	28	5.45
	More livestock		3.6	11-13?	20	1.51	0.64	17.4	1.0	8.0	2.0	28	6.65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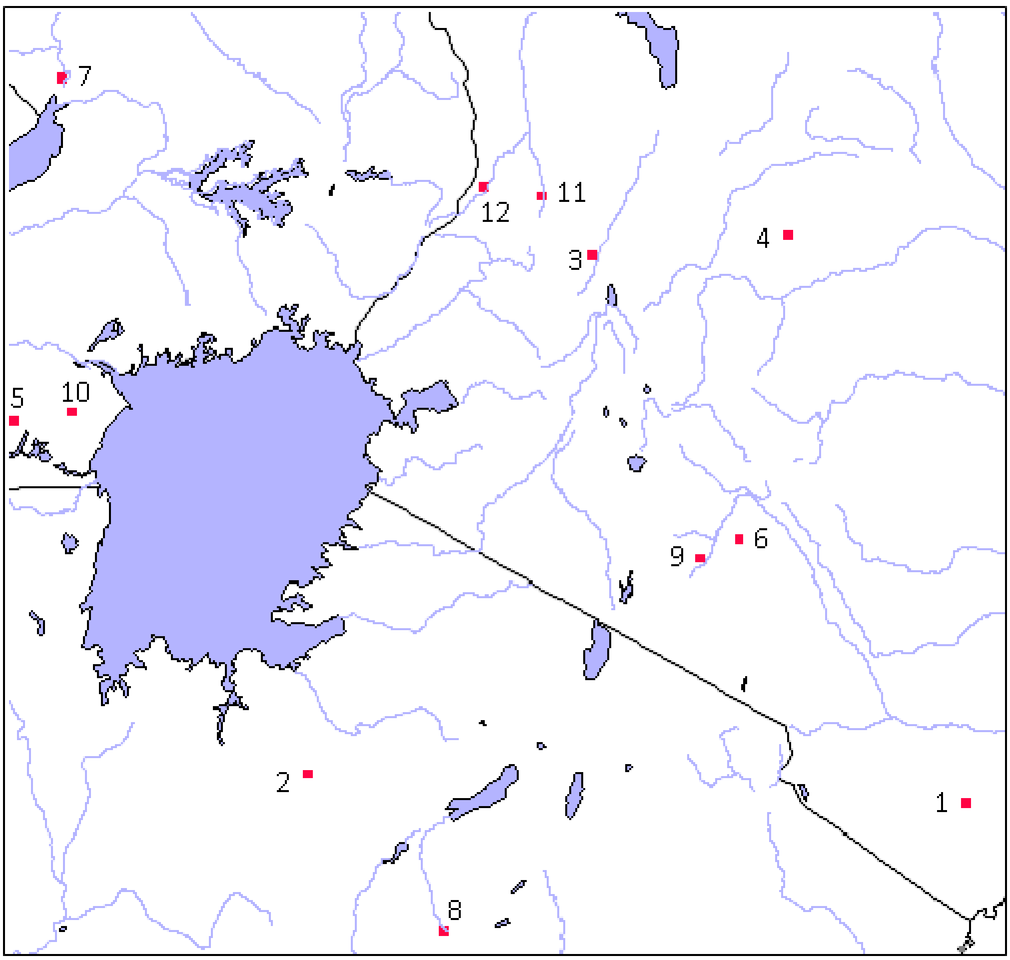
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Figure

Figure 2: The sampled pixels in relation to water bodies and rivers. Numbers refer to the cluster number in Figure 1.

Figure 3: History of cropping in years at each of the study sites. Information provided by key informants (traditional authority and governmental officer)

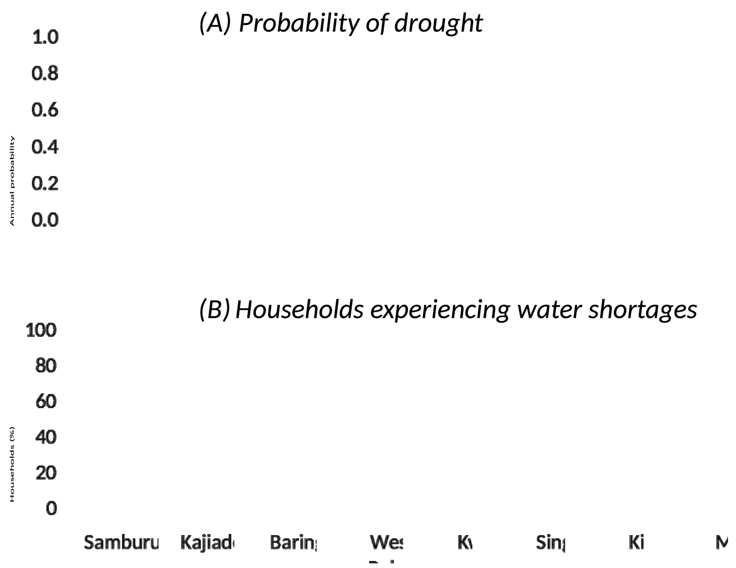


Figure 4: Households´ perceptions of (A) frequency of droughts,(B) proportion of households experiencing problems due to water shortages.

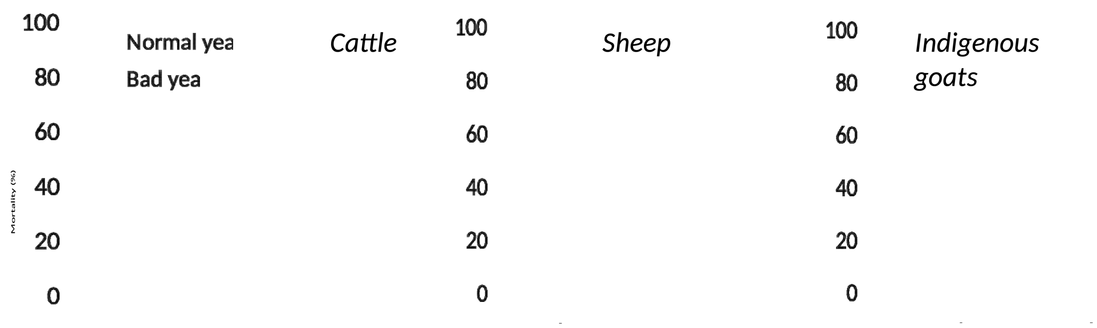


Figure 5: Livestock mortality in normal and bad years for cattle, sheep and goats.

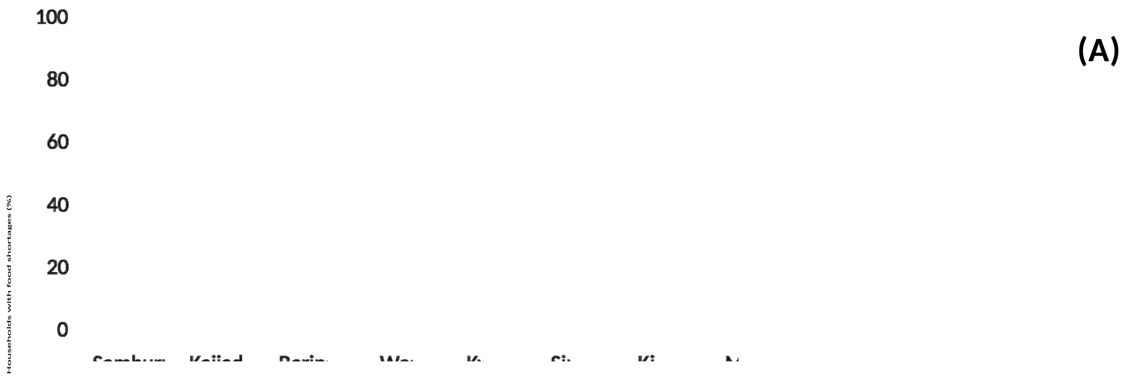


Figure 6: Status of food shortages across study sites: A) Percentage of households experiencing food shortages, B) Average length of the typical food shortage across sites.

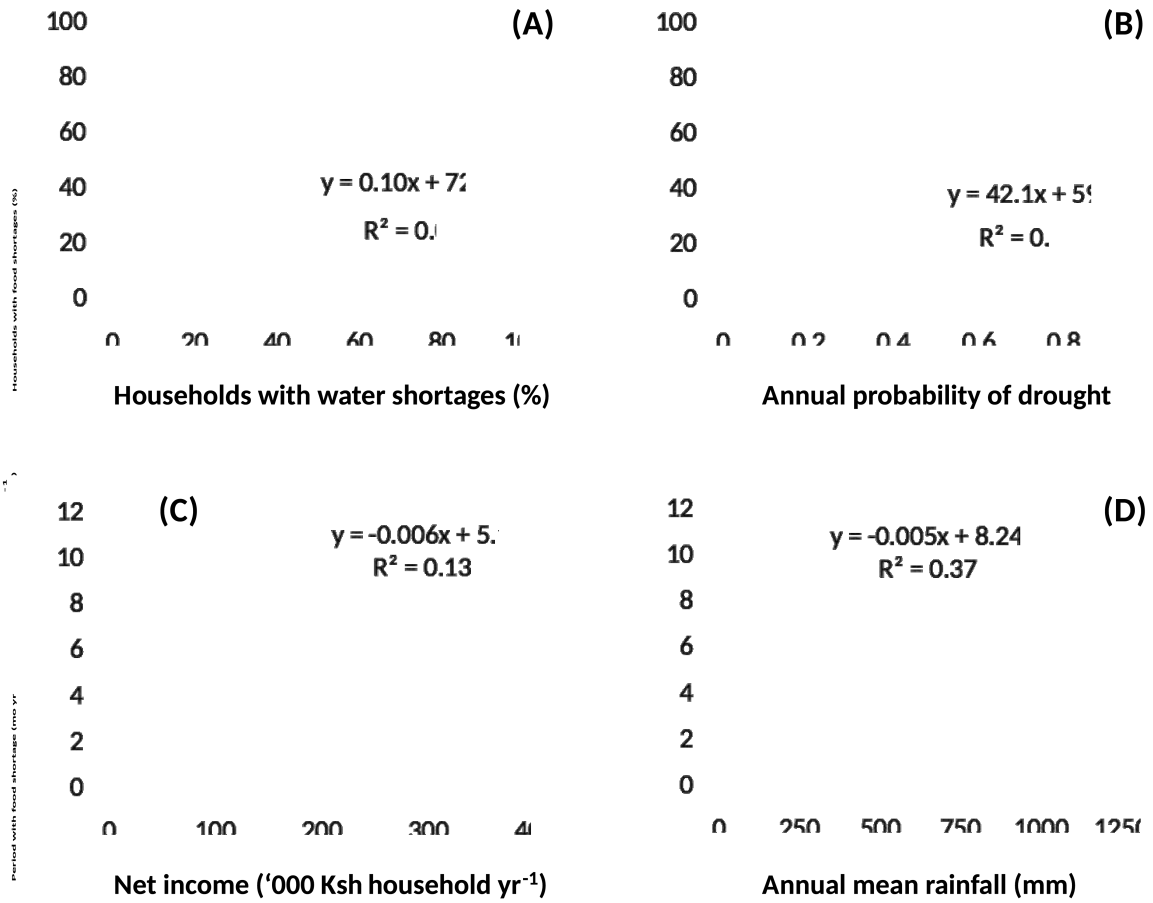
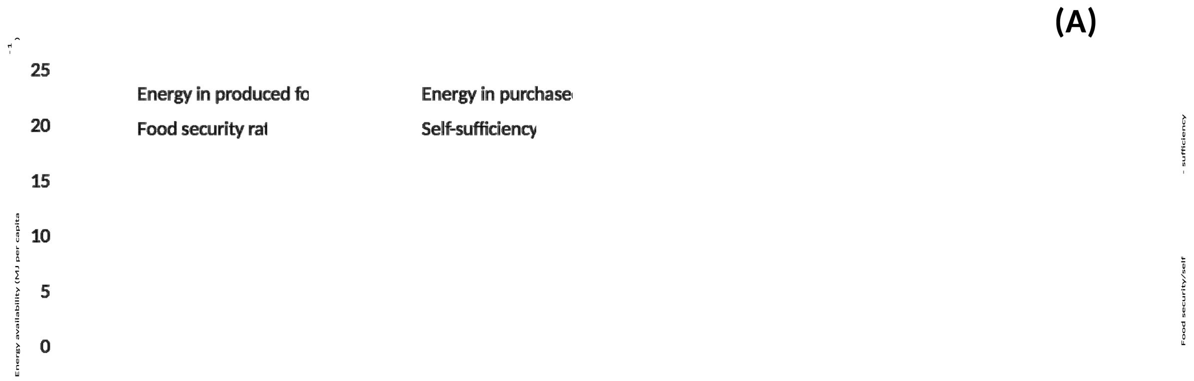


Figure 7: A) Relationship between percentage of households having food and water shortages, (B) Relationship between households having food shortages and annual probability of experiencing a drought, (C) Relationship between the length of the period with food shortage and net household income, and (D) Relationship between the length of the food shortage period and annual average rainfall at the study site.



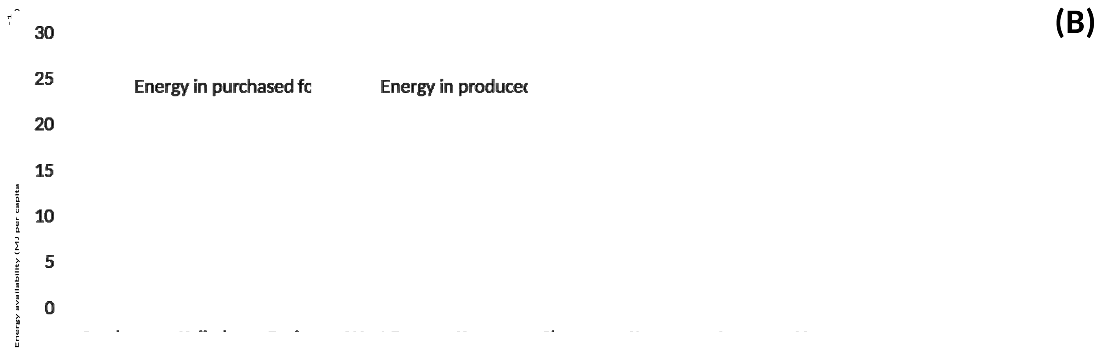


Figure 8: A) Energy availability per household member (produced on farm and purchased food items) and food security and food self-sufficiency ratios across the 12 study sites. B) Variability in energy availability per household member from food produced on farm and from purchased food items.

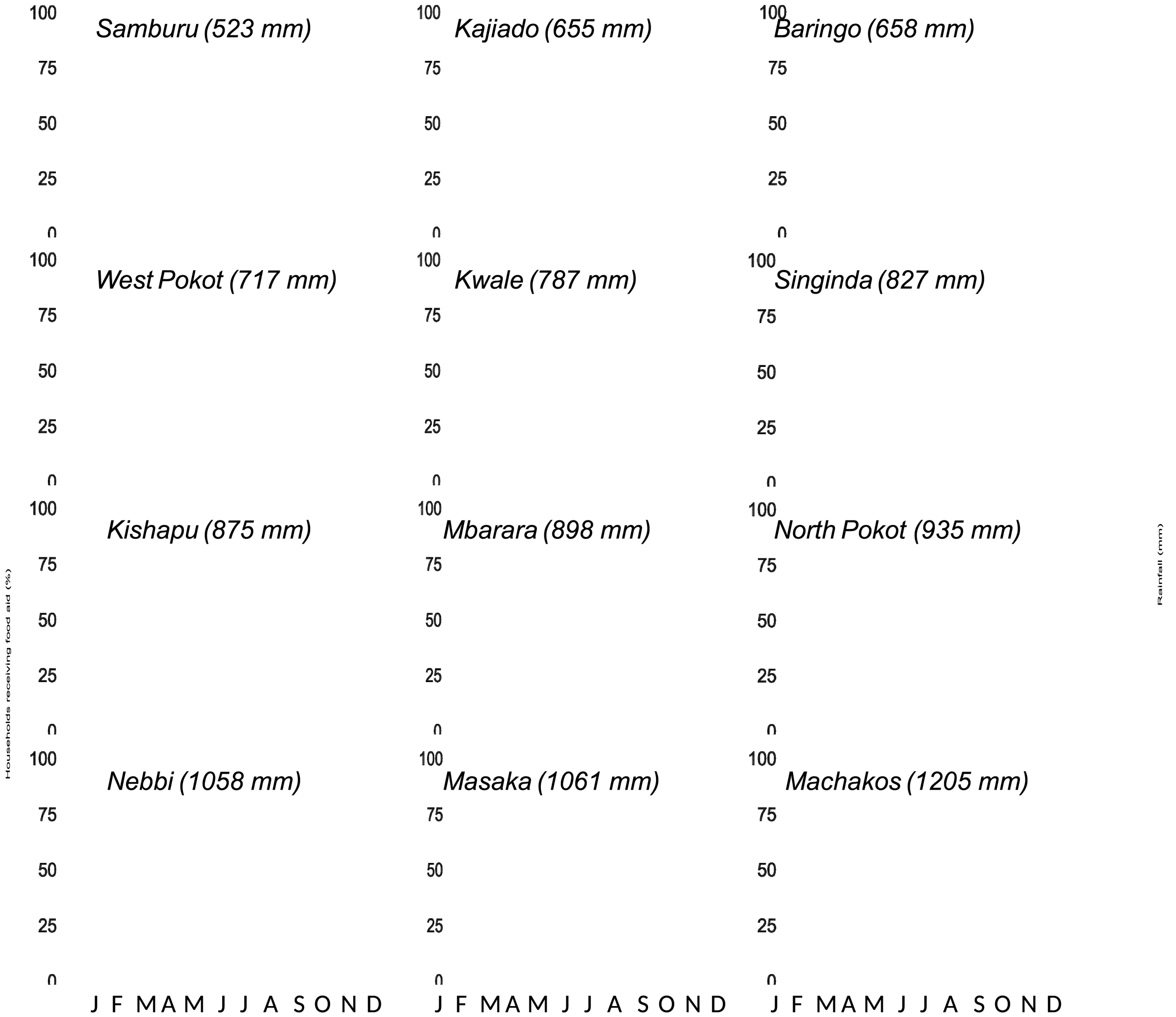


Figure 9: Distribution of monthly rainfall and percentage of households receiving food aid in different months at 8 of the study sites.

Figure 10: Percentage of households valuing the most important sources of income across districts (including those ranked 1st, 2nd and 3rd), ordered according to average annual rainfall. Activities include crop production, employment (informal and formal), trade (other than agricultural produce), livestock trade (buying and selling livestock) and livestock production.

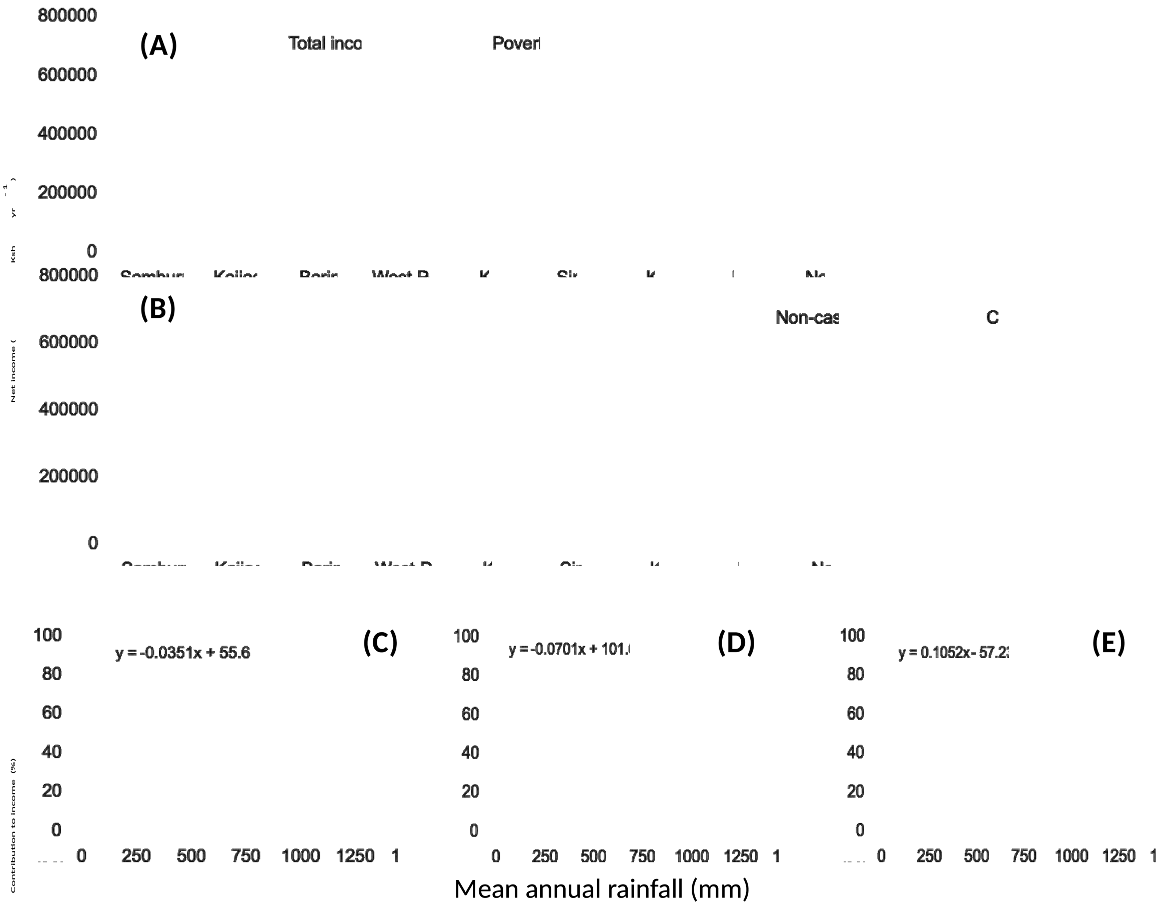


Figure 11: A) Total net household income across sites, and poverty line calculated considering household size and standard deviation at each site, an income of USD 1.25 per capita per day and a conversion rate of 1USD= 95.3 Kenyan shillings; B) Cash and non cash incomes across sites; and the contribution to household income of C) Livestock household activities, D) Off-farm income, and E) Cropping activities.

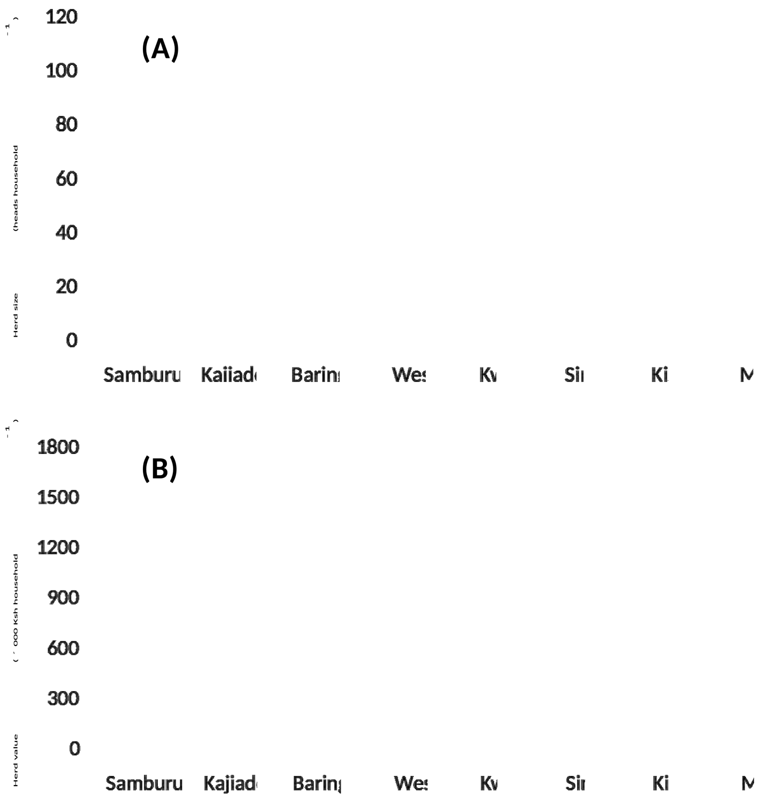


Figure 12: A) Herd sizes for the most important livestock species across study sites; B) Monetary value of the livestock at each of the study sites.

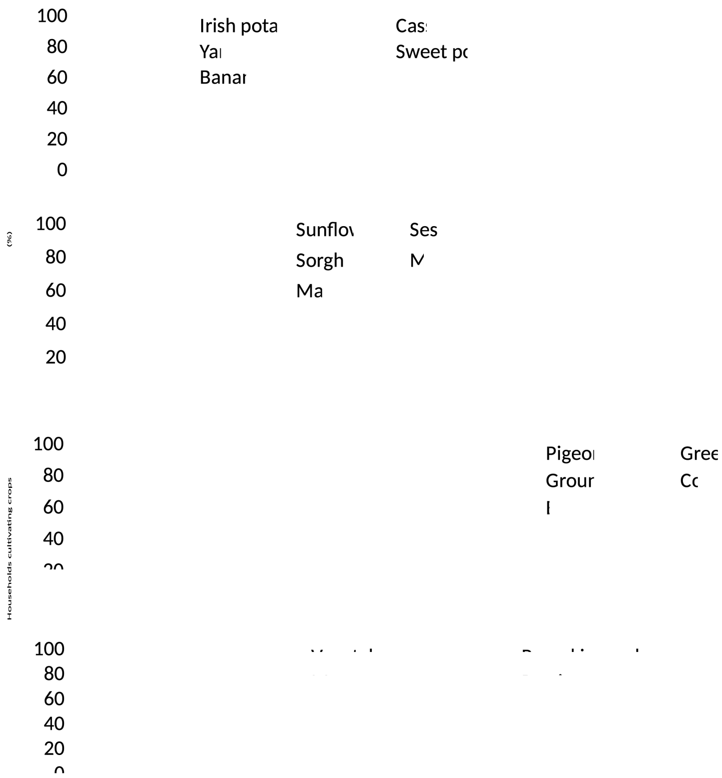


Figure 13: Diversity of crops cultivated at each of the study sites

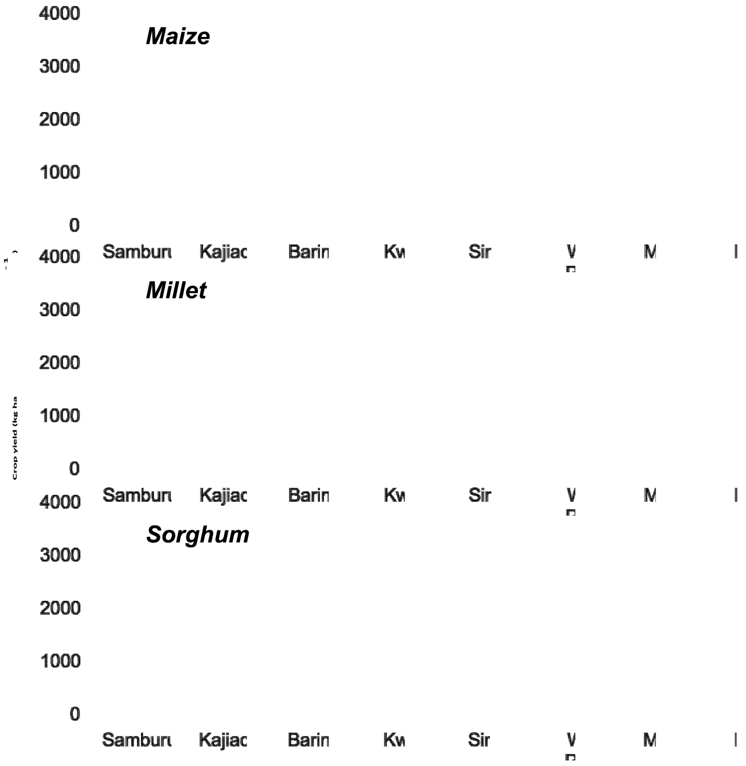


Figure 14: Average grain yields for maize, millet and sorghum across study sites.

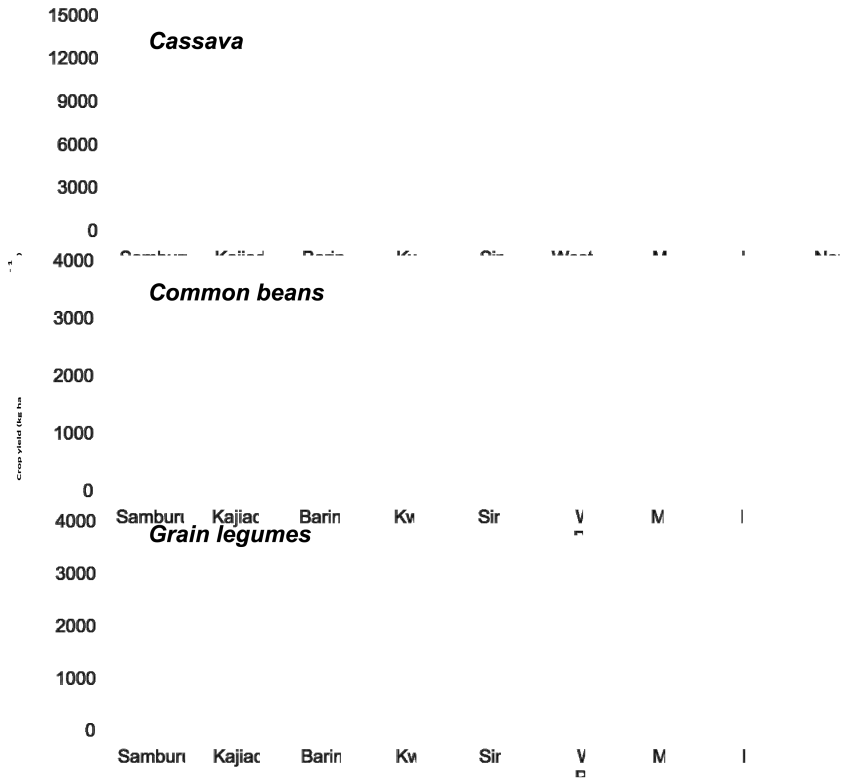


Figure 15: Average grain yields for cassava, common beans, and other grain legumes.

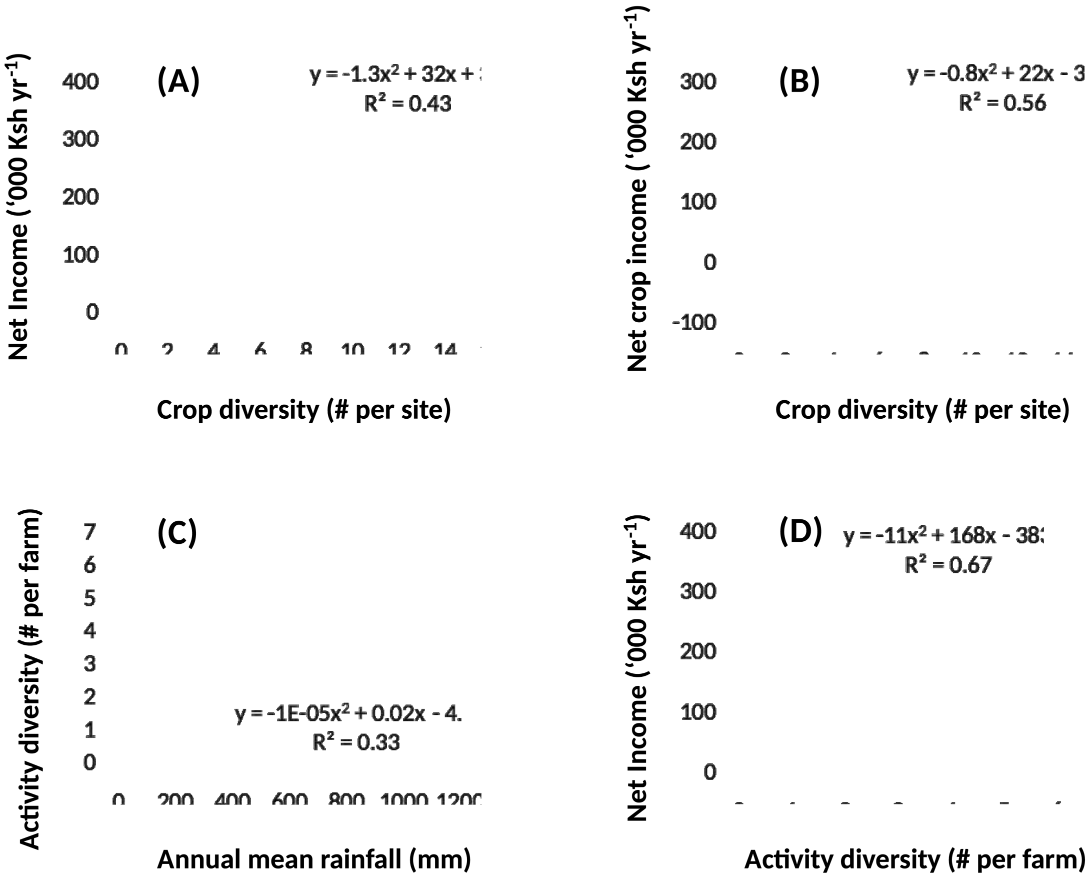


Figure 16: (A) Relationship between crop diversity (i.e. number of crops cultivated) and net household income. (B) Relationship between crop diversity and net income from cropping. (C) Relationship between activity diversity (number of activities per farm) and annual mean rainfall. (D) Relationship between net income per year and activity diversity.

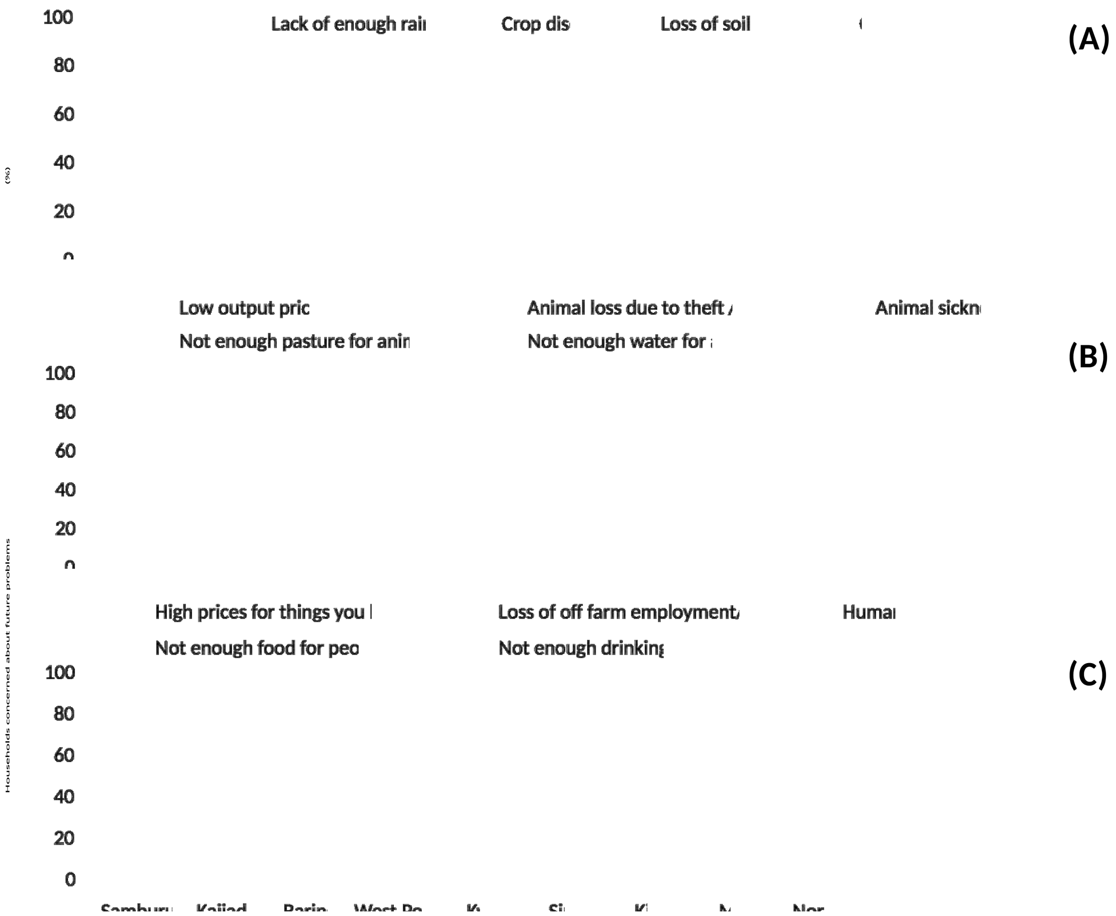


Figure 17: Household concerns about future problems, which have been grouped into 3 categories (A) Concerns related to cropping, (B) Concerns related to livestock, and (C) Concerns related to the household family (human concerns).

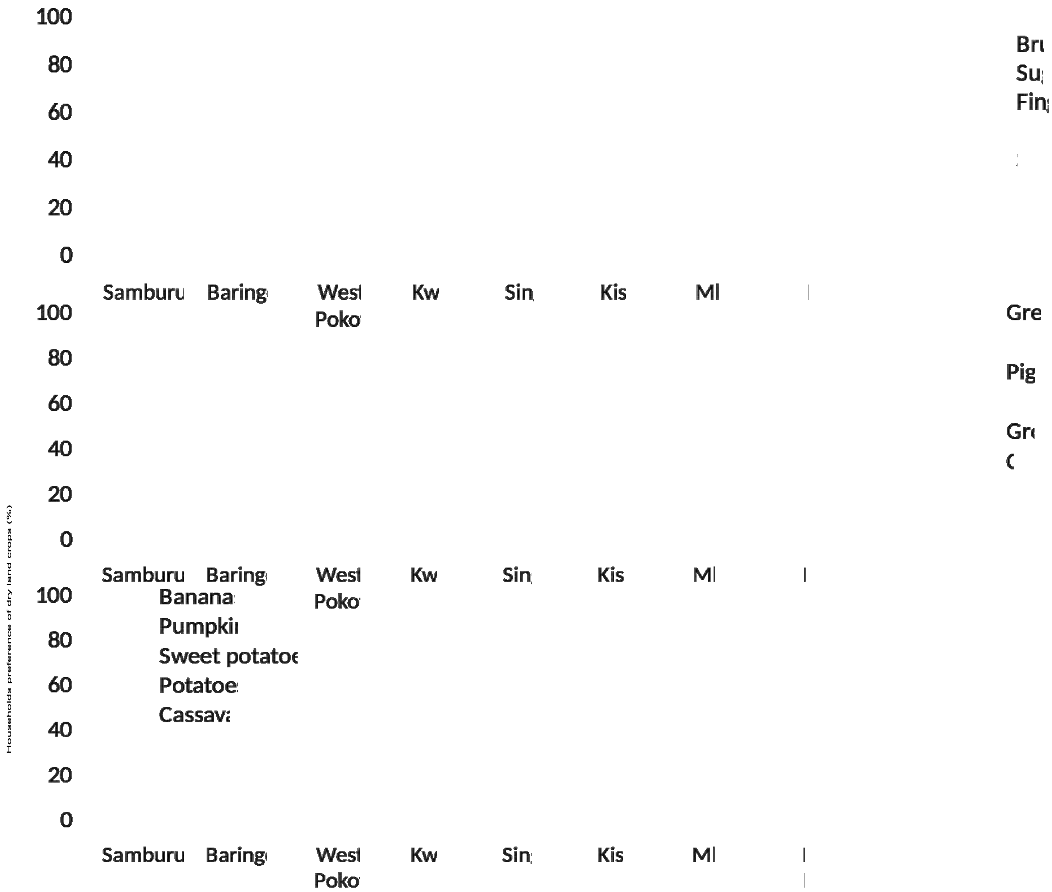


Figure 18: Households preference for drought tolerant crops across sites. Crops are separted in grains, legumes, and others.

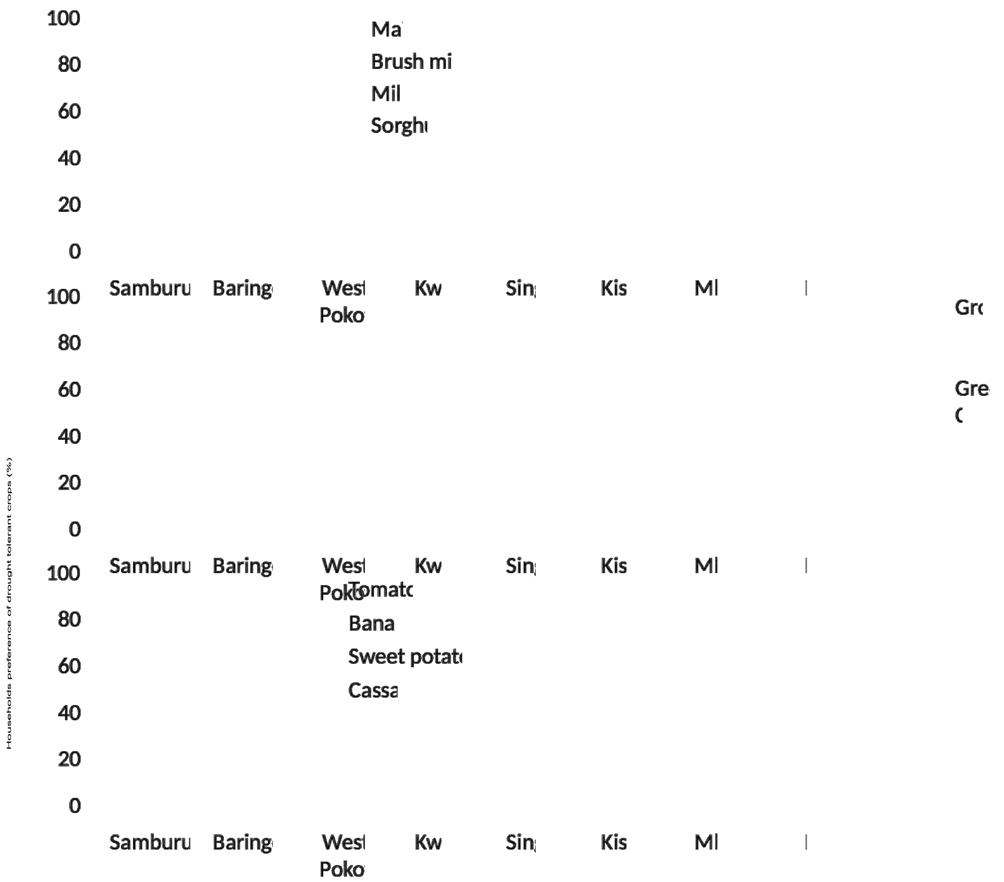


Figure 19: Households preference for drought tolerant crops across sites in case it gets drier in the future. Crops are separated in grains, legumes, and others.

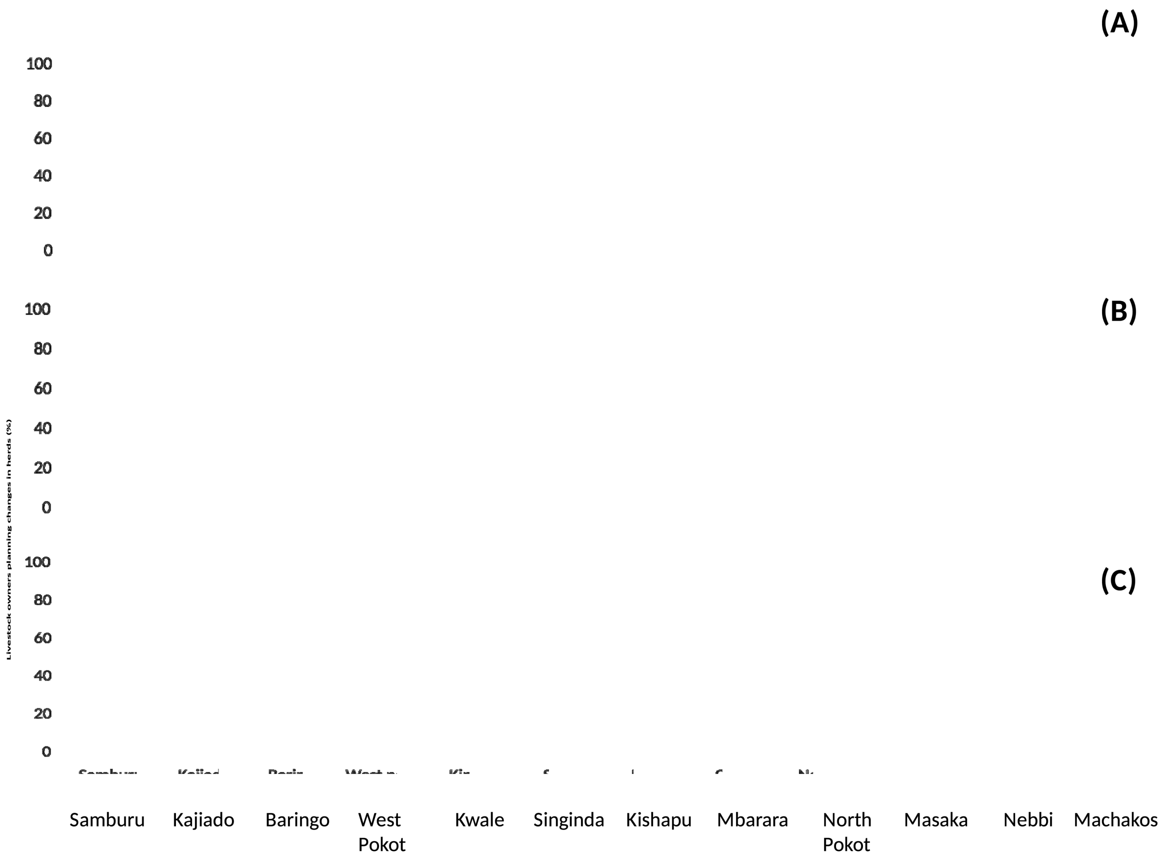


Figure 20: Proportion of livestock owners who plan future changes in herd sizes (A) Increase, (B) Reduce, and (C) No changes.