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Transitions in agro-pastoralist systems of East Africa: Impacts on food security and poverty☆

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ABSTRACT

Climate-induced livelihood transitions in the agricultural systems of Africa are increasingly likely. There is limited evidence on what such transitions might look like. We carried out fieldwork in 12 sites in Kenya, Tanzania and Uganda to understand changes in farming systems in the recent past, and to test the hypothesis that sedentary farmers in zones that may become warmer and drier in the future may be forced to increase their reliance on livestock *vis-à-vis* cropping in the future. We estimated the contribution of crop and livestock activities to incomes, food security and poverty. Householders were asked how to adapt farming in the future. We found no direct evidence for the hypothesised extensification of production across study sites. Human diets have changed considerably in the last 40 years, as cropping has been taken up by increasing numbers of pastoral households, even in marginal places. Maize and legumes predominate, but some householders are increasing their crop and diet diversity, particularly in locations with annual rainfall higher than 800 mm. At all sites people want more livestock. Food insecurity is common at all sites with an annual rainfall of 800 mm or less, and critical levels are seen at sites with <700 mm. Households are self-sufficient in securing adequate dietary energy from food production in 7 of the 12 sites, all with rainfall higher than 800 mm. Although many householders have some knowledge about drought-tolerant crops, few cultivate millet, sorghum and cassava. Policies aimed at increasing the consumption of cassava, sorghum, millet and pigeon pea could be highly beneficial for future food security in the region. Vulnerability in the drier locations is already high, and policies should support safety nets and market and infrastructural development. Households in the wetter areas need to manage risk and to increase crop productivity. A critical requirement is knowledge transfer concerning the growing and utilisation of unfamiliar and untraditional crops.

1. Introduction

The increases in food production necessary to feed the growing global human population have to occur in conjunction with climate change. Climate change may affect the regional distribution of hungry people, and particularly large negative effects are expected in many parts of sub-Saharan Africa (SSA) because of the projected declines in agricultural production that affect both food availability and access (IPCC, 2007). The linkages between climate change and future food security in East Africa, as in other regions, are uncertain, partly because climate and impact models themselves are incomplete and subject to considerable uncertainty. While progress is being made, there is considerable work still to do to reduce these uncertainties to reasonable levels (Ramirez-Villegas et al., 2013). Nevertheless, there is evidence that climate change will have serious impacts on crop and livestock production in many parts of SSA (Challinor et al., 2009; Thornton et al., 2011).

The effects of climate change on agricultural systems in developing countries will depend on location and people's adaptive capacity. But adapting to and coping with a changing climate are not infinitely plastic, and it may be envisaged that in some places climate change may push agro-ecological conditions beyond the 'coping range', such that current adaptation measures may not be longer be viable. In such places, livelihood options may have to change. In the mixed crop-livestock rainfed arid and semiarid

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systems of Africa, cropping will become increasingly risky, and this could lead to increased dependence on livestock keeping or increasing diversification into non-agricultural activities and migration to urban areas (Jones and Thornton, 2009). Such livelihood changes could be seen as antithetical to an evolutionary process of agricultural intensification, in which increasing human population pressure on relatively fixed land resources is seen as the driving force of agricultural intensification (Boserup, 1965). Nevertheless, this reversal of an evolutionary process is entirely plausible; the ability of householders in regions of high climatic risk to adapt, using blends of old and new techniques as well as a host of methods to extensify and/or diversify the production system has long been the subject of study (Matlon and Kristjanson, 1988; Tache and Oba, 2010).

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 social implications would be profound. As for many other types of widespread livelihood transition, there would be social, environmental, economic and political effects at local, national and even regional levels, and these effects would need to be appropriately managed and facilitated.

Livelihood transitions mediated via changes in climate *vis-à-vis* changes caused by other drivers (e.g. immigration, conflicts for natural resources, and changing economies) need to be elucidated to disentangle the impacts of climate change on African rural households. In this study we tested the hypothesis that sedentary farmers who currently keep livestock in transition zones that are becoming warmer and possibly drier in the future may ultimately be forced to increase their reliance on livestock *vis-à-vis* cropping in the future, despite other potential driving forces shaping their livelihoods. We analyse past and current responses of farming households to climate variability and regional change in marginal cropping areas of East Africa, and assess impacts on household income, food security, and food self-sufficiency, while at the same time providing evidence on future coping and adaptation mechanisms.

2. Methods

This work builds on Jones and Thornton (2009) using high-resolution methods to identify, analyse and characterise hotspots where climate change might induce system extensification in the future. The site selection process identified case studies for in-depth analysis working across contexts sufficiently heterogeneous to ensure that outputs and recommendations would have wider application and relevance at other sites.

For the target countries, Kenya, Tanzania, Uganda, we refined the original hotspot analysis of identifying transition zones, using up-to-date data layers (Jones and Thornton, 2009). We developed a sampling framework using cluster analysis, sampled the transition zones, and identified a small number of locations in each country, giving a total of 12 study sites in all. From each site we collected on-the-ground information on what are the prevalent crop and livestock systems, together with information on cropping calendars, input use, production levels and local prices via key-informant interviews and household survey.

2.1. Sampling frame design

We generated a sampling frame for 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. The following variables were used in subsequent analysis, standardised to a resolution of 5 arc-min:

- Season failure rates for current conditions and for a future world with +4 °C of warming; details of the methods used are given in Jones and Thornton (2013).
- pH, cation exchange capacity (CEC), base saturation, silt and clay contents of the topsoil, and soil water holding capacity were taken from the digital version of the FAO soils map of the world (FAO, 1998, 2009) and collated with soil profile information following Gijsman et al. (2007).
- Elevation and slope data were compiled from the datasets of Jarvis et al. (2008).
- Human population was derived from GPWv3 (CIESIN/CIAT, 2005) and ILRI (2006) for the year 2000.
- Livestock densities for cattle, sheep and goats were derived from Robinson et al. (2007).
- Images of the extent of land cropped in maize, sorghum, beans, cassava, cowpea and pigeon pea were from Monfreda et al. (2008). The proportions of each pixel under cultivation and in pasture were obtained from Ramankutty et al. (2008).

All pixels in the window with current crop failure rates of fewer than 1 year in 10 and >4 years in 5 were excluded; all remaining pixels were taken to represent areas where cropping was possible but risky. Of these, pixels with <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. Twenty variables (Appendix Table 1) for the remaining pixels were analysed in a principal components analysis. A cluster analysis was then carried out using the first eight eigenvalue scores (accounting for 77% of the variance) to minimise the sums of squares within clusters. Twelve distinctive clusters were produced from the data (Table 1). These are mapped in Fig. 1. The 12 clusters vary in size because the clustering was designed to maximise the between-cluster distances and minimise the within-cluster variances. We sampled one point from each cluster to spread the samples as widely as possible. In an attempt to minimise logistical problems, we chose a sample pixel from each cluster that was relatively close to the main road network. The selected sample pixels are also mapped in Fig. 1.

2.2. Selection of households

Using the coordinates of the sample pixels, a working map for each site was developed to identify province, district, division, location and sub-location where each of the pixels was situated. The maps, drawn to scale, 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 uploaded into global positioning system (GPS). The GPS and working area map were used as a guide to the specific location of the site.

At each site, the administrative officer of the location was identified, and the objective of the study explained. The key person was then asked to help organise 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. Key persons were mainly government appointed administration officers for each location and traditional authorities. They included Chiefs in Kenya, Village Executive Officers in Tanzania and Local Councillors in Uganda. In some sites, the agricultural Extension Officers were also interviewed.

Table 1
Main characteristics of the 12 distinctive clusters derived from a multivariate analysis (see Section 2.1 for details). The clusters are mapped in Fig. 1.

Cluster	Country	Pixels in cluster	Location	District	Latitude	Longitude	System[a]	System 2[b]	Access index[c]	Population (people km^{-2})	LGP[d] days
1	Kenya	961	Taru	Kwale	−3.708	39.125	LGA	MBM	104	19	179
2	Tanzania	99	Kolandoto	Kishapu	−3.458	33.542	MRA	MBM	350	24	168
3	Kenya	480	Nginyang	Baringo	0.958	35.958	MRA	APMSB	592	15	134
4	Kenya	299	Seredupi	Samburu	1.125	37.625	LGA	MBM	516	1	85
5	Uganda	294	Chiruhura	Mbarara	−0.458	31.042	MRA	HP	243	15	211
6	Kenya	137	Mua Hills	Machakos	−1.458	37.208	MRT	MBM	160	498	159
7	Uganda	5	Pakwach	Nebbi	2.458	31.458	MRA	MBM	395	55	210
8	Tanzania	871	Madewa	Singida	−4.792	34.708	MRA	MBM	414	28	139
9	Kenya	312	Kisanyu	Kajiado	−1.625	36.875	LGT	MBM	48	21	146
10	Uganda	46	Lwengo	Masaka	−0.375	31.542	MRA	HP	254	294	217
11	Kenya	102	Lomut	West Pokot	1.458	35.542	MRA	MBM	594	17	139
12	Kenya	42	Lokichar	North Pokot	1.542	35.042	MRA	MBM	493	22	196

Cluster	Ethnic group	Rainfall (mm)	Rainfall CV (%)	Elevation (m)	Cattle (×10 km^{-2})	Chicken (×10 km^{-2})	Goats (×10 km^{-2})	Sheep (×10 km^{-2})	Pigs (×10 km^{-2})	Cropland (%)	Pasture (%)
1	Duruma	787	28	372	445.7	665.1	156.3	66.2	0.04	15	48
2	Sukuma	875	23	1187	1260.0	1167.1	648.0	337.4	0.98	19	35
3	Pokot	658	28	906	134.4	297.9	253.5	45.2	0	10	85
4	Samburu	523	26	724	6.2	4.6	168.1	139.3	0	18	57
5	Banyankole	898	22	1305	0	0	0	0	0	67	0
6	Kamba	1205	29	1923	478.3	920.4	436.6	169.2	0	13	49
7	Acholi	1058	26	652	132.8	700.9	429.1	40.6	62.4	64	36
8	Wanyaturu	827	32	1505	741.8	784.1	455.8	276.5	0.52	2	98
9	Masai	655	29	1619	116.6	1.0	30.6	230.2	4.2	24	0
10	Bunyore	1061	21	1218	2.5	1548.2	23.3	490.5	53.7	88	0
11	Pokot	717	27	939	229.6	298.3	698.7	447.1	0.09	34	65
12	Pokot	935	26	1275	204.9	366.3	131.2	753.6	0	74	26

2.3. Household surveys

The key persons helped in selecting a random sample of 10 households from village lists provided by the key persons. This was followed by a visit to the household homes for structured interviews. To facilitate ease of information exchange during the interviews, the key persons introduced the research team to the household's head. 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 in total. The survey comprised detailed information household composition, livelihood strategies

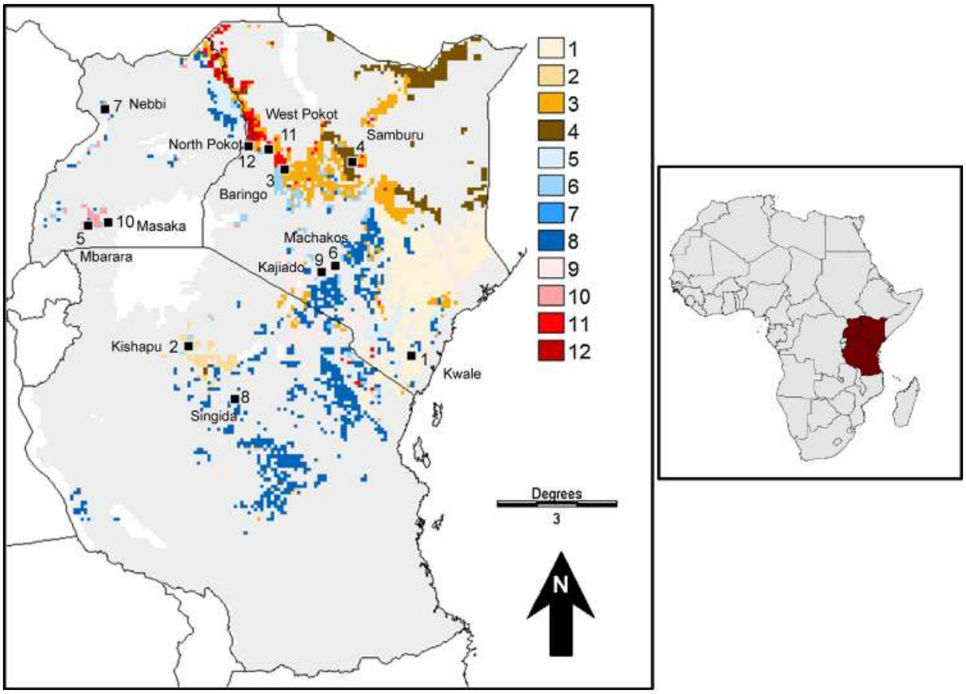

Fig. 1. Twelve sampling clusters for East Africa (Kenya, Tanzania and Uganda) were derived from a multivariate analysis using spatial layers on (i) season failure rates, (ii) soil characteristics (pH, cation exchange capacity, base saturation, silt and clay contents of the topsoil, and soil water holding capacity) (FAO, 1998, 2009), (iii) elevation and slope (Jarvis et al., 2008), (iv) human population for 2000 from GPWv3 (CIESIN/CIAT, 2005) and ILRI (2006), (v) livestock densities for cattle, sheep and goats (Robinson et al., 2007), and (vi) cropped land (Monfreda et al., 2008), and proportions of each pixel under cultivation and in pasture (Ramankutty et al., 2008). The study sites are the numbered sampled pixels shown as black squares, together with their district names.

and assets, land and livestock ownership and management, and an analysis of vulnerability to shocks. 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 (species, breeds, number, inputs and management cost) and other assets such as land (size, and type of ownership) were also collected. Main sources of income for the household members were recorded: crop income, livestock income, and off-farm income (salaried income, remittances, business income, income from casual labour and sale of forest/woodland products such as charcoal). We collected comprehensive data on household food consumption and expenditure on food items. For periods of drought, information was collected on food availability, preferred crops types, and access to food aid.

2.4. Data analysis

2.4.1. Income calculations

Total net income, cash income, non-cash income and off-farm income for the household were calculated using revenues from livestock, crops, value of consumed food products and as shown in Eqs. (1)–(4).

Total net income

$$T\_inc_i = Lsale + Crsale + VP - Lcost - Crcost \tag{1}$$

where T_inc_i is total annual income for household i; *Lsale* is annual income from livestock sales; *Crsale* is annual income from crop sales; *VP* is the annual monetary value of consumed farm produce; *Lcost* are the annual direct costs of livestock production; and *CrCost* are the annual direct costs of crop production

Cash income

$$C\_inc_i = Lsale + Crsale \tag{2}$$

where C_inc_i is the annual cash income for household i; *Lsale* is the annual income derived from livestock sales; and *Crsale* is the annual income from crop sales

Non-cash income

$$NC\_inc_i = T\_inc_i - Cinc_i \tag{3}$$

where Nc_inc_i is the annual non-cash income for household i

Off-farm income (4) was the sum of the cash earned from all j off-farm activities the household members are engaged in:

$$Off\_inc_i = \sum_{j=0}^{n} (Off\_farm \quad income)_j \tag{4}$$

where Off_inc_i is the annual off-farm income of household i and $Off\_farm\ income_j$ is the revenue from each j off-farm activities.

Poverty line at household level (5) was calculated by considering household size, an income of USD 1.25 per capita per day, and a conversion rate of 1 USD = 95 Kenyan shillings.

$$PovLine_i = HHsize \times 1.25 \times 365 \times 95 \tag{5}$$

where $PovLine_i$ is the poverty line expressed as annual income in Kenyan shillings for household i and $HHsize_i$ is the number of members of household i.

2.4.2. Crop diversity and activity diversity

Crop diversity (6) was the maximum number of crops grown by the households in a site.

$$CropDiv_k = \max \quad NumCrops_i \tag{6}$$

where $CropDiv_k$ is the crop diversity for site k and $Max\ NumCrops_i$ is the maximum number of crop grown by the i households at site k.

Activity diversity (7) is the maximum number of farm and non-farm activities households are engaged in a site.

$$ActDiv_k = \max \quad NumAct_i \tag{7}$$

where $ActDiv_k$ is the activity diversity for site k and $Max\ NumAct_i$ is the maximum number of activities in which the i households are engaged at site k.

2.4.3. Food and water shortages and recurrence of drought

The period of food shortage was calculated as the average number of months in a year that a household reported having not enough food. We calculated the proportion of households in a site that reported having food and water shortages. The annual probability of drought for each household was computed from the number of droughts that a household experienced in the last 10 years.

2.4.4. Food security and food self-sufficiency

Energy availability was calculated for each household based on production data and food consumption. Households reported food items produced on-farm and those purchased on a weekly basis, indicating seasonal differences. With this information we calculated a food security ratio (FSR) as shown in Eq. (8) and a food self-sufficiency ratio (FSSR) as shown in Eq. (9) to reflect the reliance on farm production and food purchase to meet energy needs, calculated using World Heath Organisation standards.

FSR includes total energy in available food (purchased and on-farm produce) divided by total energy requirements for the household family. FSR higher than one means that the family meets energy requirements and has access to surplus energy. FSSR is total energy in on-farm produce divided by total energy requirements for the household family. FSSR higher than one means that the family geneterates a surplus of energy from on-farm production.

$$FSR_i = \frac{\sum_{m=1}^{p} (QtyC_m \times E_m) + (QtyP_m \times E_m)}{\sum_{j=1}^{n} K_j} \tag{8}$$

$$FSSR_i = \frac{\sum_{m=1}^{p} QtyC_m \times E_m}{\sum_{j=1}^{n} K_j} \tag{9}$$

where FSR_i is the food security ratio for household i; $FSSR_i$ is the food self-sufficiency ratio for household i; $QtyC_m$ is the quantity of food item m produced on-farm that is available for consumption (kg or litre); $QtyP_m$ is the quantity of food item m purchased that is consumed (kg or litre); E_m is the energy content of food item m (MJ kg^{-1} or litre); K_j is the energy requirements in MJ per capita for j member; and n is the number of members in household i.

2.4.5. Coping and adaptation strategies

Households were asked to list main concerns in relation to their farming livelihoods. After the listing, they were asked to rank concerns in terms of importance, and to explain what they do to cope with each problem. Next, they explained their long-term activities to prevent recurrence or negative effects of facing the same problems in the future (adaptation strategies). The data were categorised into concerns related to cropping, related to livestock and related to the household family. For each site we calculated the proportion of households that ranked each concern as the most important, and documented the actions taken to cope and to adapt to these problems.

3. Results

This section presents first historical changes that happened across sites, documents current livelihood strategies, and shows how householders cope and adapt to current challenges to their farming livelihoods.

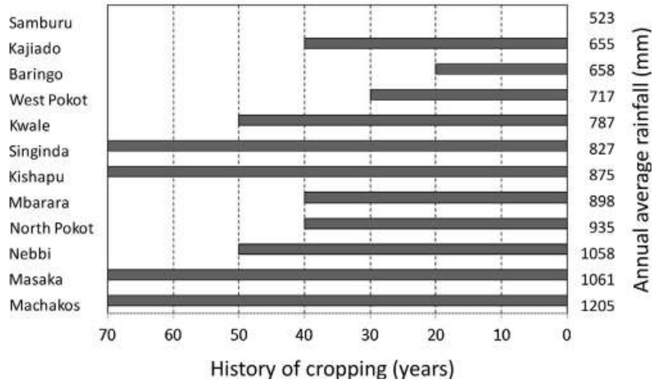

Fig. 2. History of cropping in years at each of the study sites. Information provided by key informants (traditional authority and governmental officer).

3.1. *Historical changes across study sites*

We report here the changes in diets, agricultural activities and the environment described by key-informants. Several of the study sites do not have a long history of cropping. Fig. 2 shows the time line of the introduction of cropping at each of the sites. Especially in the remote sites (i.e., Baringo and West Pokot), cropping is relatively new to the households (20–30 years), who were traditional pastoralists. 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, bananas, sorghum and millet.

3.1.1. *Seredupi, Samburu (Kenya)*

Pastoralism is still the main source of livelihoods in Samburu. Until the 1980s, the diet of the Samburus was mainly meat, milk and blood. Nowadays the majority of households consume maize, milk, and meat. According to the local chief and his assistant, the Samburus of Seredupi have never grown crops, with a culture strongly attached to livestock keeping. Both informants believe that households will continue being nomadic pastoralists. Livestock is thus the major income-generating activity – mainly goats, followed by cattle, sheep and camels. Land is communally owned and managed as group ranches by people elected by the community. Households may use trees for construction or as firewood but not for commercial purposes. Households have free access to water from public boreholes. Livestock are free to graze anywhere without restrictions. The main constraints to people's livelihoods are lack of markets, cattle rustling, and frequent droughts. Livestock rustling from Borana and Somali communities is common.

3.1.2. *Kisanju, Kajiado (Kenya)*

About 40 years ago, Kajiado had large wildlife populations until the government allowed wildlife killings. Since then, irrigation of the land started, followed by flower farming and land privatisation, including fencing. Crops were introduced in the mid-1970s. 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 enforced. A few decades ago, the Maasai of Kajiado had fewer goats and sheep than cattle; however the trend has changed and now small ruminants dominate. Nomadic pastoralism is still common with long distance migration in search of pasture and water during droughts. The main source of livelihoods is livestock keeping, followed by cropping, livestock trading, and informal and formal employment. Crops include maize, beans, and horticulture. Livestock markets are found 5–10 km away. The extension officer believes that farmers in the area will intensify farming but will still practise *ad hoc* nomadic pastoralism.

3.1.3. *Nginyang, Baringo (Kenya)*

Cropping started in Baringo in the mid-1990s. This was caused by frequent livestock deaths and people's willingness to diversify. However, cropping is still perceived as riskier than livestock keeping. Maize became a common food item in the 1960s. Before that, the diet consisted mainly of meat, milk, blood, and honey. The chief and the extension officer believe that households are not going to abandon cropping, and that more households will engage in cropping in the future. Livestock is the main income-generating activity, with goats as the major species. Some 20–30% of the households are engaged in cropping with maize as main crop but millet and green grams are also common. 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, while community members are allocated a piece of land based on clan rules. Each clan has a piece of land close to the river for cropping and in the upper land for grazing.

3.1.4. *Lomut, West Pokot (Kenya)*

The main diet of the Pokot people is maize, whose production started in the 1980s. Before that, millet and sorghum were the main ingredients of the diet. According to the chief, people in this area still practise nomadism, but are progressively turning to mixed farming. Most households have plots close to the river and are reducing livestock numbers and mobility. According to the extension officer, farmers who practise mixed farming are wealthier than pure livestock keepers. Goats are the major livestock species, with fewer cattle because of mortality during past droughts. Land is communally owned with plots for cropping mostly found along the river banks where cropping is practised in groups using schemes of labour sharing. Most common conflicts are due to: (i) livestock theft, (ii) access to water, (iii) crop damage by livestock, and (iv) charcoal production that reduces dry-season feed resources. Livestock keepers of this community often invade the neighbouring Turkana community to steal livestock.

3.1.5. *Taru, Kwale (Kenya)*

According to the local chief, cropping started in Taru about 50 years ago. Before that, the Duruma people used to hunt wildlife. Currently, the human diet consists of maize, millet, and sorghum. The chief believes that local farmers will not become nomads. Livestock species are indigenous cattle, sheep, goats and chickens. Indigenous cattle are preferred as they can move in search of water when drought is prolonged. Although the land is communally owned, the croplands are divided according to clans. Community members are free to graze their animals within the communal land. During drought, livestock from outside the community come for watering at the community pans for a fee. The main risks faced by households include uncertain onset of the rainfall, water shortages, damage of crops by wildlife, and theft of grain and livestock.

3.1.6. *Madewa, Singida (Tanzania)*

Cropping has been practised in Madewa by the Wanyaturu people since colonial times. However, croplands are shrinking as the urban centre expands. Fifty years ago, the human diet was mainly millet and sorghum with some maize. Crop failure is never widespread and there is always some harvest. Herd sizes are small because most households have moved their livestock to other areas in search of pastures. The village executive and the extension officers believe that householders will not go back to nomadic pastoralism but will be practising stall feeding. Most farmers are involved in cropping, cultivating horticultural crops, millet, sorghum and fruits. Livestock species comprise cattle, sheep, goats and pigs. Crossbreeding with exotic cattle is being slowly introduced. Land is communally owned, and subdivided into clans: those that settled first in the area own large pieces of land. As Singida town expands, the owners of farms close to the main road are relocated elsewhere away from the town by the town council.

3.1.7. *Kolandoto, Kishapu (Tanzania)*

About 50 years ago millet and sorghum were the main diet of the Sukuma people. Nowadays, most households consume mainly maize. Yet, most households cultivate millet in case maize fails. Setting aside a portion of land for growing millet and sorghum is advised by the government to curb food insecurity in the region. The village extension and the extension officers believe that households will not practise again nomadic pastoralism. Livestock species consist of cattle, sheep and goats. Crops include cotton, maize, groundnut, millet, sorghum, cowpeas and sweet potatoes. Grazing of livestock is done only along the roadsides or on farm. Conflicts caused by livestock grazing on crops are common. These are solved through the village officer and elders appointed by the community. For firewood, households depend on pruning trees on their own farms as there are no common woodlands in the area.

3.1.8. *Chiruhura, Mbarara (Uganda)*

Crops were introduced into this area in the 1970s. Before that, the Banyankole people were pastoralists with a diet of meat, milk and blood. At the moment, the main diet consists of maize and cooking bananas. The local chief believes that households are not going to practise again nomadism, because most are engaged in cropping. In 1982, a neighbouring area was declared a national park in which hunting was prohibited. In 1980 the average land size per household was 5 square miles, but it was reduced in 1986 to 2 square miles. In the early 1990s people started fencing their land, thereby hindering free movement of livestock. Currently, farmers mostly graze their animals on private land.

3.1.9. *Lokichar, North Pokot (Kenya)*

Cropping started in the early 1970s with millet. Maize was introduced in the mid-1980s and became the main staple food of the Pokot people replacing millet and sorghum. Land is communally owned and each household has the right to cultivate a piece of land. However, plot sizes differ: clans whose grandparents used to grow millet along the river banks have larger plots. The local chief believes that nomadic pastoralism is gradually decreasing because of the shortage of grazing areas, and because cropping is used as a diversification strategy. Livestock species comprise cattle, sheep, goats, and camels, which are new in the area. Main crops are millet, sorghum, maize, and green grams. Other sources of income include the collection of wild *Aloe vera* plants sold at the local market, and casual labour for cropping,

Table 2
Main household characteristics across study sites.

Cluster	Site	HH size (#)	Farm size (ha)	Crop land (ha)	Main crops	Livestock (TLUs)	Main livestock species	Main income sources
4	Samburu	7.8 ± 2.5	0	0	No crops	3.8 ± 3.7	Goats, sheep, cattle, camel	Livestock, employment, trade
9	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
3	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
11	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
1	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
8	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
2	Kishapu	5.9 ± 2.1	1.8 ± 1.5	1.8 ± 1.5	Maize, cowpeas, sorghum	11.1 ± 6.9	Cattle, goats	Cropping, employment
5	Mbarara	6.8 ± 1.7	2.6 ± 4.1	0.7 ± 0.6	Bananas, maize, beans	62.2 ± 51.5	Dairy cattle	Livestock, employment
12	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,
7	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
10	Masaka	7.3 ± 2.6	1.5 ± 1	1.5 ± 1	Maize, cassava, bananas	5.9 ± 4.1	Zebu cattle	Cropping, employment
6	Machakos	5.7 ± 2.8	3.6 ± 4.3	2.7 ± 2.1	Maize, beans	14.1 ± 12	Dairy, Zebu cattle, goats	Cropping, livestock

masonry and bush clearing. Households are free to use woodlands for construction and fuel but not for commercial purposes.

3.1.10. Pakwach, Nebbi (Uganda)

This site was covered by forest about four decades ago. The Acholi people have cut down most of the trees for charcoal production, which started in the 1970s. According to the local councillor, crop-livestock farming has been practised for the last 50 years, and he sees no possibilities to revert to nomadism. Fifty years ago the main household diet was cassava, millet and sorghum with milk and meat. Nowadays, most people consume maize. Farmers keep cattle, sheep and goats and cultivate maize, sorghum, millet and cassava. Cash crops include sesame and cotton. Farmers believe land productivity has halved. Land is communally owned, but in a customary way: people inherit land from parents who have occupied a certain area for a long time. Conflicts for water are common, and are handled by the village elders. Householders get water for consumption from piped water from the closest town. Livestock are taken to drink water from the Nile. Households receive food aid in times of drought.

3.1.11. Lwengo, Masaka (Uganda)

Cropping has been practised in Lwengo for over 50 years. Twenty years ago Bunyore people used to own 2–8 ha of land but currently <2 ha. Human diets have changed in the last three decades from mainly cooking bananas to maize. The local councillor thinks that the diet is changing because bananas are no longer producing enough due to pests, diseases and declines in soil fertility. People also prefer maize because it is easier to store than cooking bananas. The main crops are cooking bananas, maize, beans, groundnuts, cassava and sweet potatoes. Coffee is the main cash crop. Tree crops include mangoes, avocadoes and jack fruits. Livestock species comprise cattle, sheep, goats and poultry. There are no conflicts due to water access. Land is privately owned. Households get firewood from their own farms, and some people have started planting trees. The local councillor believes that because of land subdivision it is impossible for households to practise nomadism.

3.1.12. Mua Hills, Machakos (Kenya)

The Kamba people from Machakos have been practising cropping for as long as the local chief can remember. However, some crops common 20 years ago (e.g. sugarcane, millet and sorghum) are unimportant nowadays. In the 1970s there used to be one cropping season per year because of low temperatures. Bananas were not grown in the region, but they currently do well. Herd sizes have declined due to shrinkage in land holdings. The main crops grown include maize, beans, onions, peas, and sweet potatoes. Farm inputs are purchased in Machakos town, which is the main market for farm produce. Land is privately owned and grazing of livestock takes place on-farm. Public boreholes are managed by a committee appointed jointly by the government and community members. The chief believes that farmers will not go back to nomadic pastoralism because cropping generates good income.

3.2. The present: diversified livelihoods

Results of the household surveys across the 12 sites are shown along a gradient of average annual rainfall, from the lowest in Samburu to the highest in Machakos. Except for Samburu, householders are all engaged in cropping, livestock keeping and off-farm activities. Farm sizes are small, smaller than 2 ha across sites (Table 2), with the exception of Kwale and Nebbi where farmers own around 5 ha. On average, 80% of cropland is cultivated, and close to 100% above 800 mm of annual rainfall. In the drier sites, land is communally owned and livestock graze on common rangelands following grazing rights. Households practise both livestock keeping and cropping along the rainfall gradient, although the proportion of households that keep livestock is smaller in the wetter sites (Table 3).

Livestock numbers vary across sites and there is no trend along the rainfall gradient (Fig. 3A). Goats are the most common livestock with 10–30 head per household across sites. Cattle numbers are relatively large at two sites (Kajiado and Mbarara), where they range from 30 to 60 heads. There is specialised dairy production at Mbarara and Machakos, which is reflected in the high herd value at both sites (Fig. 3B). This is not only the result of the larger livestock populations but also of the exclusive presence of crossbred and exotic cattle. In the Kenyan sites, livestock prices were in general higher than in the Ugandan and Tanzanian sites. There is no trend in the value of the herd along the rainfall gradient.

Maize and legumes are cultivated at all sites where people practise cropping. The importance of dryland cereals such as sorghum and millet varies across sites, and none dominates at any site. Sorghum is cultivated in five of the 12 sites, and millet in six, with an annual rainfall between 600 and 900 mm. Root crops are specially cultivated in wetter sites (above 800 mm) with cassava being common only in Uganda (Fig. 4). Beans are the most commonly grown legume, followed by green grams and groundnuts. Pigeon peas are only cultivated at one site, Machakos, with the highest annual rainfall.

3.2.1. Sources of income and income variability

Across sites, householders identified a variety of income generating sources with mixtures of livestock keeping, cropping, employment and trade (Fig. 5). Livestock (including production and trade) is ranked as the most important source of income at five sites spread along the rainfall gradient. Cropping was ranked as the most important source of income only at two sites, both with annual rainfall higher than 1000 mm. Trade and non-farm employment are noticeably more important than farming in three sites (Kwale, Singida and Kishapu), all close to urban centres.

In four sites (Samburu, Baringo, West Pokot, and Singida) net incomes are critically below the poverty line of USD 1.25 per capita per day (Fig. 6A). Annual rainfall of these sites is 800 mm and below. However, there are two sites with rainfall lower than 800 mm (Kajiado and Kwale) where incomes are higher than the poverty line. In four sites (Kajiado, Mbarara, Masaka and Machakos) within-site variability is large, reflecting large differences in wealth between households. Household income is correlated with income from livestock ($r = 0.73$), access to off-farm income ($r = 0.59$), and access to mobile phones ($r = 0.88$). Generation of cash income increases markedly

Table 3
Description of the farm households at each of the study sites.

Cluster	Site	Practising cropping (% households)	Owning livestock (% households)	Accessing off-farm income (% households)	Accessing electricity (% households)	Accessing mobile phone (% households)	Accessing mobile banking (% households)
4	Samburu	0	100	90	0	0	0
9	Kajiado	100	100	100	0	100	100
3	Baringo	30	100	100	0	30	30
11	West Pokot	60	100	40	10	20	20
1	Kwale	100	90	100	10	60	60
8	Singida	100	30	100	0	30	10
2	Kishapu	100	40	50	0	60	30
5	Mbarara	90	100	100	0	90	0
12	North Pokot	100	100	60	0	60	60
7	Nebbi	100	80	50	0	50	0
10	Masaka	100	50	30	0	50	0
6	Machakos	80	80	70	60	100	100

along the rainfall gradient, with only Kajiado as an exception of a low rainfall site with relatively high cash income (Fig. 6B).

The relative contribution of livestock to total income decreases from an average of 40% to about 10% with increasing annual rainfall, whereas the contribution of cropping increases from virtually nothing at 500 mm to more than 50% at around 1000 mm of annual rainfall (Fig. 7A and B). Below 800 mm, the contribution of off-farm activities to total income is 50% or more. Livestock, however, contribute substantially to the generation of cash (on average USD 1600 per household per year) in places with very different agro-ecology and annual rainfall: Kajiado, Mbarara and Machakos. Livestock production contributes to 30–60% of the cash income in the sites with rainfall lower than 700 mm, compared to 4–20% in the higher rainfall areas. However, the absolute contribution of livestock to cash income does not decrease with rainfall, averaging USD 550 per household per year across sites.

Household income and incomes from cropping increase with the number of crops cultivated (Fig. 8A and B). There is a positive relationship as well between the number of activities a household is engaged in and annual mean rainfall, and a strong positive relationship between net income per year and the number of income generating activities (Fig. 8C and D).

3.2.2. Food security and food self-sufficiency

At all sites, households reported having food shortages (Fig. 9A). However, the length of time with food shortages varies, decreasing with increasing rainfall from about six to two months per year. In the six wetter sites with annual rainfall above 800 mm, periods of food shortage last fewer than four months per year (Fig. 9B). The incidence of food shortages is not correlated with water shortages ($r = 0.15$), although it is weakly correlated ($r = 0.33$, $p < 0.05$) with annual recurrence of drought (Fig. 10A and B). However, the length of the period with food shortages is negatively correlated ($r = -0.61$, $p < 0.05$) with annual mean rainfall (Fig. 10C) and with income from cropping ($r = -0.70$, $p < 0.05$) (Fig. 10D).

Food insecurity (a ratio smaller than 1) is common in the five sites with annual rainfall lower than 800 mm, and critically low in the site with rainfall of 500 mm (Fig. 11A). The contribution of farm produce to the food energy availability per household member increases at the sites with higher rainfall, exceeding a threshold of 9–10 MJ per capita per day needed to cover human daily energy requirements when annual rainfall exceeds 800 mm. However, although households from the wetter sites are more food self-sufficient and food secure than households from the drier sites, within site variability increased with annual rainfall, showing larger differences in food security among householders (Fig. 11B). Again, households are 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 are also those in which a large proportion of households receive food aid several times each year.

3.3. Household-level adaptation to current and future problems

Households listed their main concerns about what could happen in the future. To compare sites, we sorted the answers into three categories: (i) related to cropping,

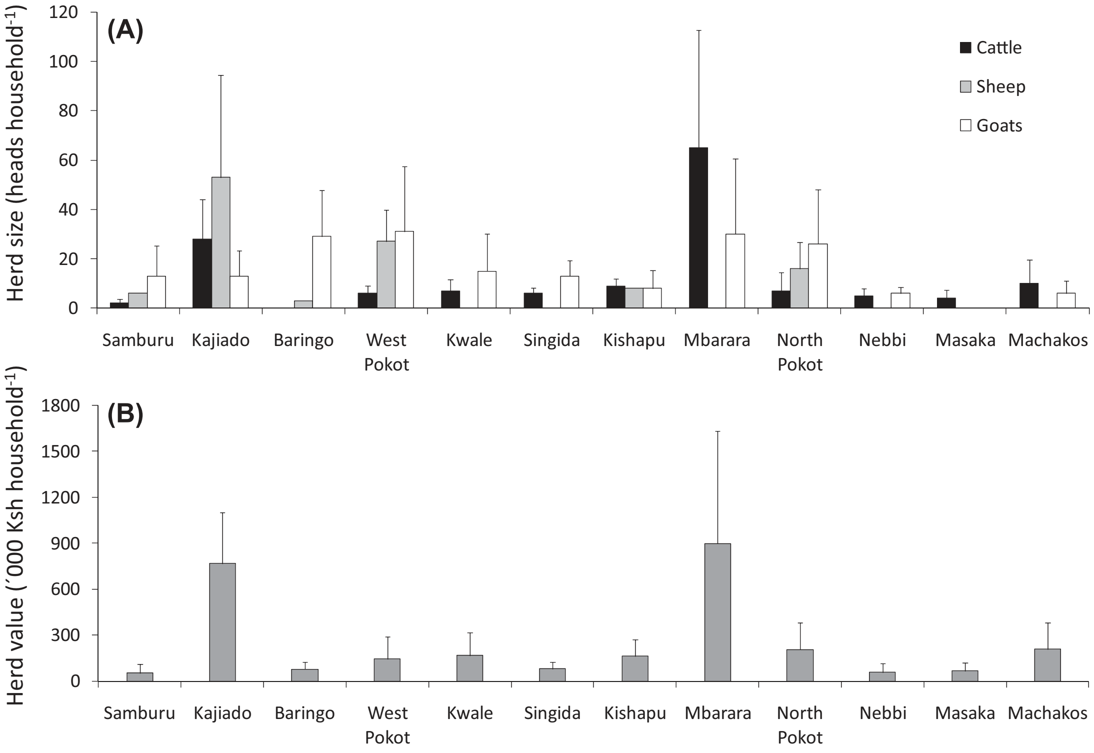

Fig. 3. (A) Herd sizes for the most important livestock species across study sites and (B) monetary value of the livestock at each of the study sites.

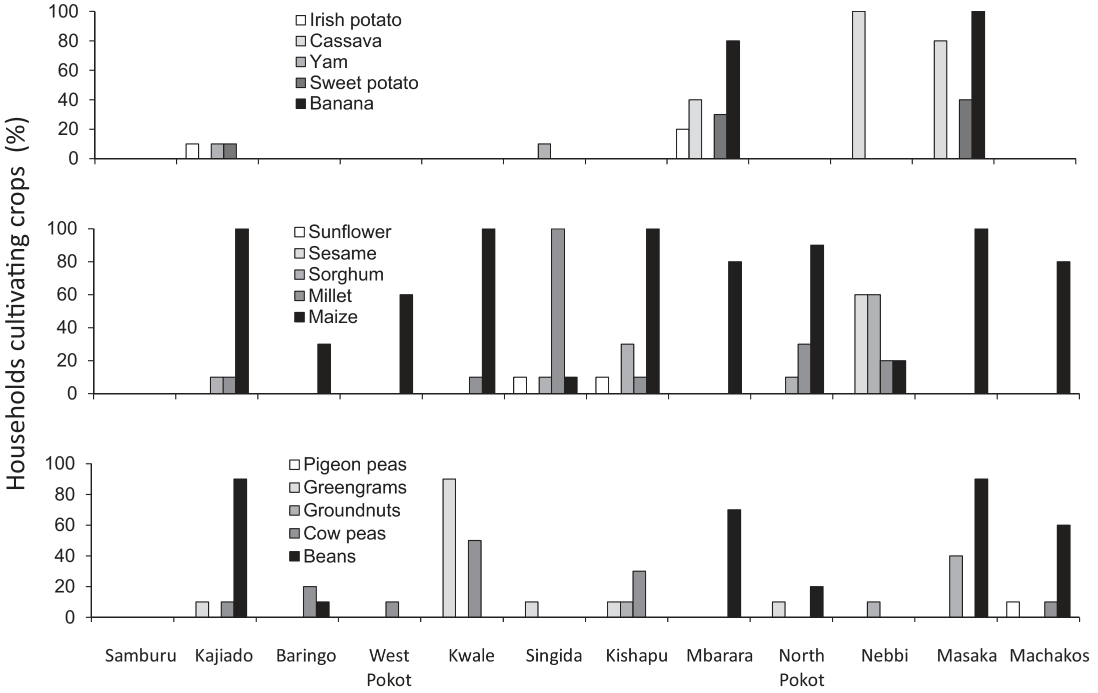

Fig. 4. Diversity of crops cultivated at each of the study sites.

(ii) related to livestock keeping, and (iii) related to household members (Fig. 12). Households at all 12 sites are concerned about water-related issues, either drinking water, water for livestock, or crop failure due to drought in the high rainfall sites. 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 only 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) (Appendix Table 2).

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 in the low rainfall sites (Samburu, Baringo, West Pokot, North Pokot), while drilling boreholes (e.g. Kajiado, Kwale) emerges as an adaptation strategy. Households cope with the lack of food by buying food or relying on food aid, and by reducing food consumption. Adaptation strategies against food deficits vary along the rainfall gradient: in the low rainfall sites, households mentioned (i) income diversification (e.g. in Samburu people send their sons to towns to look for jobs), (ii) expansion of cropping (e.g. in Baringo, with a short history of cropping, people were interested in intensifying crop production and trying irrigation), (iii) diversification of crops, and (iv) increasing herd sizes (e.g. West Pokot). In the drier sites, wildlife conservancies are seen as livelihood diversification. 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 (e.g. Kajiado and Singida). When householders were asked specifically how to cope with the effects of drought, they came up with similar strategies across sites: use stored grains (at all sites with rainfall above 800 mm), cash saving, sell livestock and labour (Appendix Table 3). However, to adapt to drought, strategies vary across sites, with people wanting to start cropping at the low rainfall sites to diversify incomes, and people wanting to intensify crop-livestock farming with a diversity of crops and intercrops at the high rainfall sites. Off-farm income is extremely important in the drier sites, including seasonal migration to towns (e.g. Kwale, Kishapu, Singida, and Nebbi). In West Pokot, Baringo, and North Pokot there is a strong demand for extension to deal with livestock diseases. In the wetter sites (Mbarara, Nebbi, Machakos) where cropping is already an important component of household income, people are interested in planting drought-tolerant crops such as cassava and millet and intensifying cropping by practising intercropping.

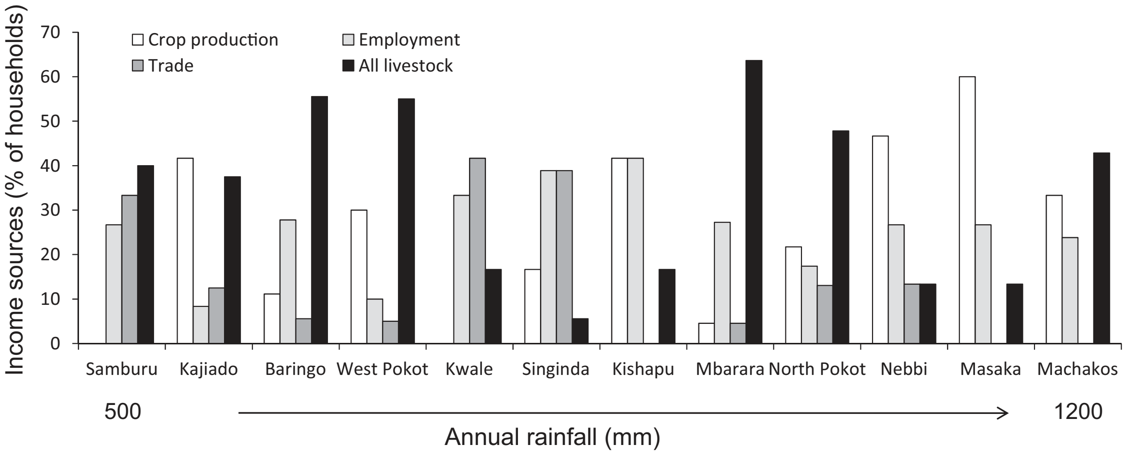

Fig. 5. Percentage of households valuing most important sources of income across districts (including those ranked 1st, 2nd and 3rd), ordered according to average annual rainfall. Activities include crop production, non-farm employment (informal and formal), trade (other than agricultural produce), livestock trade (buying and selling livestock) and livestock production.

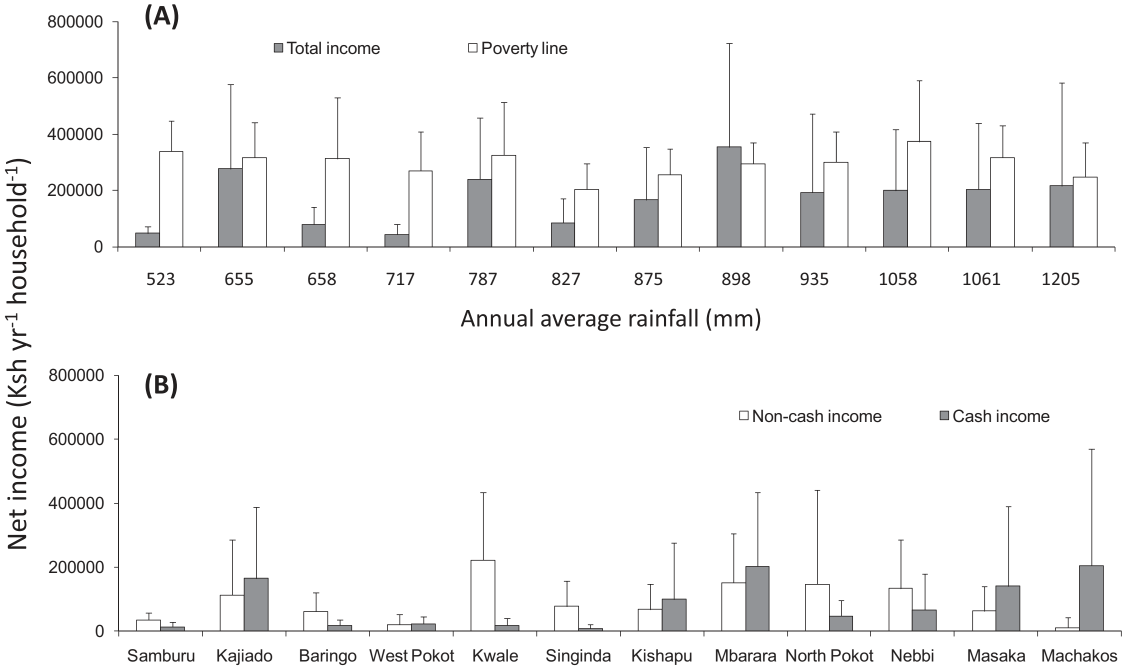

Fig. 6. (A) Total net household income across sites, and poverty line calculated considering household size and standard deviation at each site, an income of USD 1.25 per capita per day and a conversion rate of 1 USD = 95.3 Kenyan shillings. (B) Cash and non-cash incomes across sites.

3.3.1. *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. Most people want to diversify cropping by including drought-resistant crops and cultivars, and some suggested intercropping. We asked households which were their preferred crops because of their resistance to drought.

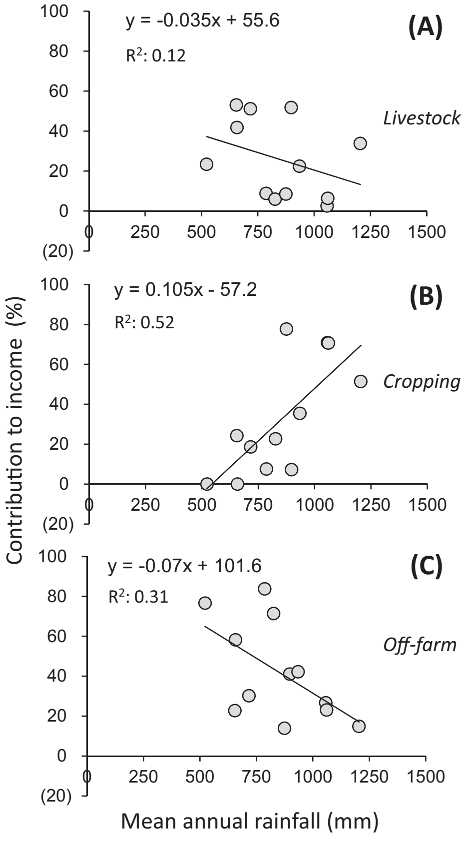

Fig. 7. Contribution to household income of (A) livestock household activities; (B) cropping activities and (C) off-farm activities.

People named 17 crops in total (Appendix Fig. A.1), but there were five which were often mentioned across sites: 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 diversity of crops that householders plant on their farms. Millet is only grown at six sites, and by few households (15% of the households), sorghum is grown at five sites (10% of the households), and cassava is grown at three sites (12% of the households). Maize is cultivated 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 (Appendix Fig. A.2). 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.

3.3.2. *Future changes in livestock production*

We asked livestock keepers whether they had plans to modify their livestock populations in terms of numbers and species. Most livestock keepers want to increase their livestock numbers in the future. Except for Masaka where households were not interested in goats, and Kajiado where few households plan to increase their numbers (30% of the households), most households (60–100%) had plans to increase flock and herd sizes.

Sheep are 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 only in Kajiado and Kwale. Between 10 and 33% of livestock owners in six sites indicated no plans to change their herd sizes in the future. These were 10% in Kajiado and West Pokot, 13% in Machakos, 33% in Singida, and 20% in Mbarara and Masaka. 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 for commercial purposes (e.g., sale of milk, animals sales, and financing purposes) and not to increase consumption of animal products (Appendix Table 4). Having more livestock as a form of savings, and to finance future expenditures or emergencies, was mentioned at all 12 sites. At 10 of the sites householders are interested in increasing livestock numbers to increase the volume of milk for sale from both cattle and goats. The main strategies to increase cattle and goat numbers are increasing recruitment rate (nine of the sites), improving health (eight sites), increasing genetic merit (six sites), increasing reproduction rates (three sites) and

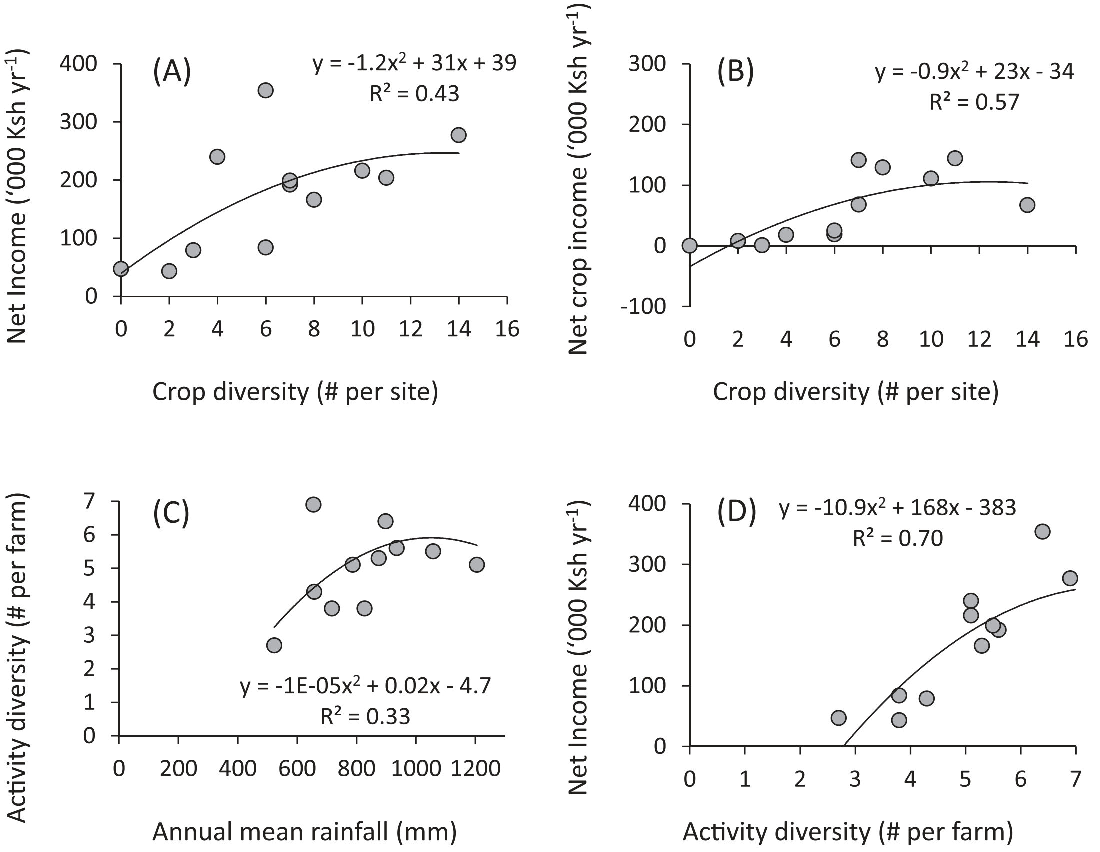

Fig. 8. (A) Relationship between crop diversity (i.e. number of crops cultivated) and net household income. (B) Relationship between crop diversity and net household income from cropping. (C) Relationship between activity diversity (number of activities per farm) and annual mean rainfall. (D) Relationship between net household income per year and activity diversity.

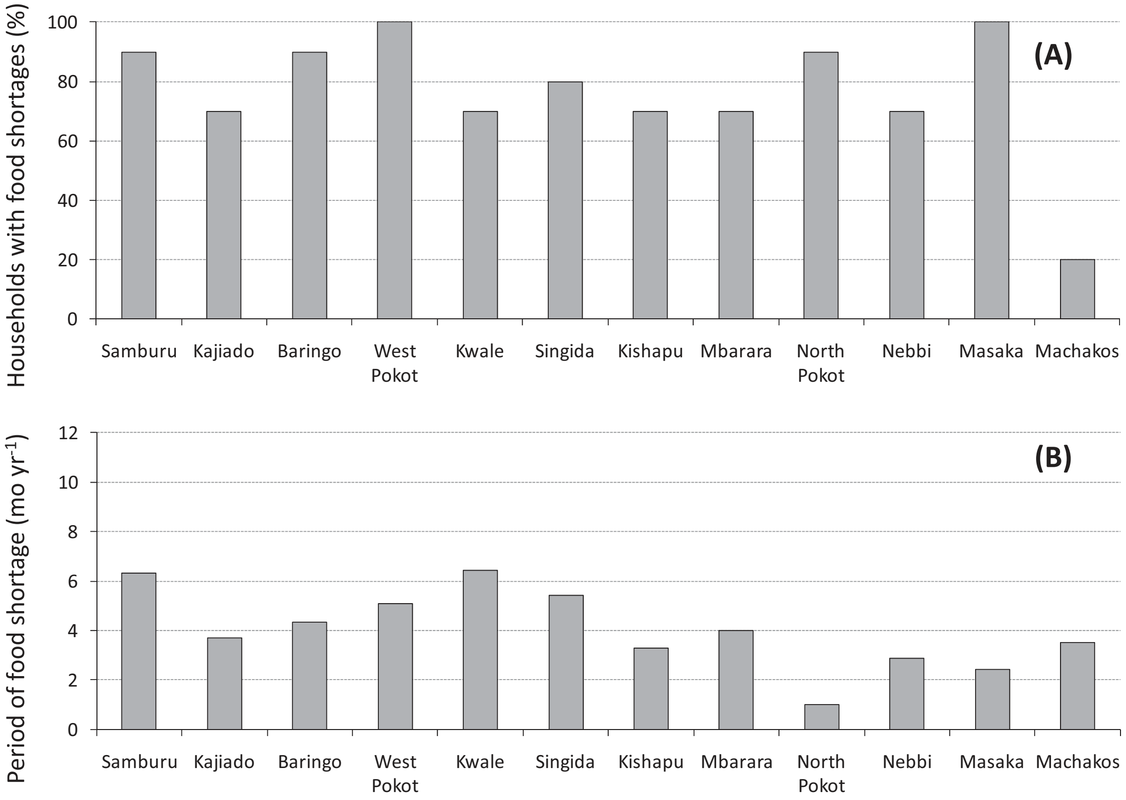

Fig. 9. Status of food shortages across study sites: (A) percentage of households experiencing food shortages and (B) average length expressed in months per year of the typical food shortage across sites.

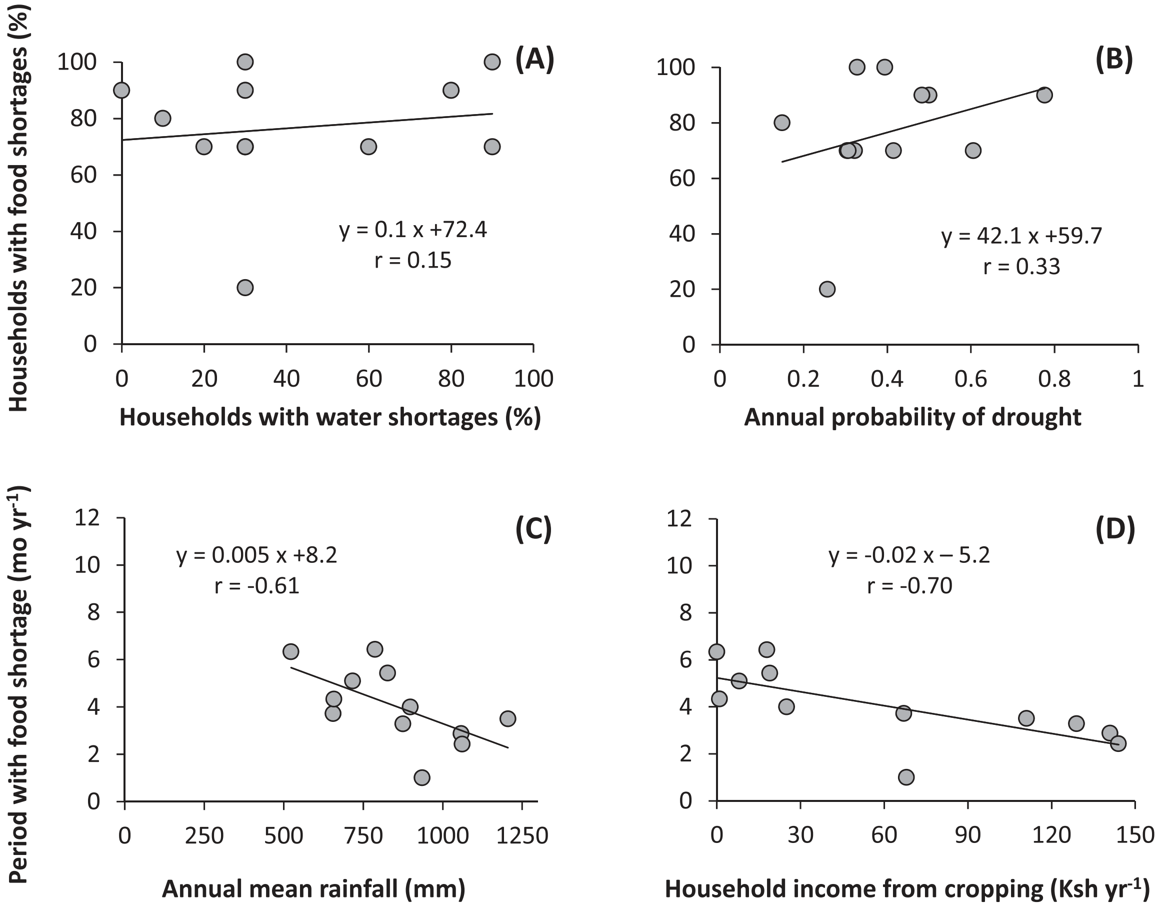

Fig. 10. (A) Relationship between percentage of households having food and water shortages, (B) relationship between households having food shortages and annual probability of experiencing a drought, (C) relationship between the length of the period with food shortage (in months per year) and net household income, and (D) relationship between the length of the food shortage period and annual average rainfall at the study site.

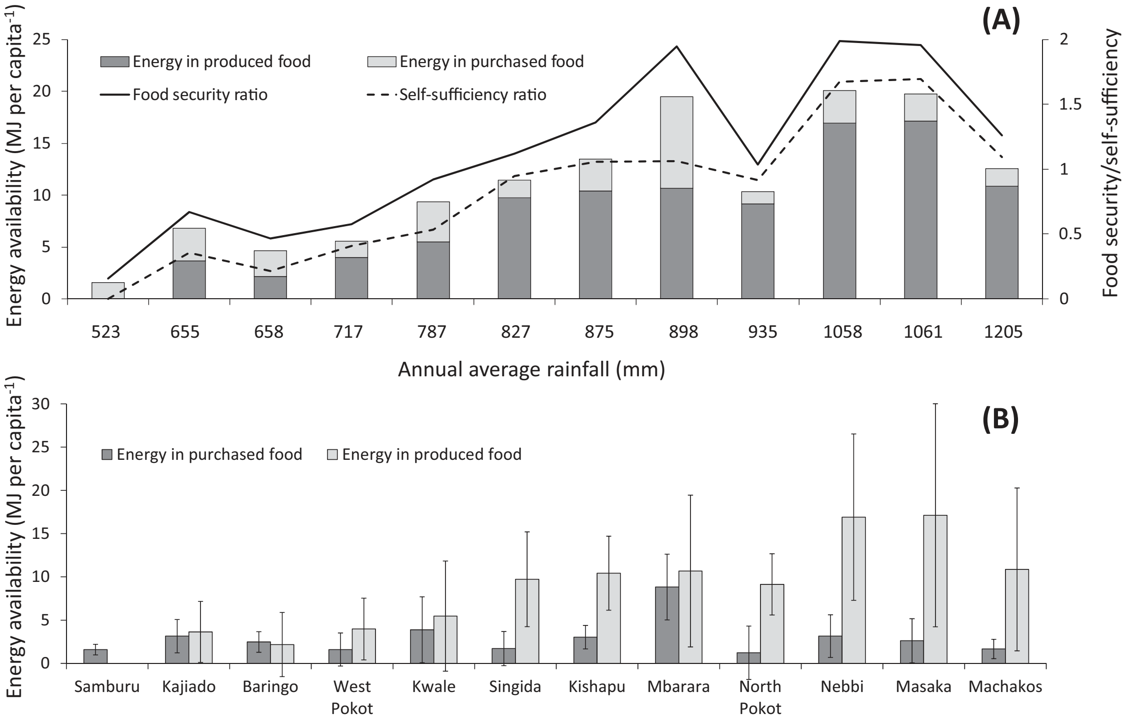

Fig. 11. (A) Energy availability per household member (produced on farm and purchased food items) and food security and food self-sufficiency ratios across the 12 study sites. (B) Variability in energy availability per household member from food produced on farm and from purchased food items.

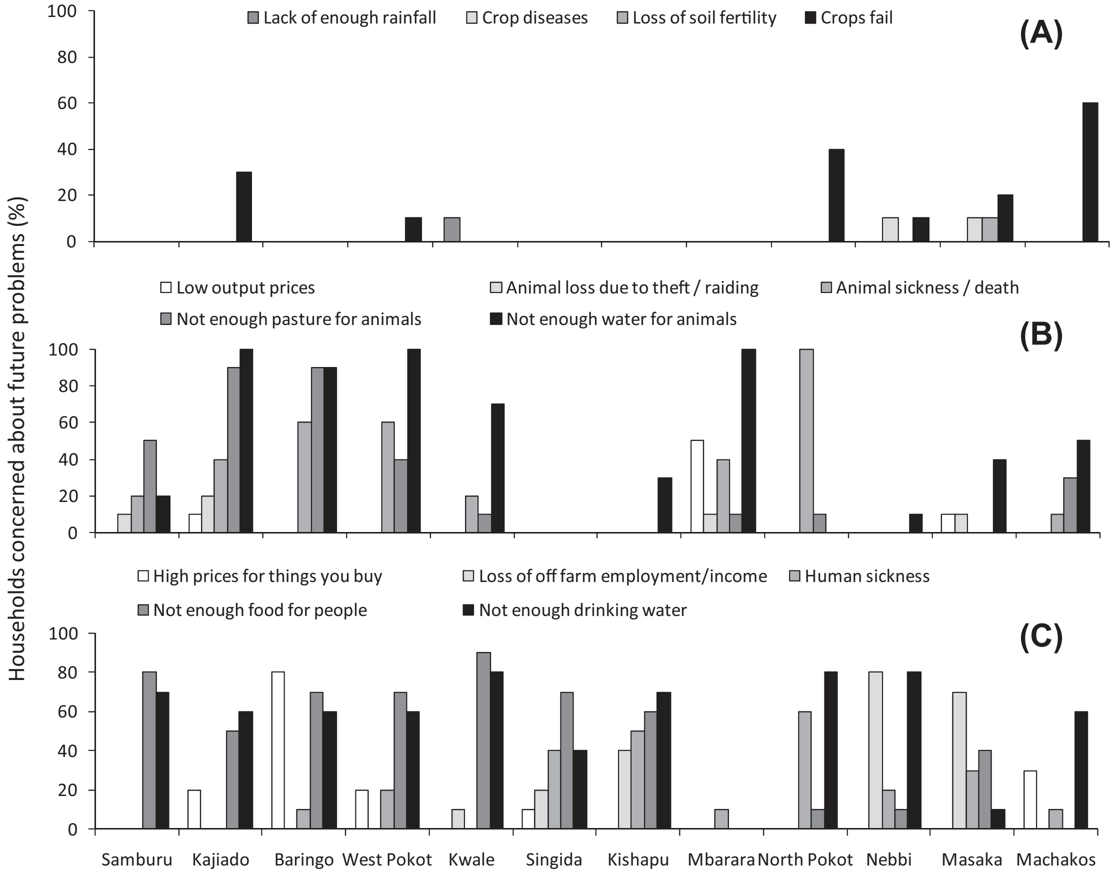

Fig. 12. Household concerns about future problems, which have been grouped into 3 categories (A) concerns related to cropping, (B) concerns related to livestock, and (C) concerns related to the household family (human concerns).

reducing mortality rates (two sites). The main strategies suggested to increase sheep numbers are increasing recruitment rates and improving health.

We asked householders 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 want to increase the productivity of all their livestock species. Clear exceptions were Kishapu in Tanzania and Nebbi in Uganda, where few households are interested in increasing livestock productivity. The ranking of the strategies varied across sites (Appendix Table 5). 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 Singida in Tanzania.

4. Discussion

4.1. Farming systems in continuous transition?

Historical changes showed that expansion of cropping occurred in the whole region in the last three decades, associated with low yields, poor management and dominance of maize. Diets have shifted from being based on animal protein and relatively small amounts of local cereals (sorghum and millet) to mostly maize with small amounts of animal protein.

There has been a shift from large ruminants to small ruminants in the more pastoralist areas most likely because of the effect of drought on cattle. Smaller animals perform better because of the advantages of smaller body size under scarce feed conditions (Illius and Gordon, 1992). In places with good market opportunities householders are shifting towards intensive livestock production with dairy and stall feeding of exotic and crossbred cattle (Staal et al., 2002; Galvin, 2009).

Consistently at all sites, key informants believed that householders will not go back to nomadic pastoralism but will intensify production towards mixed systems with fewer animals and larger croplands. In the driest areas this is caused by constraints to mobility because of fencing and fragmentation, strong competition for grazing land, and the widespread willingness to diversify income sources. This process of sedentarization and diversification is well documented in many pastoralist systems (e.g. Little et al., 2001; Hobbs et al., 2008; Galvin, 2009).

4.2. Crops and livestock to diversify

Food shortages were an issue at many sites, for which people thought of diversifying income with expanding cropping and increasing herd sizes. Cropping is practised at most sites, and there is livestock everywhere along the rainfall gradient. Maize and legumes are widely spread. Cassava, sorghum and millet were not a dominant feature of cropping in the dry areas.

Livestock numbers were somewhat higher in the drier sites, but herd values were not higher because the wetter sites specialise in dairy and keep more expensive species and breeds. Livestock was considered important for income in all sites and was associated with wealth. The asset role of livestock is well documented for arid and semiarid environments (e.g. Fafchamps et al., 1998; Kazianga and Udry, 2006). This study shows that livestock are used as a diversification strategy as well as being a financial asset. Most householders reported their desire to increase herd sizes despite the high risk of mortality due to droughts or disease burden.

Pastoralists wanted more crops, and croppers wanted more livestock. Household income was correlated with income from livestock across sites and with crop diversity. Wealthier households had a variety of crops on their farms, and were engaged in a range of income generating activity. Food insecurity is a common feature of the drier environments, and income from cropping helps to smooth periods of food shortages. That seems to be the reason for engaging in 'gambling cropping' with a high risk of crop failure in semi-arid environments (Tache and Oba, 2010; Milgroom and Grill, 2013).

4.3. An environmentally determined switch in livelihood mixtures

It is known that food insecurity is more severe in dry environments. In this study we found an environmentally determined switch, which shows a transition in livelihoods options between 700 and 800 mm of annual rainfall. Below 700 mm, households seem to be heavily dependent on food aid as a result of the frequency of drought affecting livestock-based livelihoods. Livestock's contribution to total income decreased considerably with increasing annual rainfall, whereas the contribution of cropping increased from virtually nothing at 500 mm to more than half of the income at 1000 mm of annual rainfall. Pastoralists have been progressively engaging in cropping following world trends of expansion of agriculture into arid and semiarid environments (Baldi et al., 2012). However, cropping in arid and semiarid areas of East Africa can only succeed where there is soil water such as in riverbanks. This creates of course conflicts for access within (agro) pastoral communities as the land suitable for rainfed cropping is limited.

The Kajiado site, with an average rainfall of around 600 mm, was an exception in income and poverty levels. In Kajiado, relatively close to Nairobi, land privatisation has promoted diversification of livelihoods (Galvin, 2009), and that is why Kajiado appears to be an outlier in the rainfall gradient. Off-farm income opportunities shift the focus away from farming, effect that can be observed in all sites close to urban centres such as Kwale, Kinango and Singida.

4.4. Adapting through more cropping and more livestock?

Householders were all concerned about water shortages and drought, but not because of crop failure. Water for livestock could be found by moving livestock. Livestock keepers were not willing to reduce livestock numbers to manage risk of drought. This strategy appears to be most sensible when livestock keepers live with climate uncertainty and lack support to restock after massive animal losses (Illius et al., 1998). The purpose of increasing livestock numbers was to increase livestock sales and not consumption of animal products. Increasing livestock productivity was also on the list of adaptation options. In the wetter areas where livestock are fewer and of more value, householders think of improved breeding to increase productivity. In the drier areas, householders plan to increase productivity through better health and feeds. Unfortunately, policy support for disease control has not been very effective (Perry and Sones, 2009).

Adaption through cropping in the wetter sites was related to intensifying crop production including drought tolerant crops and varieties. Although people knew of drought tolerant crops, few used them. 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 to deal with climate variability. It seems though that they diversify as much as possible with farming and non-farming activities, in line with other evidence (Little et al., 2001; Dercon, 2002).

4.5. Technical and institutional support needed

The dependence on maize throughout the study area calls for attention. 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. Some policy measures to increase the consumption of cassava, sorghum, millet and legumes such as pigeon pea could be highly beneficial for future food security. 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 in drier areas may well in the future be beyond any conceivable tipping points for self-sufficiency and food security. The number 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, nor will they stop keeping livestock. For households in the wetter areas, what is needed is a concentration on risk management through crop diversification or intensification of livestock production, where possible, again in concert with market development for reaching 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.

This work has highlighted the need for some agricultural technology development. The diversity of activities that households undertake, and particularly the diversity of crops grown, is 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 changing environments, and this warrants development of a clear research agenda. In addition to crop breeding, seed distribution systems need to be addressed, together with knowledge transfer concerning what can be done with the non-traditional food crops in relation to cooking, processing, and value addition.

Many of the households in the study sites face a wide array of problems, including poverty, food insecurity, and grossly inadequate diets if household members are to reach their full human potential. 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 feasible. A prerequisite for such efforts is physical security, without which any coordinated facilitation of systems' change is likely to be impossible.

5. Conclusions

Agro-pastoralists systems across East Africa are in transition, and climate-induced livelihood transitions are increasingly likely. We found no direct evidence for the hypothesised extensification of agricultural production in the study sites. Human diets have changed considerably in the last 30–40 years, as cropping has been taken up by increasing numbers of households, even in 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 critical at the sites with <700 mm of rainfall. 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 a viable strategy, reflecting the flexibility that many households show in adapting to their environment. 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. There is a need for extension support to successfully innovate in cropping, particularly in the locations where cropping is a relatively new activity. Policy measures aimed at increasing the consumption of cassava, sorghum, millet and legumes such as pigeon pea could be highly beneficial for future food security in the region.

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Appendix A.

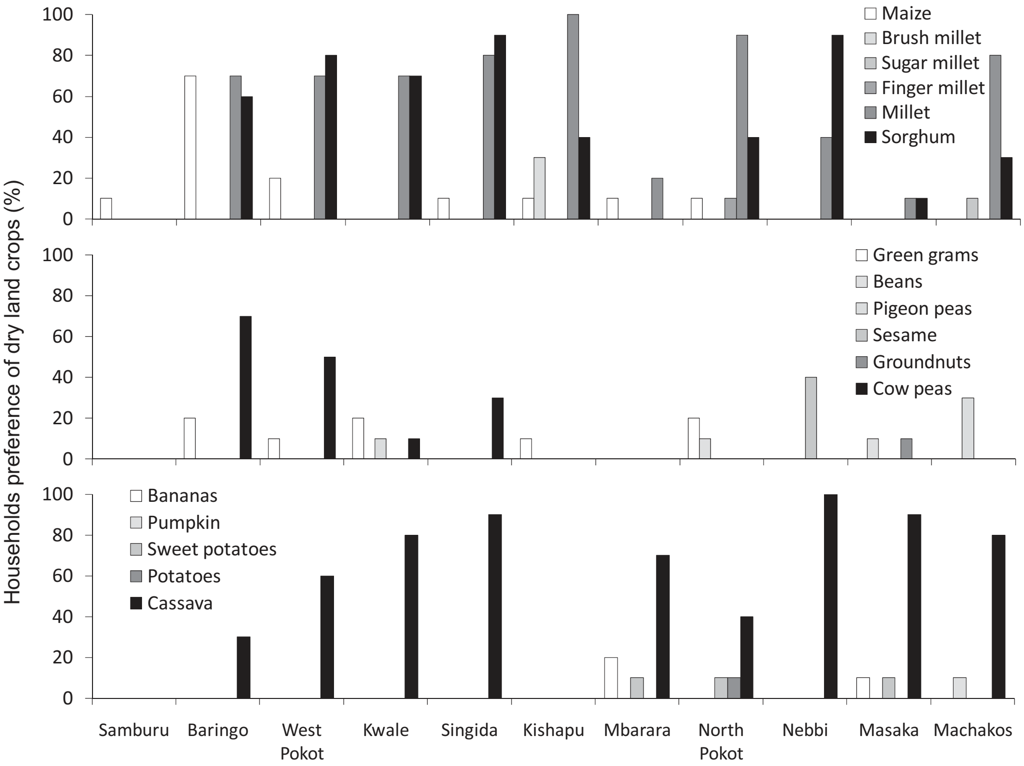

Fig. A.1. Households preference for drought tolerant crops across sites. Crops are separated in grains, legumes, and others.

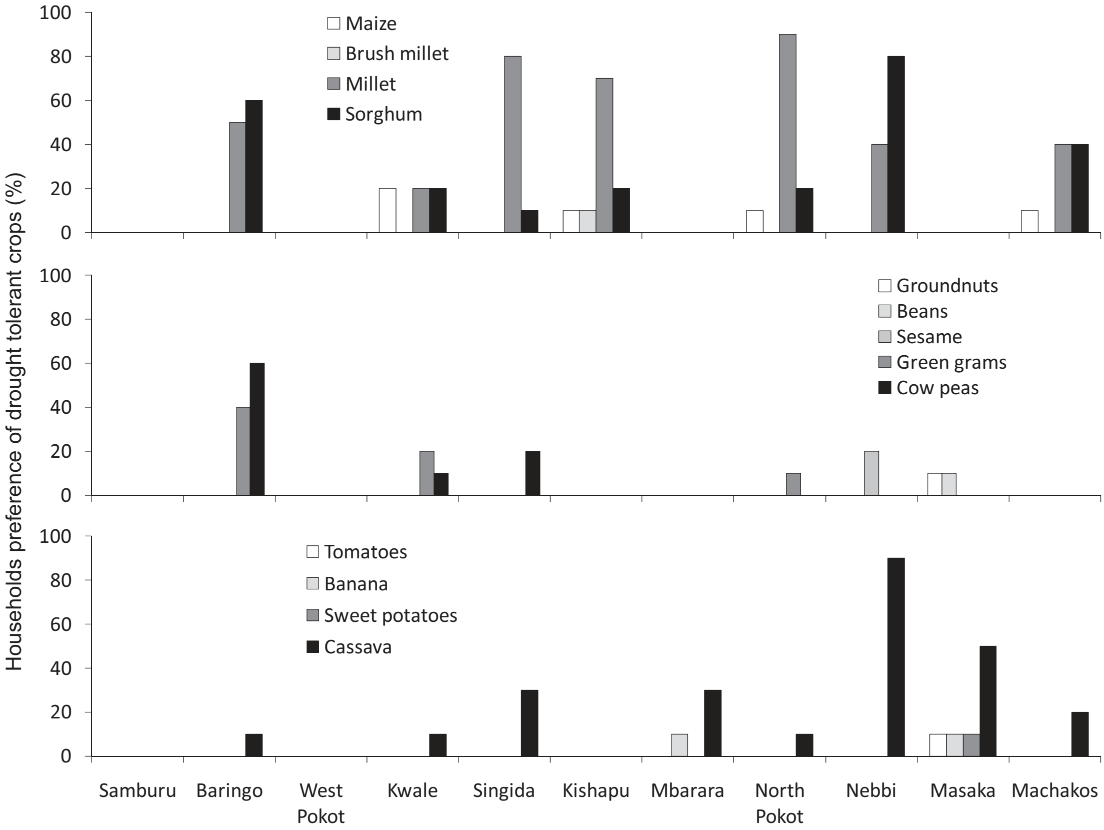

Fig. A.2. Households preference for drought tolerant crops across sites if it were to get drier in the future. Crops are separated in grains, legumes, and others.

Appendix B. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.agee.2013.08.019.

References

Baldi, G., Verón, S.R., Jobbágy, E.G., 2012. Linking landscape patterns, human activities, and ecosystem functioning in the dry subtropics. Global Change Biology, http://dx.doi.org/10.1111/gcb.12060.

Boserup, E., 1965. The Condition of Agricultural Growth: The Economics of Agrarian Change under Population Pressure. Aldine Publishing Company, London.

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. Socioeconomic Data and Applications Center (SEDAC), Columbia University, Palisades, NY, Available at http://sedac.ciesin.columbia.edu/gpw

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.

Dercon, S., 2002. Income risk, coping strategies and safety nets. World Bank Research Observer 17, 141–166.

Fafchamps, M., Udry, C., Czukas, K., 1998. Drought and saving in West Africa: are livestock a buffer stock? Journal of Development Economics 55, 273–305.

FAO, 1998. Digital Soil Map of the World and Derived Soil Properties, Original Scale 1:5,000,000 FAO/UNESCO. FAO, Rome, Italy.

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

Galvin, K.A., 2009. Transitions: pastoralists living with change. Annual Review of Anthropology 38, 185–198.

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.

Hobbs, N.T., Galvin, K.A., Stokes, C.J., Lackett, J.M., Ash, A.J., Boone, R.B., Reid, R.S., Thornton, P.K., 2008. Fragmentation of rangelands: implications for humans, animals, and landscapes. Global Environmental Change 18, 776–785.

Illius, A.W., Gordon, I.J., 1992. Modelling the nutritional ecology of ungulate herbivores: evolution of body size and competitive interactions. Oecologia 89, 428–434.

Illius, A.W., Derry, J.F., Gordon, I.J., 1998. Evaluation of strategies for tracking climatic variation in semi-arid grazing systems. Agricultural Systems 57, 381–398.

IPCC (Intergovernmental Panel on Climate Change), 2007. Climate Change 2007: Impacts, Adaptation and Vulnerability. Summary for Policy Makers. 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) http://srtm.csi.cgiar.org

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., 2013. Generating downscaled weather data from a suite of climate models for agricultural modelling applications. Agricultural Systems 114, 1–5.

Kazianga, H., Udry, C., 2006. Consumption smoothing? Livestock, insurance and drought in rural Burkina Faso. Journal of Development Economics 79, 413–446.

Little, P.D., Smith, K., Cellarius, B.A., Coppock, D.L., Barrett, C., 2001. Avoiding disaster: diversification and risk management among East African herders. Development and Change 32, 401–434.

Matlon, P., Kristjanson, P., 1988. Farmer's strategies to manage crop risk in the West African semi-arid tropics. In: Unger, P.W., Jordan, W.R., Sneed, T.V., Jensen, R.W. (Eds.), Challenges in Dryland Agriculture: A Global Perspective. Proceedings of the International Conference on Dryland Farming. Bushland, Texas USA, August 15–19, pp. 604–606.

Milgroom, J., Giller, K.E., 2013. Courting the rain: rethinking seasonality and adaptation to recurrent drought in semi-arid southern Africa. Agricultural Systems 118, 91–104.

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, http://dx.doi.org/10.1029/2007GB002947.

Perry, B.D., Sones, K., 2009. Poverty reduction through animal health. Science 315, 333–334.

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, http://dx.doi.org/10.1029/2007GB002952.

Ramirez-Villegas, J., Challinor, A.J., Thornton, P.K., Jarvis, A., 2013. Assessing the CMIP5 model ensemble in the context of agricultural impacts research. Environmental Research Letters 8, 024018.

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.

Staal, S.J., Baltenweck, I., Waithaka, M.M., DeWolff, T., Njoroge, L., 2002. Location and uptake: integrated household and GIS analysis of technology adoption and land use, with application to smallholder dairy farms in Kenya. Agricultural Economics 27, 295–315.

Tache, B., Oba, G., 2010. Is poverty driving Borana herders in Southern Ethiopia to crop cultivation? Human Ecology 38, 639–649.

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.