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Dynamic decision making in coupled social-ecological systems

Smallholder farmers' goals, resources and constraints in improving food security and adapting to climate change in Zambia

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Abstract

Climate change will lead to significant yield reductions in maize dominated farming systems in sub Saharan Africa. Combined with a growing and more demanding population, food systems in this region thus face the challenge of undergoing a considerable transformation in order to meet the challenges of achieving food security and adapting to climate change. Increasing food security and adapting to climate change is a dynamic decision making task that involves a wide range of stakeholders such as farmers, the private sector, consumers, civil society, and policy-makers. In this paper, we focus on the particular stakeholder group of small-scale farmers in Zambia and collect interview data on the multiple decisions they make in the course of a year. Our data provides a rich description of farmers' dynamic decision making and their adaptive capacity to deal with existing and future challenges related to food security. As people also need an enabling institutional and policy environment to successfully adapt in the longer term and diversify livelihoods for positive wealth accumulation, we reflect on the use of a multi-method approach that combines our qualitative interviews with quantitative system dynamics modeling.

Introduction

Climate change will lead to significant yield reductions in maize dominated farming systems in sub Saharan Africa (Lobell et al., 2008). Combined with a growing and more demanding population, food systems in this region thus face the challenge of undergoing a considerable transformation in order to meet the challenges of achieving food security and adapting to climate change. Adaptive practices are manifold and they can occur at multiple levels and at different scales (e.g., Below et al., 2010; Easterling et al., 2007; Vermeulen et al., 2010).

Food systems are social-ecological systems that consist of biophysical and social factors which are linked through feedback mechanisms (Berkes et al., 2003; Ericksen, 2008b). These mechanisms determine the development of food system outcomes such as food security, environmental welfare and social welfare over time. The food security situation of a given unit of analysis such as a country can be explained in terms of three components (Ericksen, Stewart, Dixon, et al., 2010). *Food availability* is the amount, type and quality of food a unit has at its disposal to consume, either through local production, distribution, or exchange for money, labor or other items of value. *Access to food* can be analyzed in terms of the affordability of food that is available, how well allocation mechanisms such as markets and government policies work, and whether consumers can meet their food preferences. The *utilization of food* refers to the ability to consume and benefit from food. Stability is an important dimension of all these components and describes their behavior over time.

Inter- and transdisciplinary research is generally seen as key to overcoming fundamental problems in the analysis of social-ecological systems (Carpenter et al., 2009; Hammond & Dubé, 2012; Ostrom, 2009). Such problems include the multiplicity of disciplines involved when assessing a broad range of possible outcomes; the multiplicity of stakeholders with potentially conflicting interests and differing intervention pathways; and the difficulty of modeling complex dynamics across the multiple scales and levels of a food system. Such research therefore requires hybrid frameworks where multiple qualitative and quantitative methodologies are applied, making use of a combination of existing quantitative sources, case studies, and stakeholder input (Engle et al., 2013; Ericksen et al., 2009; Janssen & Anderies, 2013). This allows system complexity to be captured in an efficient way, enabling the identification of synergies and trade-offs, and the design of corresponding policy and management actions, even in contexts where detailed data collection is not feasible.

In a different stream of work, we develop a system dynamics model that aims at supporting decision makers at different levels to effectively manage adaptation to climate change for improving and maintaining food security in Zambia. The simulation model studies the behavior over time especially of the availability and access dimension of food security as well as some dimensions of social and environmental welfare, and it analyzes their reactions to different management and policy actions. This present paper contributes to an understanding of how stakeholders in the maize dominated farming systems in Zambia make decisions to improve food security outcomes and adapt to climate change. For this purpose, we use qualitative research methods such as interviews. The results from the interviews contribute to the refinement of the simulation model and its calibration. They are also used to derive implications for the communication and use of the simulation model. This refers to guidelines on how seemingly effective management and policy actions might have to be reformulated, adjusted and combined so that they are consistent with stakeholders' conceptions of the food system and thus facilitate adoption and diffusion of such actions.

In this paper, we focus on the particular stakeholder group of small-scale farmers. This stakeholder group interacts with food systems on a daily basis and over long time periods. It thus possess crucial knowledge of food system dynamics, together with associated management practices (Berkes et al., 2000; Janssen & Anderies, 2013). Small-scale farmers account for the vast majority of farms, cropped area, maize production, and fertilizer use in Zambia. For example, as of the 2011/12 agricultural year, small-scale farmers accounted for 99% of the farms, 94% of total cropped area, 98% of maize area planted, 95% of maize production, 75% of total fertilizer use, and 93% of the fertilizer used on maize (figures are based on the 2011/12 Crop Forecast Survey). At the same time, little is understood of how small-scale farmers make decisions and manage their complex resource systems (Janssen & Anderies, 2013). By investigating small-scale farmers' dynamic decision making, we address the following research questions:

- What are the decisions that small-scale farmers make every year, including their coping and adaptive practices to increase food security and adapt to climate change? The literature distinguishes between coping and adaptation (e.g., Ericksen, Stewart, Eriksen, et al., 2010). Coping with challenges allows survival and protection of short-term food security or income. However, it often wears down assets that will be needed in the future. Adaptation, on the other hand, can be considered as modifications in behavior or strategies that enable farmers to continue to develop in the face of change over the long run.
- What are the determinants of these decisions, that is, the social, environmental and economic factors that restrain or enable these decisions?
- What are the outcomes of these decisions in terms of food security and also in terms of environmental and social welfare?

Methods

The study area consisted of four agro-ecological zones in Zambia (western, central, southern, eastern) where we conducted in-depth qualitative interviews with 20 farmers. These farmers constitute a sub-set of 470 farmers who had participated in a large-scale monitoring and evaluation program on conservation agriculture (Aune et al. (2012)); Nyanga and Johnsen (2010))) and for whom extensive survey and semi-structured interview data is available.

In a previous paper (Saldarriaga et al., 2013), we described the data collection method in detail. Based on the experiences with the pilot interviews, we adapted the procedures to focus more on the multiple decisions that small-scale farmers make in the course of a year. For this purpose, we designed and worked with a food security wheel that showed the individual months of a year and into which all information about farming decisions as well as coping and adaptive practices were entered (Figure 1).

Interviews were held in local languages and subsequently translated and transcribed. Data analysis involved the analysis of the interviews in fine-grained fashion to identify and track categories of knowledge (Parnafes et al., 2008) and to develop theories of such knowledge (Cobb et al., 2003; diSessa & Cobb, 2004).

Figure 1: Chart facilitating the elicitation of farming decisions, coping and adaptive practices (left hand side of the figure: pre-interview; right hand side of the figure: example post-interview)

Results

In the presentation of results, we start with the last research question, which was about the outcomes of farmers' decisions in terms of food security. We then explore the decisions that lead to these outcomes and differentiate between decisions regarding farming activities and decisions representing coping and adaptive practices. In the discussion section, we turn to the remaining research question, which is about the determinants of the observed decisions.

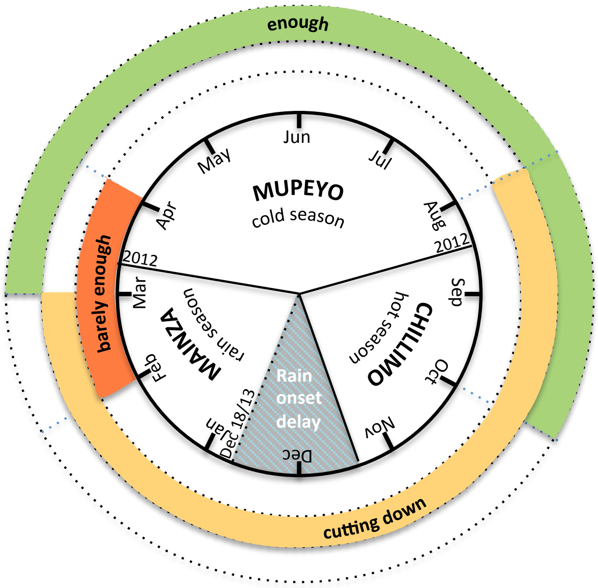
Food system outcomes: Behavior patterns of food security throughout the year

In Zambia, there are three main seasons:

- The rain season (mainza), which in the analyzed farming year started in the middle of November 2012 and ended in the middle of March 2013. Climate change causes rains to start later in the year. In the last two decades, it has shifted the onset of rains from mid October to end of November or even mid December (Neubert et al., 2011).
- The cold season (mupeyo), which in the analyzed farming year started in the middle of March 2013 and ended in August 2013.
- The rest of the year corresponds to the hot season (chillimo).

Food security of farming households' varies considerably throughout the year (Figure 2). As soon as the harvest starts in March and at the latest in April, farmers have enough to eat. This is the period during which farmers are most food secure. The duration of this period, however, depends on the rain patterns during the previous months. From August to October, some farmers still affirm to have enough while others have to begin cutting down their consumption. As of October, farmers need to cut down on their consumption while waiting for the harvest to be ready. For some farmers, March is already a month where they have sufficient food. Others face a critical period with barely enough food during February and March. Among other factors, this is explained by a small harvest in the previous year and a late harvest in the current year. A delay in the onset of rain aggravates and prolongs this period of scarcity.

Figure 2: Food security throughout the year



So far, we explored food security in terms of the amount consumed by a household. In system dynamics terminology, we explained the pattern of food security throughout the year based on the changes in the stock of available food, particularly maize. However, farmers also feel food insecure if the stock of maize is sufficient for the household but if the variety of the available food is poor. In a next step, we thus analyze the types of foods available to farmers throughout the year. For this purpose, we split farmers' diets into four categories. The order of the categories does not represent the importance of each category in farmers' diets.

A. Maize based foods: chibwantu (fermented maize drink), machebele (dried maize boiled), magwaza (dried cooked maize), musozya (maize samp) and nshima (maize pulp).

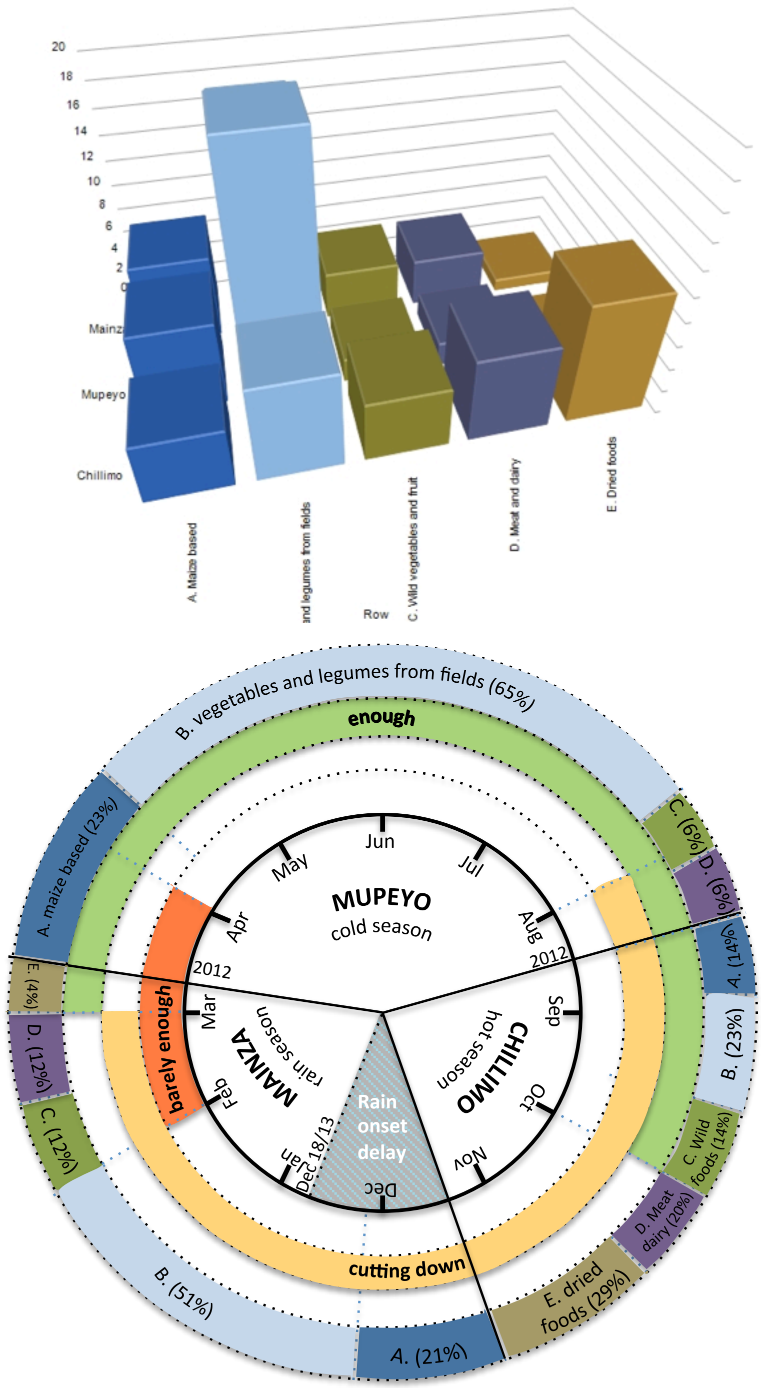
B. Vegetables and legumes from farmers' fields: e.g., beans, ground nuts, okra and sweet potatoes.

C. Wild vegetables and fruits: e.g., blackjack leaves, ibonwe and lumanda (types of wild spinach), lusala (traditional root), matobo (wild fruit).

D. Meet and dairy: beef, chicken, fish, eggs and milk.

Although our data does not allow us to evaluate the importance of these categories in farmers' diets, there are important patterns that we can highlight. Figure 3 shows the food categories available to farmers in each of the three seasons.

Figure 3: Food categories by season (upper half of the figure: detailed overview; lower half: food categories by season in the food security wheel)



The highest variety of foods comes from farmers' fields and, as expected, they are consumed more during the cold season (mupeyo). This season is also the one where farmers are the most food secure. A high variety of vegetables and legumes from the fields are also consumed towards the end of the rain season. However, the availability of the foods found in this category depends on the conditions of the rain season. Under appropriate rain conditions, cowpeas my be planted in November and harvested in January, mushrooms may be harvested in November and groundnuts may be planted between December and January and harvested in March. While the season for the main maize harvest arrives (usually in May), these early harvest foods improve farmers' food security after the hot season where food consumption is cut down.

While maize based foods are less diverse than the other foods coming from the fields, they are all eaten throughout the year. Some local varieties of maize can mature as early as January. This fresh maize helps mitigate food insecurity while the main harvest season arrives.

Although most farmers keep chicken and a few of them heard cattle, meet and dairy foods are rarely consumed. These animals represent mainly an insurance against family difficulties (e.g., illness, school fees) or special circumstances. Those that do not keep cattle sometimes exchange maize for beef, and chicken for milk.

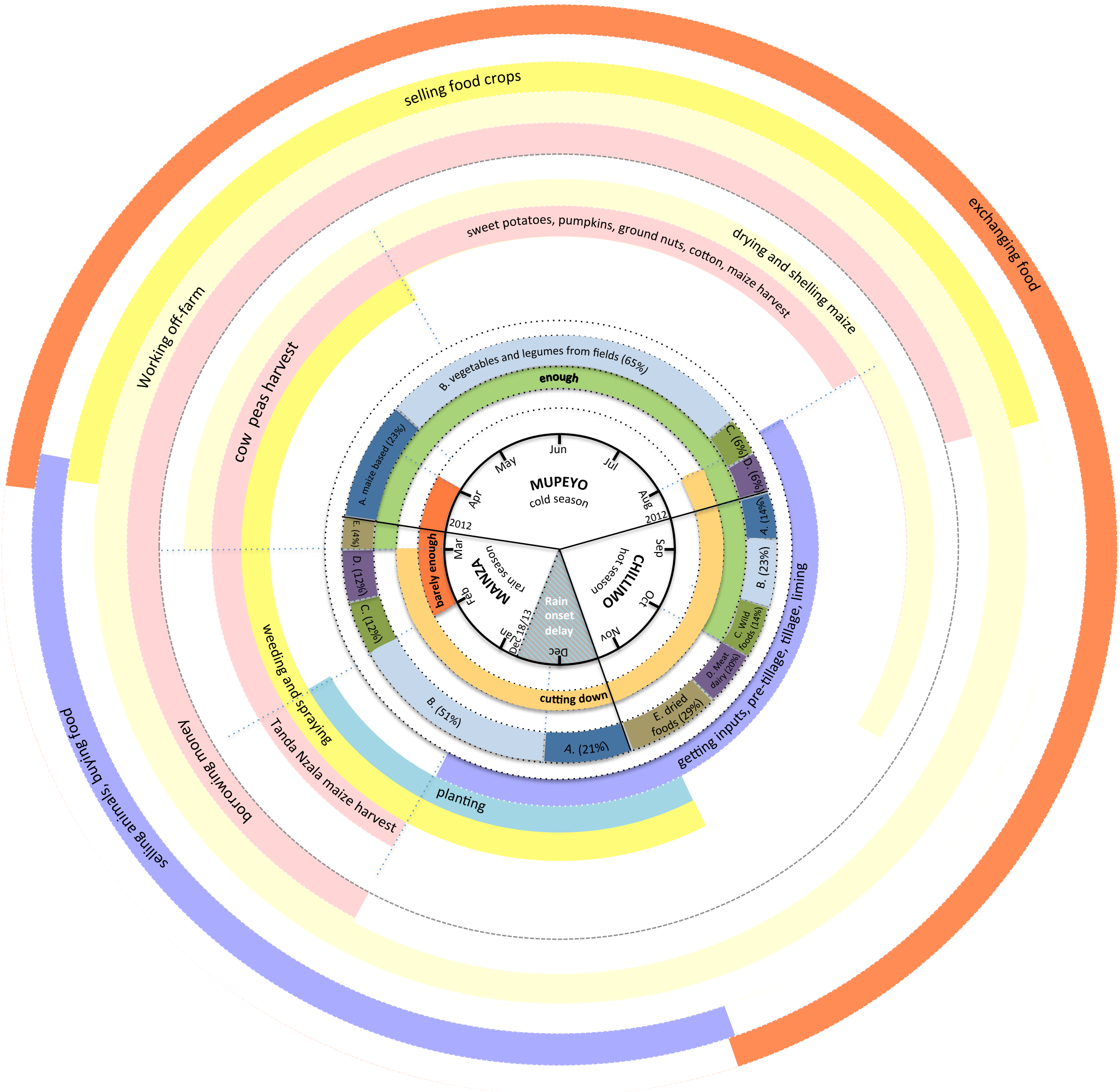
Wild fruit and vegetables complement farmers diet most year around. Although less diverse than the foods from the fields, wild foods are regarded of great importance. Wild vegetables and fruit can be found within the villages and children are sometimes in charge of collecting them.

Finally, we put dried foods into a separate category. Figure 3 shows that most of these foods are consumed during the hot season (chillimo). Some of the foods that are eaten fresh during the cold season (mupeyo) are dried and stored for later consumption. During the hot season (chillimo) foods such as groundnuts, okra and pumpkin leaves are only available dried. Other foods such as squash are difficult to keep for later consumption.

Food system activities: Decisions about farming activities as well as coping and adaptive practices throughout the year

Figure 4 shows the farming activities that are performed throughout the year. To obtain this data, we asked farmers to describe the activities realized during the previous farming season 2012 until the day of the interview in December 2013. Farmers may do things differently from one year to the other. However, the figure shows the concentration of particular activities during specific periods of the year. By adding these farming activities as well as coping and adaptive practices to the food security wheel, we can observe how the activities relate to the seasons and to farmers' food security throughout the year.

Figure 4: Food security wheel with farmers' decisions throughout the year



Crops are planted between November and January and harvested between January and July. The main period for maize harvest starts in May, however, a local variety of maize called Tanda Nzala matures over only one month and can be harvested as early as January. As shown earlier in the analysis, this local maize variety together with other early harvest crops such as cow peas, help mitigate food insecurity in the critical moths before the main harvest.

Farmers implement coping and adaptive practices to mitigate food insecurity. Coping and adaptive practices often involve but are not limited to the utilization of food and production resources. An example is drying vegetables and fish so that they can be stored until seasons of food scarcity.

From farmers' descriptions of all food related activities that they perform throughout the year, we found 11 coping and adaptive practices that farmers use to mitigate food insecurity. Table 1 lists these practices and the respective seasons when they are mostly implemented. These practices represent farmers' responses to past, present or potential future changes perceived in the food available to the household. Therefore, the time of year when these practices are used is in most cases associated to the level of food security in the household at that particular point. For instance, farmers exchange food mostly during the cold season (mupeyo) when food is most abundant, and during the hot season (chillimo) when milk, meet and fish are most available (see Figure 3).

Table 1: Coping and adaptive practices

Practice	Season			Description
	Chillimo (Hot)	Mupeyo (Cold)	Mainza (Rain)	
Choosing seeds and crops	x		x	During the hot and the beginning of the rain season, farmers are preparing their land and acquiring all the inputs necessary for growing their crops.
Choosing planting time			x	A critical decision during the farming season is to decide when to plant the crops. If the seeds are planted before the rain, the rain will find the seeds in the ground when it arrives, thus increasing the chances of germination. However, if the rains do not come on time, the crops may fail, increasing the chances of food insecurity. If, in contrast, the seeds are planted only after the rain has arrived, the chances of crop failure may decrease but the rains may be so strong that farmers may be unable to do the planting work. To predict the onset of the rain farmers use two heuristics: 1) assuming that the rains will begin at a similar time than in the previous year 2) using traditional knowledge of nature such as: the position of the moon in the sky, the yield of wild fruit trees, and the direction of the wind
Borrowing money		x		Some farmers have access to credit, which they acquire to pay for farming inputs. This is done usually around August (end of cold season and beginning of hot season).
Doing piece work	x	x	x	Piecework is a common source of income among small-scale farmers. Piecework consists mainly of working for other small-scale farmers doing weeding (during the rain season) and harvesting (during the cold season). During the hot season, when the farmers begin preparing the land, it is also common to hire ox-carts. Children are sometimes in charge of doing this work.
Taking other jobs	x	x	x	Some farmers take part time jobs to bring more income to the household. Women also play an important role in bringing extra income home. In some cases, they set up small shops in front of their houses where they re-sell products like soap and other utilities.
Selling food		x	x	Two main categories can be distinguished in selling food: 1) farmers sell their crops after the main harvest in the cold season. Some farmers, however, produce only enough for their own household consumption; and 2) farmers sell from their own reserves, i.e., from what has been stored for household consumption. This is usually a critical practice used in cases of illness or other emergencies. However, sometimes, even when maize stocks are low, farmers exchange maize with the purpose of bringing variety to their diets.

Practice	Season			Description
	Chillimo (Hot)	Mupeyo (Cold)	Mainza (Rain)	
Exchanging food	x	x	x	Exchanging food is perhaps the most common way of increasing food variety in farmers' diets. After the main harvest, maize is usually exchanged for meat, wild vegetables, fish, cabbage, tomatoes and onions and milk.
Rationing food	x		x	Food rationing is usually done after a sudden decrease in the food stored for household consumption. For instance, after selling a part of their food stock to cover a family emergency, farmers may need to reduce the per capita consumption in the household. This helps stretch the food stock until the next harvest season.
Drying food	x		x	Dried vegetables are commonly eaten during the hot season where they are not available fresh. Drying food seems to be the most common way of storing food for later consumption. Refrigeration was not available to any of the 20 households in our sample.
Buying food			x	Farmers may buy food when money is available to acquire rarely consumed foods such as meat. However, in some cases, buying food is an emergency measure used when the food stock of the household has been completely depleted. This happens more commonly during the rain season where food security is critical for some farmers.
Selling animals			x	Some farmers keep cattle, chicken and goat as insurance against family emergencies and for school fees payment. Sometimes however, animals are sold to mitigate food insecurity.

The coping and adaptive practices listed in Table 1 can be categorized in three groups based on how they act to mitigate farmers' food insecurity:

- Food variety and duration: The first category involves practices through which farmers use the food already available to the household to increase diet variety or extend the duration and consumption life of the food stock. This includes exchanging, drying, rationing and buying food. Practices that focus on mitigating food insecurity by increasing food variety and duration are most common during the hot season (chillimo). This is indeed the time of year when food stocks are getting low and farmers need to find ways to make this stock last until the next harvest.
- Income available: The second category involves practices that increase the income available to farmers, thus increasing the likelihood of food availability. This group includes selling animals and food, taking other jobs and doing piecework, and borrowing money. Practices aimed at increasing the income available to the household for food are most used during the rain (mainza) and the cold (mupeyo) seasons. During these seasons, doing weeding and harvest piecework can bring extra income to the household.
- Certainty and resilience. The last category of practices increases the likelihood of food availability by decreasing the uncertainty caused by the change in rainfall patterns and by increasing farmers' resilience to change. Here we find choosing seeds, crops and choosing the planting time. By the end of the cold season and the beginning of the rain season, before and after the onset of the rains, farmers need to make important decisions about the *crops* and

maize seeds to be used and the appropriate *time for planting* these seeds. Furthermore, although we focused on farmers' decisions about these three variables, many other choices need to be made during the entire farming season (e.g., tillage (e.g., basins, ripping, plowing), weeding (hand, herbicide), harvest (direct, stacking)).

Discussion and conclusions

Social-ecological systems such as maize dominated farming systems in Zambia are complex and dynamic systems. They thus require stakeholders to continuously test, learn about, and develop knowledge and understanding in order to cope with and adapt to change and uncertainty (Carpenter & Gunderson, 2001; Ericksen, 2008a; Folke et al., 2005). Increasing food security and adapting to climate change is a dynamic decision making task that involves a wide range of stakeholders such as farmers, the private sector, consumers, civil society, and policy-makers. In this paper, we focused on the particular stakeholder group of small-scale farmers and provided a fine-grained description of the multiple decisions they need to make in the course of a year, the determinants of these decisions and their outcomes that eventually feed back into subsequent decisions.

Our results show that small-scale farmers perceive the dynamic complexity of the resource systems they manage very well. They provide operational descriptions of stock management problems such as the management of soil fertility or of food inventories and they try to make decisions that rebuild and maintain safe stock levels. They also consider the main delays in the system in their decisions. Persistently low levels of food security are mainly caused by farmers' extremely low access to various assets and resources such as land, water, nutrients and seeds or to alternative employment opportunities that would allow them to purchase food necessary for a nutritious, balanced and culturally valuable nutrition.

The finding that persistent food security problems are caused only in lesser part by the mismanagement of natural resources and more by demand-side factors (policy-led or induced by demographic growth) are in line with results from other regions in sub-Saharan Africa (e.g., Mortimore & Harris, 2005). Our current data does not allow us to conclusively evaluate the role of supply-side constraints such as scarcities of cultivable land, soil amendments, labor or capital. This is illustrated in Table 2 that compares coping and adaptive practices suggested by the literature (e.g., Ericksen, et al., 2010; Mendelsohn, 2008; Vermeulen et al., 2012) with the coping and adaptive practices found in our interviews. The table shows that most practices that require substantial investments such as capital- or water-related practices are unthinkable for the interviewed farmers.

Table 2: Findings on small-scale farmers' dynamic decision making

Decision	Suggested by literature	Found in interviews
Production input: land	Expansion of agriculture land	No
	Reduced deforestation	No
	Reforestation	No
Production input: capital	Increasing mechanization (for adaptation)	No
	Decreasing mechanization (for mitigation)	No
Production input: water	Increasing irrigation	No
	Water storage and management	No
Production input: seeds	Use of improved seed varieties	Yes

Production input: mineral fertilizer	Increasing use of fertilizer (for adaptation)	Yes
	Decreasing use of fertilizer (for mitigation)	No
Production management	Match varieties to climate	Yes
	Experiment with alternative planting dates	Yes
	Experiment with alternative crops	Yes
	Move from growing crops to livestock and back	Yes
	Soil conservation	Yes
	Pest and disease management	Marginal
	Agroforestry	Marginal
Production output	Food storage	No
Beyond production	Exchange of food	Yes
	Distribution of food	Yes
	Laboring for food	Yes
	Laboring for cash	Yes
	Consumption of unusual food, e.g., wild plants	Yes

Our data provides a rich description of the existing adaptive capacity of small-scale farmers to deal with existing and future challenges related to increasing food security and adapting to climate change. It is, however, increasingly recognized that people also need an enabling institutional and policy environment to successfully adapt in the longer term and diversify livelihoods for positive wealth accumulation (Adger et al., 2007; Ellis & Freeman, 2004; Ericksen, et al., 2010). To support this process, we thus accompany our research in Zambia with quantitative system dynamics modeling. The application of multiple methods to the rich range of challenges for maize dominated farming systems in Zambia allows developing the basic principles that govern the dynamics of social-ecological systems and their capacity to cope with and adapt to change (Janssen & Anderies, 2013). The simulation model enables us to systematically explore the consequences of management and policy actions on food system outcomes and, by doing so, provides the basis for an enabling institutional and policy environment. Insights from case studies and qualitative research, in turn, stimulate modeling. They also provide evidence of real achievements and internal potentials and therefore point the way toward a foundation for evidence-led policies for the management of social-ecological systems. Such evidence-led policies aim to build on local experience, suggesting a more organic model for development rather than aiming to transform seemingly inappropriate local practices (Mortimore & Harris, 2005).

Further qualitative research in this domain will thus expand the current focus on small-scale farmers to other stakeholder groups and it will move from the analysis of current knowledge and decision making to exchange and integration of knowledge held by different stakeholders. For instance, the data described in this paper suggest that predictability and uncertainty regarding economic and climatic context factors play an important role in small-scale farmers' decision-making. A next step thus needs to investigate how science-based knowledge held e.g., by researchers on these subjects can integrate with farmers' knowledge and how farmers will use it for decision-making. This line of research will generate insights into the factors that need to be considered in the implementation of seemingly effective management and policy actions and into how these actions might have to be reformulated, adjusted and combined to be truly effective.

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