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Sources of vulnerability to a variable and changing climate among smallholder households in Zimbabwe: A participatory analysis

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ABSTRACT

Vulnerability analysis is essential for targeting adaptation options to impacts of climate variability and change, particularly in diverse systems with limited resources such as smallholder farms in sub-Saharan Africa. To investigate the nature and sources of vulnerability of smallholder farmers to climate variability and change, we analysed long term climate data and interviewed farmers individually and in groups in Makoni and Hwedza districts in eastern Zimbabwe. Farmers' perceptions of changes in climate characteristics matched the recorded data. Total seasonal rainfall has not changed, but variability in the rainfall distribution within seasons has increased. The mean daily minimum temperature increased by 0.2 °C per decade in both Makoni and Hwedza. The mean daily maximum temperature increased by 0.5 °C per decade in Hwedza. The number of days with temperatures >30 °C also increased in Hwedza. Farmers indicated that livestock production was sensitive to drought due to lack of feed, affecting resource-endowed farmers, who own relatively large herds of cattle. Crop production was more sensitive to increased rainfall variability, largely affecting farmers with intermediate resource endowment. Availability of wild fruits and social safety nets were affected directly and indirectly by extreme temperatures and increased rainfall variability, impacting on the livelihoods of resource-constrained farmers. There was no evidence of a simple one-to-one relationship between vulnerability and farmer resource endowment, suggesting that vulnerability to climate variability and change is complex and not simply related to assets. Alongside climate variability and change, farmers were also faced with biophysical and socioeconomic challenges such as lack of fertilizers, and these problems had strong interactions with adaptation options to climate change. Diversifying crops and cultivars, staggering planting date and managing soil fertility were identified as the major adaptation options to stabilize yields against increased rainfall variability. There is need to evaluate the identified adaptation options on farm and with the participation of farmers to provide empirical evidence on the best options for different households.

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Introduction

While climate variability and change are global phenomena, vulnerability differs by location. Sub-Saharan Africa (SSA) has been identified as the most vulnerable region to climate variability and change because many areas inherently receive unpredictable rainfall (IPCC, 2007). Zimbabwe is one of the 'hotspots' for climate change, with predicted increases in temperatures and rainfall variability (Lobell et al., 2011; Rurinda et al., 2013), and increased probability of extreme events such as droughts and flash floods (Houghton, 1997). Smallholder farmers are vulnerable to impacts of the changing climate because of multiple interacting stresses, such as soil degradation (Mapfumo and Giller, 2001), lack of lucrative output markets (Nyikahadzoi et al., 2012), a declining natural resource base linked to population pressure (Frost et al., 2007), and deterioration of societal 'safety nets' related to extreme poverty (Mapfumo et al., 2013). Climate variability and change is therefore an extra burden that exacerbates existing challenges.

Patterns of vulnerability vary among smallholder households, even within the same community (Westerhoff and Smit, 2009). Smallholder farmers are often classified into different categories largely based on resource endowments in different regions in SSA (Mtambanengwe and Mapfumo, 2005; Tittonell et al., 2005). First, these distinct endowments and livelihood options between smallholders would be impacted differently by either single or multiple climatic variables leading to differential vulnerability. Farmers practicing improved soil fertility management were less vulnerable to increased temperatures than non-practicing farmers with respect to wheat production (Luers, 2005). Second, the variation in endowments among smallholder households is associated with different responses to hazards (Adger, 2006). Larger farm size has been found to increase adaptive capacity of farmers and hence reduce vulnerability (Reidsma et al., 2009). However, in another study smallholder farmers with relatively small farms were found to be less vulnerable to droughts than privately owned large farms due to a range of livelihoods options (Toni and Holanda, 2008). These findings suggest that even the perceived marginalized households can use a range of options to reduce vulnerability. However, being resource-endowed does not necessarily mean one is less vulnerable. Furthermore, institutions and social networks within a local community also play a key role in decreasing vulnerability (Mapfumo et al., 2013).

Detailed vulnerability analyses not only require context specificity, but also involvement of the target communities at local level (Cutter, 1996). Given that the determinants of vulnerability, whether climatic, or social and biophysical conditions change over time, the target communities would play a key role in identifying indicators and thresholds for vulnerability (Cutter, 1996). In addition, the uncertainties in climate change research due to both lack of knowledge and the stochastic nature of processes underpinning climate change, prompt for bottom-up approaches to enable continual co-learning to respond to future climatic surprises (Dessai and van der Sluijs, 2007). Participatory analysis helps to integrate knowledge from both local farmers and science, particularly when comparing local farmers' perceptions of climatic exposure characteristics and measured data.

Despite the reported differences in resource endowment and management between farm types in SSA, there is little knowledge available to understand the relationship between smallholder households of different endowments and vulnerability to climate variability and change relative to other stresses such as soil fertility depletion. Yet, understanding vulnerability of different households is essential to identify 'best fit' adaptation options particularly in diverse environments with limited resources. In addition, vulnerability analysis helps to target and reach the most vulnerable households (Luers, 2005). Although research on vulnerability analysis has increased (Janssen, 2007), efforts have been focused more on building theoretical concepts and how they can be applied to systems in general [e.g. Turner et al., 2003]. Such frameworks are important to understand the concept of vulnerability, but they lack practical relevance for intervention (Luers, 2005) as their usefulness has not been tested in real situations. Given that the impacts of climate variability and change are context specific, there is a need for local vulnerability analyses [e.g. Cutter, 1996] to derive lessons on the how the relationship between farmer resource endowment and vulnerability to climate variability and change is mediated by the socio-economic and environmental resources present in the system. As a result, lessons could be learnt to share with other communities and other regions. Some analyses of vulnerability have focused on the impact of single climate variables such as drought (Eriksen et al., 2005) or temperature (Luers, 2005), which may conceal impacts of other climatic factors (O'Brien et al., 2009). Thus, analysis of vulnerability requires a holistic systems approach recognising multiple climatic exposure as well as social and biophysical constraints. Recent definitions of vulnerability recognise the interaction between external and internal forces characterised by exposure, sensitivity and adaptive capacity of a system, sub-system or system components (Cutter, 1996; IPCC, 2007).

The focus of this study was to understand the nature of, and to identify the sources of vulnerability among smallholder farming households to impacts of climate variability and change in two distinct communities representing similar smallholder environments in Zimbabwe. The objectives were (i) to analyse the relationship between vulnerability and farmer resource endowments; (ii) to identify adaptation options used by different households in response to sources of vulnerability and to link them to the socioeconomic and environmental resources available in the region; (iii) to identify opportunities for enhancing the capacity of farming households to adapt to climate variability and change for informed policy decisions.

Research approach

Study sites

The study was carried out in two communities; namely Nyahava in Makoni district and Ushe in Hwedza district, in Zimbabwe, between 2009 and 2012. The two communities were selected in the context of benchmark sites of the Soil Fertility Consortium for Southern Africa (SOFECSA) marked by high climate variability (Mapfumo, 2009; Rurinda et al., 2013). Both communities largely depend on agriculture for their livelihoods. Makoni is a resettlement area with an average farm size of 6 ha per household. Hwedza is a communal area with farm sizes range from 2 to 5 ha per household. Makoni receives annual rainfall ranging between 750 and 1000 mm and Hwedza between 650 and 800 mm. The soils are generally granite-derived sands with inherently poor soil fertility (Nyamapfene, 1989). In these smallholder farming systems, the livelihoods of farmers are strongly dependent on the interactions between crop and livestock production and common natural resource pools. Crop production provides feed for livestock, while livestock provide draught power and manure for crop production. Common natural resources provide feed for livestock and organic material for crop production. In times of crop harvest failure, communities in these districts depend on non-timber forest products, mainly fruits of *Parinari curatellifolia* and *Uapaca kirkiana* as food (Woittiez et al., 2013). Some households mostly wealthier ones also maximize production during favourable rainfall and store surplus grain in granaries to compensate for drought years (Rurinda et al., 2014).

Analysis of vulnerability of smallholder households

This study draws on both qualitative and quantitative research approaches. Participatory diagnostic techniques, monitoring of farming livelihoods systems using farm diaries, a household questionnaire survey, and analysis of long-term climate data were used to understand the nature of vulnerability of households, and to identify adaptation options.

The analysis of vulnerability was performed across households belonging to three farmer resource endowments, based on an existing classification (Mtambanengwe and Mapfumo, 2005). Farm size and cattle ownership were the main assets used for classification of farmers into different resource groups. The proportion of households in each resource group was determined together with local extension officers using a list of all households in each community compiled by the Department of Agriculture and Extension Services (AGRITEX) (Table 1).

Qualitative data collection approaches

Characterisation of smallholder farming livelihood systems in relation to climate variability and change

A series of community meetings were organised at each site to (i) record farmers perceptions of climate variability and change; (ii) identify issues and problems affecting farmers in the face of climate variability and change; (iii) describe who is vulnerable and establish the causes; (iv) identify adaptation options used by different farmers during drought and flood years. These participatory diagnostic meetings were also helpful in designing relevant and clear questions for the farm diaries and for the household questionnaire survey that were implemented to study in more detail the above mentioned key issues. The number of farmers that participated in these meetings was 350 in Makoni and 400 in Hwedza and each community comprised a total of about 1500 households.

At the first meeting at each community, farmers were grouped into three broad categories based on endowments: resource-endowed, intermediate and resource-constrained, matching the existing farm typology (Mtambanengwe and Mapfumo, 2005). Separation of farmers into the appropriate resource group was done with the assistance of local extension officers at each site performed using cards coded with letters A, B and C, representing the three resource groups. Care was taken to ensure that the group participants had no knowledge of the actual significance of the letters. A fourth group comprising key informants, including chiefs, headmen, village heads, and councillors, was strategically formed to avoid bias and dominance likely to occur as a result of their presence during the group discussion. Researchers equipped with participatory

Table 1
Proportion (%) of household and household heads in each farmer resource category in Makoni and Hwedza in Zimbabwe.

Site/farmer category	Male-headed household	Defacto female-headed household[a]	Widowed female-headed household	Child-headed household	Overall proportion
Makoni					
Resource-endowed: $n = 36$	14	1	3	0	18
Intermediate: $n = 84$	32	7	3	0	42
Resource-constrained: $n = 80$	25	5	9	1	40
Hwedza					
Resource-endowed: $n = 34$	12	3	2	0	17
Intermediate: $n = 54$	19	4	3	1	27
Resource-constrained: $n = 112$	31	9	15	1	56

[a] Defacto female-headed household is a household headed by a woman because her husband is away most of the time.

action research (PAR) skills (German et al., 2008) facilitated and documented both the process and the technical information emerging from each of the four groups.

Vulnerability to climate variability and change

Another meeting was organised specifically to understand the nature of exposure to climate variability and change, and how households would respond. A total of 49 farmers (23 women and 26 men) in Makoni, and 68 farmers (39 women and 29 men) in Hwedza were present at the meetings. Three groups were formed, a mix of young and older, and men and women. Focus group discussions within each group were guided by such questions as: (i) what were the main climatic variables impacting the farming livelihood system?; (ii) what were the frequency/magnitude/duration of identified climatic hazards?; (iii) if there was a drought for instance, what sub-systems and components of the farming livelihood system would be affected?; and (iv) which were the most vulnerable households and to what particular climatic hazard were they vulnerable?

During plenary, consensus was reached about the main climatic exposure characteristics and the affected sub-systems. Farmers were asked to rank how each sub-system would be impacted by each of the identified climatic exposure characteristics. Each group was allocated a different climatic exposure characteristic, and was asked to analyse it for the same sub-systems. In each group, circles were drawn on the ground to represent each sub-system. Each farmer was given maize seeds and asked to place them in the circles to rank the most affected sub-systems. The sub-system with the largest number of seeds was the most affected by a defined particular climatic exposure characteristic. Then the circle for this sub-system was removed and the ranking exercise started again for the remaining sub-systems until each of the sub-systems was ranked against each of the defined climatic hazards. The extent of loss and time needed of recovery of indicators of household well-being (food, income, social value, draught power, manure, stover for livestock) were the main attributes defined by the community that were used for ranking.

Household food insufficiency and loss of cattle were identified as the main indicators of vulnerability. Farmers considered a household with enough food to last for one agricultural season (12 months) to be food self-sufficient, which was about 1 tonne of maize (or 0.5 tonne of small grains e.g. finger millet) for a family of six. The number of cattle considered sufficient to deal with drought events was seven for wealthier farmers and three for poorer farmers.

Quantitative approaches

Detailed characterisation of farming livelihood systems

Informed by the participatory work and initial surveys, a sample of 10 households for each resource group was selected in each community to acquire detailed information. These households were selected to represent the diversity within the group (Mtambanengwe and Mapfumo, 2005). Farming activities were monitored for two agricultural seasons: 2009/2010 and 2010/2011 using farm diaries with the assistance of extension personnel. Data on cropping patterns, types and amounts of fertilizer used, and crop yields were recorded in diaries. To determine grain yield, three farms were selected from each of the sub-sample of 10 under each resource group. The yields were measured at each field allocated to maize on each farm. Maize grain yield was determined at physiological maturity from a net-plot of 2 rows $\times$ 5 m replicated twice.

Farmer perceived climatic exposure and adaptation options

A household questionnaire was also administered to complement information gathered during the focus group discussions. The questions mainly focused on the perceptions of farmers: (i) to climate variability and change, (ii) factors constraining crop production, and (iii) existing and possible adaptation options. Stratified random sampling was used to select 100 households in each community. Each community was divided into strata based on villages sharing common pool resources (e.g. grazing area, dip tanks). As a result, in Hwedza the villages were divided into 6 strata and 17 households were randomly selected from each. In Makoni 20 households were selected from each of the 5 strata. A number of variables such as farmers' perceptions of climate variability and change and factors constraining crop production were analysed and frequency tables were produced.

Analysis of long-term climatic data

Daily rainfall and temperature data collected by the Meteorological Services Department of Zimbabwe over a 48 year period (1962–2010) for Hwedza were analysed for trends. Variables analysed included total annual rainfall, date for the start of rain season, frequency of dry spells, means of maximum and minimum daily temperatures, and the number of days with temperatures >30 °C. This latter indicator was chosen because analyses have shown that each day spent with temperatures >30 °C reduces maize grain yield by 1% under optimal rain-fed conditions, and by 1.7% under drought conditions in Africa (Lobell et al., 2011). Rainfall data for Makoni was incomplete and inconsistent and hence could not be used. Date of the beginning of the rain season was analysed using a threshold of 48 mm of rainfall in at least two rainy days out of ten consecutive days (Unganai, 1990). The starting date to search for the beginning of the rain season was mid-October. The analyses were done in Instat Plus 3.36 (Stern et al., 2006), and the frequency of dry spells was analysed using the Markov chain modelling option in Instat.

Results and discussion

Farmer derived conceptual framework for vulnerability analysis in smallholder farming livelihood systems

A conceptual framework to define vulnerability among smallholders to climate variability and change was developed combining local farmers' and expert empirical knowledge (Fig. 1). Three components of vulnerability: exposure, sensitivity, and adaptation were at the core of the framework. Cropping, livestock production, availability of natural resources such as wild fruits and social safety nets were identified as the main sub-systems of a broader farming livelihood system exposed to different climatic exposure characteristics. The indicators for the perceived impacts of climatic exposure characteristics on these sub-systems and their components, were household food self-sufficiency and cattle ownership. Increased rainfall variability, frequency of droughts and extreme temperatures were identified as the major climatic exposure characteristics. Farmer suggested adaptation options were classified after De Koeijer et al. (2003) into operational (short-term e.g. staggering planting date), tactical (medium-term e.g. diversifying crop cultivar/type) and strategic (relatively long-term e.g. strengthening social safety nets). The extent to which households adopt these adaptation options depends on the availability of and access to both biophysical and socioeconomic resources, and also the support they receive from different institutions operating at different levels (Fig. 1).

Exposure to climate variability and change of smallholder livelihood systems and its implications

Increased rainfall variability characterised by delayed seasonal rainfall and prolonged dry spells, droughts, and increased temperatures were the most important climate indicators identified by farmers during the study (Table 2). The results of the survey showed that there was no significant difference on how households of different endowments perceive climate exposure characteristics (Table 2). This could be due to the interdependence of households of different types with respect to livelihoods (Zingore et al., 2007). This is also a demonstration of the complexity of African smallholder farming livelihood systems (Giller et al., 2011).

Farmers' recall of weather and climate closely matched climatic records. Analysis of long-term rainfall indicated that the total seasonal rainfall has not changed, but there was increased variability in the rainfall distribution within seasons (Fig. 2). Although there was a large variability in the date for the start of the growing season, a delay of a week was observed for the period, 1990–2010 compared with the period, 1962–1989 (Fig. 2b). Similarly, the probability of dry spells between the end of January and early February has also increased in the last two decades (Fig. 2(c and d)). The mean maximum temperature has not changed, but the mean minimum temperature has increased by 0.2 °C per decade in Makoni (Fig. 3a). The mean minimum temperature has increased by 0.2 °C per decade, while the mean maximum has increased by 0.5 °C per decade in Hwedza (Fig. 3b). The number of days with temperatures >30 °C have also increased in Hwedza but not in Makoni (Fig. 3(c and d)). These findings are consistent with Houghton (1997) who projected increased rainfall variability and

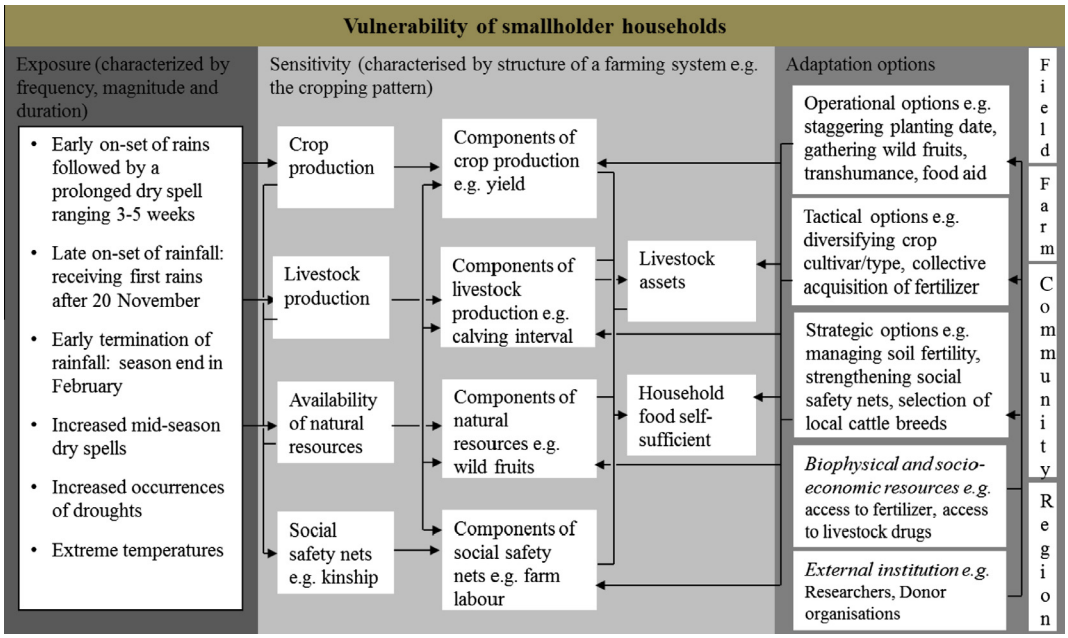

Fig. 1. Operational conceptual framework for vulnerability analysis in smallholder farming communities.

Table 2
Farmers' perceptions of climatic exposure characteristics in Makoni and Hwedza in Zimbabwe (based on a household survey conducted in 2009).

Site/climate exposure characteristic	Resource-endowed	Intermediate	Resource-constrained
	%		
Makoni	*n* = 25	*n* = 35	*n* = 40
Increased rainfall variability	56	68	57
Late on-set of rainfall	33	35	32
Prolonged dry spells	11	5	11
Increased drought incidences	5	10	12
Extreme temperatures	9	10	8
Other (reduced rainfall, cyclones)	5	10	5
Hwedza	*n* = 18	*n* = 30	*n* = 52
Increased rainfall variability	78	61	64
Late on-set of rainfall	33	35	32
Prolonged dry spells	11	23	14
Increased drought incidences	6	21	13
Extreme temperatures	28	17	15
Other (reduced rainfall, cyclones)	7	5	4

Note: The overall percentage exceeds 100 due to multiple responses.

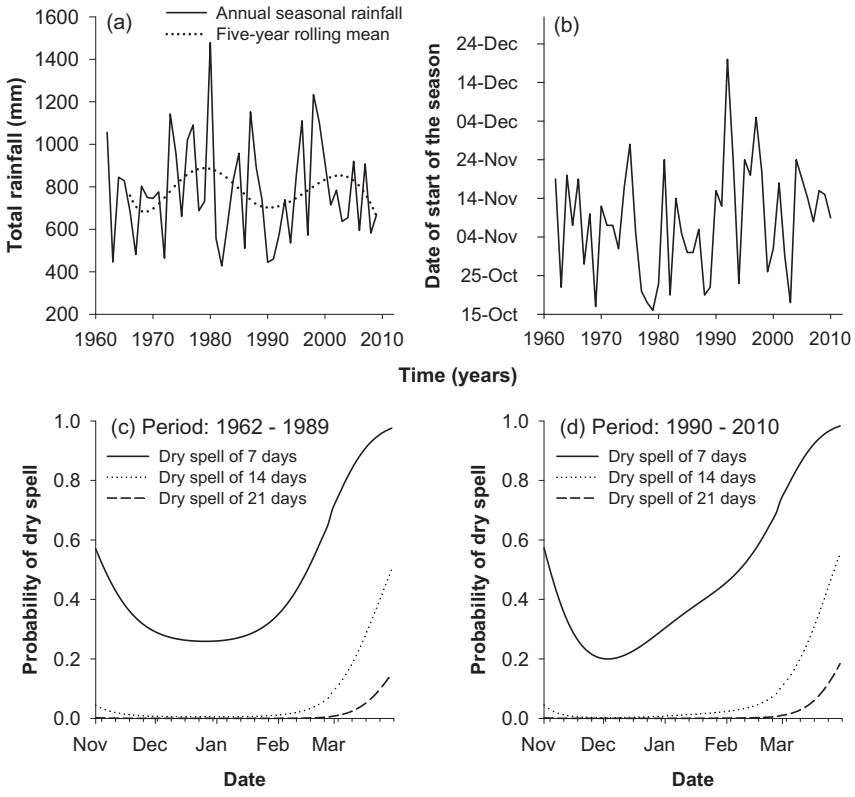

Fig. 2. Rainfall analysis in Hwedza: (a) variation in annual seasonal rainfall (tau-b = −.021, *P* = .831), (b) date of start of rainy season (using 48 mm in at least two rainy days out of ten consecutive days) (tau-b = .104, *P* = .296), (d) probability of dry spells of different lengths for period 1962–1989, and (d) probability of dry spells of different lengths for period 1990–2010. Rainfall data for Makoni was incomplete and could not be used.

extreme events such as droughts in southern Africa. Unganai (1996) found that temperature had increased by up to 0.8 °C in Zimbabwe between 1933 and 1993 and also projected temperature increase in the range 2–4 °C by 2100 in Zimbabwe and other parts of southern Africa.

Increased frequency of within season dry spells coupled with rising temperatures are likely to impact negatively on soil moisture availability thereby increasing the risk of crop failure. The magnitude of impact of these dry spells on crop production, and consequently household food security could be large given that their probability of occurrence seem to have increased around the critical flowering period of crops, i.e. between end of January and early February (see Fig. 2(c and d)).

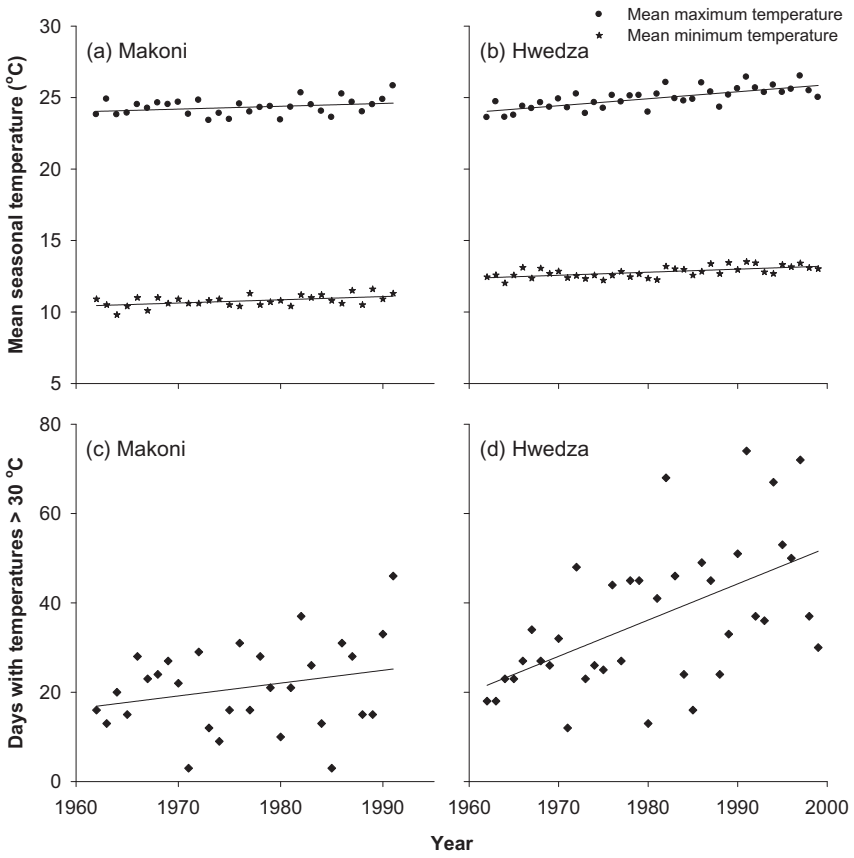

Fig. 3. Time series trend for (a) mean maximum (n = 30, tau-b = .191, P = 0.139) and mean minimum (n = 30, tau-b = .300, P = 0.024) daily temperatures in Makoni; (b) mean maximum (n = 38, tau-b = .556, P = 0.000) and mean minimum (n = 38, tau-b = .391, P = 0.001) daily temperatures in Hwedza; and (c) number of days with temperatures >30 °C in Makoni (n = 30, tau-b = .163, P = 0.211) and (d) Hwedza (n = 38, tau-b = .414, P = 0.000), Zimbabwe.

The change in temperature characteristics was greater in Hwedza than in Makoni, because not only the minimum and maximum temperatures have increased, but also days with temperatures >30 °C, affecting crop production (Lobell et al., 2011). This indicated high temperature variability in otherwise proximal areas. Livestock production is also likely to decrease due to increased temperatures and droughts. For example, livestock production is likely to decrease due to unfavourably high temperatures (e.g. in Hwedza) which will inevitably promote multiplication of disease transmitting vectors (e.g. ticks and flies), or simply render the environment unfit for domestic animals (Thornton et al., 2011).

Vulnerability of different farmer groups to climate variability and change

Farmers perceived that the four sub-systems of a farming livelihood system namely cropping, livestock production, natural resources and social safety nets were impacted differently by different climatic exposure characteristics (Table 3). Farmers revealed that crop production was affected most by increased rainfall variability, whereas livestock production was threatened most by droughts (Table 3). Availability of rangeland and non-timber forest products collected from natural environments were affected most by extreme temperatures (Table 3). Social safety nets were affected indirectly by both increased rainfall variability and droughts due to decreasing crop and livestock productivity (Table 3).

The livelihoods of resource-endowed households were most vulnerable to droughts as a result of cattle loss due to lack of feed. As resource-endowed farmers own relatively large herds of cattle, they often find it difficult to feed these large herds in times of drought. This can result in substantial cattle losses, unless farmers have access to capital to buy supplementary feed. For example about 1.03 million (>23% of the Zimbabwean national herd) cattle died during the 1991/1992 drought (Tobaiwa, 1993). Many farmers who lost cattle during this drought indicated that they have not yet recovered and their herds will not be able to do so without external support. Thus, the impact of drought can be long term, not only because the reproductive rate of cattle is slow (Campbell et al., 2000), but also because huge investments are required to restock. Given the importance of cattle on one hand and the high frequency of droughts 1–2 times per decade in Zimbabwe on the other hand (Rockström, 2004), several approaches have been proposed to buffer livestock production against droughts. Scoones (1992) recommended sale of cattle during droughts and restocking in favourable conditions. Lack of insurance and price differences

Table 3
Farmer ranking of sub-systems of a farming livelihood system impacted by different climatic exposure in Makoni and Hwedza, Zimbabwe (Rank 1 is the most affected sub-system and 4 is the least).

Climatic exposure	Rank of a sub-system	Main system component impacted	Impact	
			Positive	Negative
Increased rainfall variability: prolonged mid-season dry spells ranging from 3 to 5 weeks, and late on-set of rainfall	1. Crop production	Yield	Increased crop yield in wetland fields	Decreased crop yield in dry land fields due to soil moisture deficits
	2. Social safety nets	Hired labour	–	Reduced hiring of farm labour
		Yield of milk		Reduced sharing of draught power
	3. Livestock production	Fruits	Reduced livestock diseases	Reduced milk yield due to lack of quality pastures
	4. Natural resources			Reduced availability of fruits
Droughts	1. Livestock production	Weight of cattle	–	Poor livestock condition and death
		Calving interval		Reduced reproduction potential
	2. Crop production	Yield of milk		Drastic reduction in milk yield
	3. Social safety nets e.g. kinship			Increased incidences of diseases
		Yield	–	Crop failure
	4. Natural resources	Hired labour	–	Reduced hiring of farm labour
		Fruits		Reduced sharing of draught power
			–	Decreased availability of wild fruits
				Increased extraction of natural resources for sale e.g. firewood
				Reduced availability of pastures
Extreme temperatures	1. Natural resources	Fruits	–	Reduced availability of fruits
		Human health	–	Increased outbreak of diseases
	2. Social safety nets	Weight of cattle	–	Poor livestock condition
		Yield	–	Reduced production due to frost
	3. Livestock production			
	4. Crop production			

Table 4
Maize grain yield, energy produced and food self-sufficiency (FSS) for each farmer resource category in Makoni and Hwedza for the 2009/2010 and 2010/2011 seasons. Data in parentheses indicate range.

Site/farmer category	2009/2010 season			2010/2011 season		
	Maize yield t ha^{-1}	Total energy $\times 10^6$ kcal/household/year	FSS %	Maize yield t ha^{-1}	Total energy $\times 10^6$ kcal/household/year	FSS %
Makoni						
Resource-endowed	7.0 (3.1–11.5)	25.1 (11.1–41.2)	583	2.0 (2.0–2.5)	7.2 (7.2–9.0)	167
Intermediate	5.4 (2.5–6.3)	19.3 (9.0–22.6)	450	1.5 (1.0–2.0)	5.4 (3.6–7.2)	125
Resource-constrained	3.4 (2.3–4.5)	12.2 (8.2–16.1)	283	1.3 (0.8–1.3)	4.7 (2.9–3.7)	108
Hwedza						
Resource-endowed	2.6 (2.1–3.1)	9.3 (7.5–11.1)	217	1.7 (1.5–2.0)	6.1 (5.4–7.2)	142
Intermediate	1.6 (1.0–2.8)	5.7 (3.6–10.0)	133	1.2 (0.8–1.5)	4.3 (3.2–5.4)	100
Resource-constrained	0.7 (0.5–0.7	2.5 (1.8–2.5)	58	0.5 (0.2–0.8)	1.8 (0.7–2.9)	42

Notes: 100 g of grain maize, at 12% moisture content provide 358 kcal of energy (FAO).
Minimum dietary energy requirement (MDER) is 1790 kcal/person/day (FAO, 2009) = 3.9×10^6 kcal/6 persons/year.
Average dietary energy requirement (ADER) is 2260 kcal/person/day (FAO, 2009) = 4.9×10^6 kcal/6 persons/year.
Food self-sufficiency (FSS) = household production/sufficient quantity required for household consumption $\times$ 100.

between the drought period and the period of restocking, however, would complicate the implementation of this strategy (Campbell et al., 2000). Normally prices of cattle fall during droughts due to poor cattle condition and increased supply. The value of money may also depreciate so that cattle can only be purchased at a much higher price. However, resource-endowed households have enough food (Table 4) because of timely access to crop production inputs such as seed, fertilizers, manure and draught power.

Farmers of intermediate resources, which depend mostly on crop production, were vulnerable to increased rainfall variability within a season coupled with rising temperatures. This dependency might mean that such households have relatively limited number of other livelihood options to cope with a decline in crop production. Cattle ownership among the intermediate households is often low, so farmers are reluctant to sell cattle in times of food deficits unless the impact of drought on household food availability has reached alarming levels. Instead, some opt to change their consumption patterns – rationing food within the household as a coping strategy (Eldridge, 2002) rather than selling their productive assets with the objective of enhancing their future entitlements. The impacts of increased rainfall variability on household food availability can be

huge, but generally short-term and can be addressed in a shorter time compared with the impact of drought on livestock production. However, if poor rainfall events occur over consecutive seasons, farmers would be forced to sell the few cattle they have, which would lead to long-term impacts on their livelihood.

The resource-constrained households, who depend on social safety nets and common natural resource pools, were threatened by both extreme temperatures and increased rainfall variability. Maize grain yields of resource-constrained households were poor (<1 t farm^{-1}) even in the good 2009/2010 rainfall season in Hwedza resulting in low food self-sufficiency (Table 4). The low food self-sufficiency demonstrated that poor households fail to produce enough food for the household. Consequently, they supplement household food with other livelihood options. Thus, resource-constrained households largely depend on off-farm activities, especially exchange of labour for food and income with the wealthier households (Zingore et al., 2007), and use of products such as wild fruits from natural resource pools (Woittiez et al., 2013).

Weakening of social safety nets was driven by both social and biophysical variables. Declining crop and livestock productivity due to increased rainfall variability and droughts forced resource-endowed and resource-intermediate households to compete with resource-constrained for scarce natural resources such as non-timber forest products, thereby creating conflicts between households. Woittiez et al. (2013) reported an increased energy intake from wild fruits by wealthier households in times of crop failure in Zimbabwe. Decline in crop productivity also reduce the amount of farm work available to poor households on resource-endowed farms. Eldridge (2002) concluded that in Zimbabwe, food (or cash) obtained in exchange for work on richer farmers dropped in parallel with the reduction in harvest. Wealthier farmers would prefer to hire relatively cheap labour from outside their communities, often creating tension with their poor neighbours.

Vulnerability to climate variability and change and other drivers

Limited access to fertilizer in Makoni and limited access to fertilizer and draught power in Hwedza were the main economic factors constraining crop production (Fig. 4). Farmers' ranking of factors constraining crop production in Hwedza had the following order: increased rainfall variability (64% of the respondents) > lack of access to draught power (20%) > lack of access to fertilizer (18%). In Makoni, 64% of farmers ranked increased rainfall variability first followed by lack of access to fertilizer (30%) (Fig. 4). Timely access to affordable fertilizers, improved access to draught power and improved soil fertility management were also given high priority by farmers of different endowments as options for reducing vulnerability to climate variability and change (Table 5).

Because of limited access to fertilizer, resource-constrained farmers failed to produce sufficient food for household consumption, even in a good rainfall year (see Table 4). The resource-endowed households, however, demonstrated that with fertilization food self-sufficiency could be achieved even in a relatively bad rainfall season. Similarly, Fraser et al. (2008)

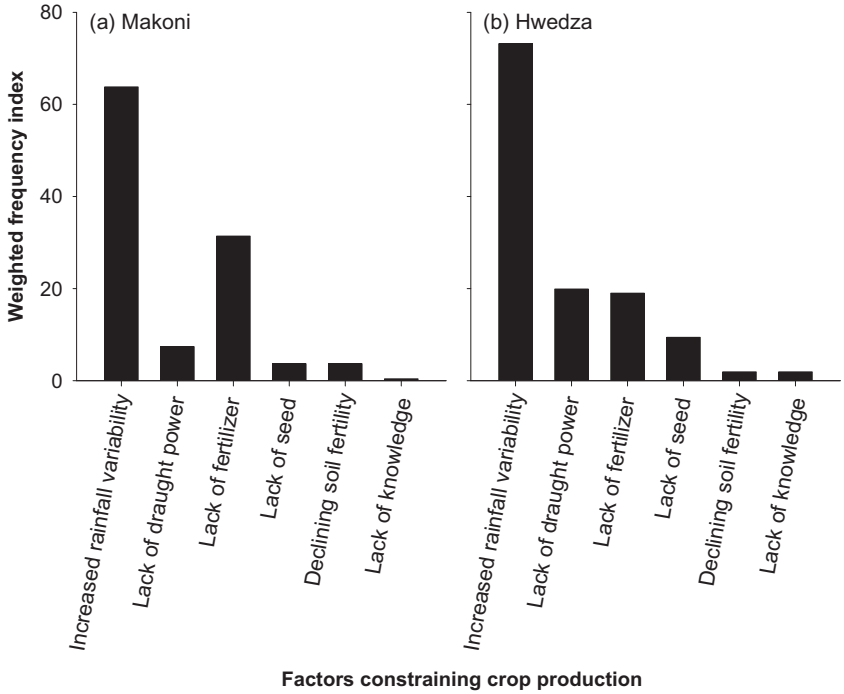

Fig. 4. Farmer ranking of main factors constraining crop production in (a) Makoni and (b) Hwedza, in Zimbabwe. Weighted index was calculated from frequency divided by rank, $n = 100$ in each site.

Table 5
Farmer ranking of prioritized options to reduce vulnerability to climate change and variability in Makoni and Hwedza in Zimbabwe (Rank +++++ is the most important and + is the least important per farmer resource category).

Site/farmer resource category	Prioritised options to reduce vulnerability to climate change and variability							
	Timely access to affordable fertilizers	Develop local input and out markets	Improved access to draught power	Improved management of poor soils	Need for appropriate production technologies e.g. crop cultivar/type	Enhance performance of learning and knowledge sharing platforms e.g. [a]LC	Need for local criteria to better target the most vulnerable households	Conservation of natural resources e.g. wild fruit trees
Makoni								
Resource-endowed	+++++	++++				+++	++	+
Intermediate	++++	+				+++	++	+++++
Resource-constrained	+++++	+++				++	+	++++
Hwedza								
Resource-endowed	+++++			++++	+++	++	+	
Intermediate	++++			+++	+	+++++	++	
Resource-constrained	+++++		++		+++		+	++++

[a] A learning centre (LC) is defined as a field-based, interactive platform for practical integration of local, conventional and emerging knowledge on superior agricultural innovations requiring promotion or farm-level adaptive testing to address complex problems by alliances of farmers, research and extension agencies, agro-service providers and other stakeholders (Mapfumo, 2009).

reported that fertilizer input was important for stabilizing yields in low rainfall years. Despite the importance of fertilizer, farmers, particularly the resource-constrained, often fail to access fertilizers due to prohibitive costs (Nyikahadzoi et al., 2012). Availability of cattle not only provides draught power, but was also identified as a major source of diversified and improved livelihoods among smallholders (Scoones, 1992). Timely access to draught power would allow farmers to plant in windows of favourable rainfall conditions. Draught power can be rented to other farmers and thereby provide household income. Livestock also provide manure, a key organic nutrient input for sustaining soil productivity. Livestock are a central means of concentrating nutrients within a farming system (Giller et al., 2006).

Lack of quality pastures and increased incidence of livestock pests and diseases were the main biophysical factors cited as affecting livestock production thereby increasing the sensitivity of cattle to droughts (Table 6). The high incidences of livestock diseases may have been caused by the dis-functioning of ectoparasites control dip tanks in the districts. This also led to the prices of vaccines becoming unaffordable (Chatikobo et al., 2013). The dis-functioning was caused by the economic meltdown and associated hyper-inflation that affected many smallholder farmers in Zimbabwe. Lack of quality pastures were caused by declining grazing areas due to land use change. Because of population pressure, new homesteads for young families have been established in areas traditionally designated for grazing. Reduced stover biomass, a key feed component at the end of the dry season, due to deteriorating crop production, has exacerbated shortages of cattle feed. Increased incidences of cattle diseases such as bovine dermatophilosis and inadequate grazing were also ranked as the major constraints to livestock production in north-western Zimbabwe (Chatikobo et al., 2013).

During the participatory diagnostic enquiry, it became apparent that farmers were variably dependent on relief aid, but many of the farmers were against the criteria used by food relief organisations to select the most vulnerable households (see Table 5). The problem was aggravated by non-involvement of local communities in the development of criteria for targeting the most vulnerable households. Tobaiwa (1993) reported that amounts of food aid received by the poorest households were considerably less than could be expected based on the amounts distributed, due to logistical and organisational constraints and inappropriate targeting. Farmers perceived that failure to inappropriately target the most vulnerable households would punish hard working farmers by rewarding the lazy ones. Consequently this creates conflicts between members of the same community and hence weaken the social capital. The weakening of social capital would affect the resilience of smallholder communities in the medium to long term because sharing of resources such as draught power and labour would also be affected. Farmers sometimes rely on government programmes such as 'food for work'. Traditionally the vulnerable households used to rely on social safety nets such as the *Zunde raMambo*, *Humwe* and kinship relationships (see Table 7). However such social safety nets have deteriorated in these case study communities mainly due to lack of policy and institutional support and non-involvement of local communities in the development of criteria for targeting the most vulnerable households (Mapfumo et al., 2013).

Table 6
Farmer identified adaptation options to climate change and variability and other stresses in Makoni and Hwedza.

Climate exposure characteristic	Impacted sub-system	Other factors affecting sub system	Adaptation options	Suggested key players
Increased rainfall variability	Crop production	Lack of access to fertilizers	Collective acquisition of fertilizers e.g. through farmer groups	Farmers, Agritex, Fertilizer companies
			Develop local input and output market channels	Farmers, researchers, agro-dealers, Agritex
		Lack of access to draught power	Revive the Humwe concept to assist farmers with limited access to draught power	Local leaders, farmers
		Lack of knowledge on climate change	Improve performance of learning and knowledge sharing platforms such as learning centres	Researchers, Agritex, farmers
Increased droughts	Livestock production	Lack of quality pastures	Selection of local cattle breeds that are adapted to local conditions	Researchers, extension and farmers
			Increased production of small ruminants that are more resistant to droughts than cattle e.g. goats	Livestock unit, extension, farmers
			Government facilitated collective acquisition of pastures from distant areas	
		Increased incidences of pests and diseases	Integrating locally available resources, medicinal herbs and synthetic vaccines	Veterinary services, extension, farmers
Extreme temperatures	Natural resources provisions	Deteriorating social safety nets	Reviving local institutions to strengthen social cohesion	Local leaders, farmers
			Involvement of the community to better target the most vulnerable households	Local leaders, farmers, food aid organisations, Rural District Council
		Land use change	Establish community woodlots and plant valuable indigenous trees at homesteads	Farmers, Environmental Management Agents, Rural District Council

Table 7
Farmer suggested options to assist the most vulnerable households in Makoni and Hwedza in Zimbabwe.

Resource-endowed	Intermediate	Resource-constrained
The most vulnerable households should organize themselves to work in groups	Collective ploughing, weeding and harvesting through *Humwe*[a]	Exchange labour for food (or cash) with wealthier households (maricho)
Every vulnerable household should have a Learning Centre	Mutual arrangements: households with no draught power should arrange with those with cattle to access draught power in time	Provision of food to the most vulnerable households
Resource-endowed farmers should ensure that the vulnerable households plant early by assisting them with draught power	Farmers without access to draught power should exchange labour for draught power	Resource-endowed farmers should ensure that the most vulnerable households plant early by assisting them with draught power
The local leaders should organize a Zunde raMambo[b] field for the most vulnerable households	The community leaders should tighten rules to reduce incidences of crop damage by straying animals	

[a] *Humwe* refers to a local custom in which a community collectively provides labour to a fellow farming household irrespective of wealth and social status, to hasten critical and time-bound farming operations such as ploughing, weeding and harvesting. The *Humwe* can be as a result of a distress call by the beneficiary member or a local leadership initiative within the context of a local social safety net systems. The host farmer provides food and beverages for energy to keep the moral, and as a token of appreciation to fellow farmers.

[b] *Zunde raMambo* is a traditional practice whereby the traditional leader, usually the chief, kept a strategic grain reserve that was intended to support the needy and vulnerable within the community such as orphans, the elderly, widows and the disabled. This food would also be used for village ceremonies and functions. The community provided labour and worked on a piece.

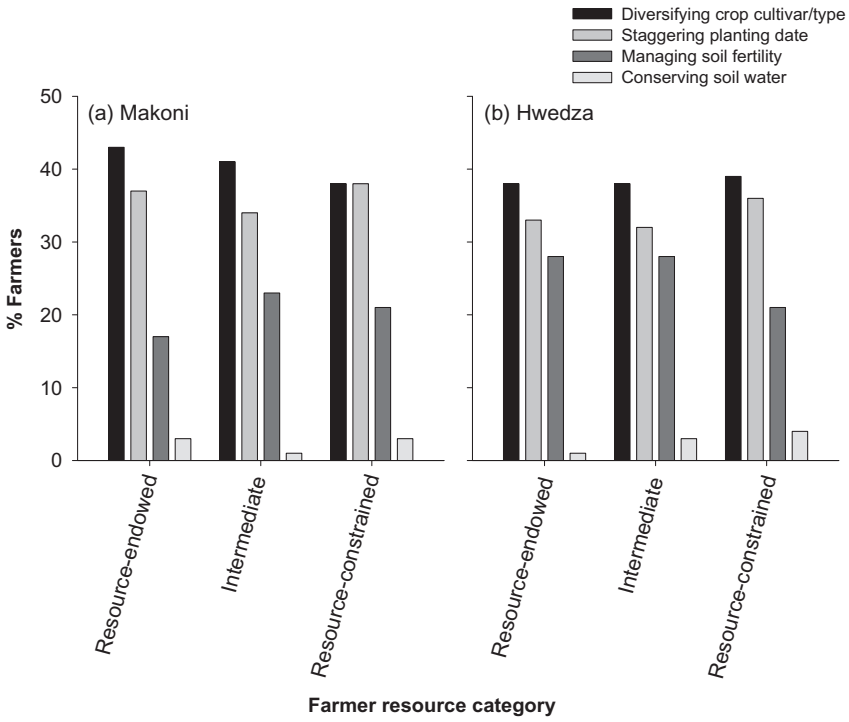

Fig. 5. Adaptation options suggested by farmers of different endowments, to stabilize yields in the face of climate variability and change in (a) Makoni and (b) Hwedza, in Zimbabwe.

The analysis of household vulnerability to climate variability and change shows a complex picture, and cannot be related simply to poverty. Both poor and wealthier households are vulnerable depending on the specific climatic exposure and resources at their disposal. In a another study, it was shown that because of diversified livelihood strategies, farmers who were using common pastureland for livestock production and were regarded as poor, were less vulnerable to droughts than private farms that were regarded as rich (Toni and Holanda, 2008). Furthermore, the vulnerabilities for the different households are intertwined because farmers depend on each other (see Table 7). Thus, alongside climate variability and possible climate change, farmers are also faced with other biophysical and socioeconomic constraints, that can exacerbate their vulnerability.

Risk management: adaptation options for different farmer resource groups to climate variability and change

To increase resilience of smallholder communities, adaptation options need to address both climatic risk, and other constraints. Farmers suggested various short, medium and long-term strategies, which we classified into tactical, operational and strategic adaptation options based of the concept of strategic farm management of De Koeijer et al. (2003). Diversifying crop cultivar/type, staggering planting date and managing soil fertility were identified as the major adaptation options to stabilize yields in the face of increased variable rainfall (Fig. 5). Collective farming action (i.e. working in groups) was suggested as a potential tactical adaptation option not only to access draught power, but also to acquire fertilizer in time and at a reduced cost (Table 6). Collective acquisition of fertilizers reduces transaction costs because farmers share the cost of transport and buy fertilizer at wholesale price. Similar adaptation options have also been suggested elsewhere in Africa (Milgroom and Giller, 2013; Rufino et al., 2013) and other regions [e.g. Fraser et al., 2008]. Luers (Luers, 2005) reported that soil fertility management reduced vulnerability of farmers to droughts.

Farmers suggested only few adaptation options for livestock production such as selection of local breeds that are adapted to harsh conditions such as drought (Table 6). Failure by farmers to identify diversified adaptation options for livestock suggests a major gap requiring both technical and policy intervention given that livelihoods of these smallholder farmers depend strongly on the interaction between cropping and livestock. For example farmers have relied on mixed breeds with no clear livestock improvement support in place. Crop production through crop residues provides feed for livestock, while livestock provide draught power and manure for crop production. Such linkages mean that any adaptation option designed for each sub-system will tend to increase the interaction between the two. Establishing community woodlots and planting indigenous fruit trees at homesteads was seen to be important to compensate for the decline of common woodlands (Table 6). Involvement of the community in better targeting the most vulnerable households was identified as critical to strengthen social safety nets.

Many farmers do not yet make use of these adaptation options, mainly due to the lack of resources such as fertilizers and draught power (Ajayi et al., 2007). Farmers suggested several key players that could strengthen their capacity to adopt these adaptation options (see Table 6).

Because many smallholder farmers in sub-Saharan Africa remain focused on ensuring their survival, or 'hanging in' Dorward (2009), it was not surprising that most of the adaptation options identified focused on changing farming management practices. Some literature suggests that stepping out of agriculture is actually the most robust adaptation option for farmers (Bryan et al., 2009), but this venture might be difficult for them because of limited opportunities elsewhere. Poverty would also constrain farmers to move out of agriculture (Dorward, 2009). Overall, however, it is clear that because farmers have different endowments and climate sensitivities, adaptation options should be tailored to their specific needs.

Conclusion

There was no simple one-to-one relationship between vulnerability and farmer resource endowment. Each part of the farming livelihood system was sensitive to a unique climatic exposure characteristic leading to differential vulnerability among households of the same community. Better targeting of the most vulnerable to climate variability and change therefore requires understanding of the prevailing climatic conditions rather than a focus solely on poor households to prevent other households from falling into a poverty trap. Various adaptation options including diversifying crop cultivar/type, staggering planting date, using fertilizer, selecting local cattle breeds and establishing community woodlots were suggested to reduce the impacts of climate variability and change. Whilst there was clarity on adaptation options for other sub-systems, suitable adaptation options for livestock production were less clear. This suggests a major gap requiring both technical and policy interventions given that livelihoods of smallholder farmers strongly depend on the interaction between cropping and livestock. Rebuilding the livestock herd and strengthening the social capital of the local communities, for example by facilitating formation of farmer learning groups, could reduce the vulnerability and increase the resilience of smallholder communities to climate variability and change. Because each sub-system of the farming system was vulnerable to either single or multiple climatic variables, policy needs to target complementary adaptation options outside agriculture to build robust and resilient Livelihood system.

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