Vulnerability and resilience of competing land-based livelihoods in south eastern Zimbabwe

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Vulnerability and resilience of competing land-based livelihoods in south eastern Zimbabwe

Chrispen Murungweni

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Abstract

Vulnerability and resilience have emerged as powerful analytical concepts in the study of socio-ecological systems. In this research these concepts are used to enhance our understanding of heterogeneous rural livelihoods in a semi-arid area on the western border of protected wildlife areas in Zimbabwe's southeast lowveld. The purpose of this thesis is to develop a methodological approach that helps understanding the vulnerability of rural livelihoods to change and relate this to adaptive mechanisms employed by people to cope with the resulting change. Although most households in the study area keep livestock, practice arable farming, and receive remittances, they differ in terms of their dependency on cattle, cropping, and non-farm and off-farm activities, especially in years of drought. Households most dependent on livestock – the cattle-based livelihood type – generally cope with hazards by selling cattle. Households of the crop-based livelihood type strive to spread the risk of crop failure by cropping across the landscape, ranging from flood plains to uplands on the interfluves. Households of the non-farm livelihood type rely for their survival on paid employment outside the study area, mostly of households' members working in South Africa. Fuzzy Cognitive Mapping (FCM) was used to assess the vulnerability of the three livelihood types to different hazards. The vulnerability analysis shows that policies relating to the permeability and/or enforcement of protected area boundaries can strongly aggravate the effects of other external influences, such as drought or climate change. To cope with drought-induced fodder shortages, people of cattle-based households have recently started to use *Neorautanenia amboensis* (Schinz). This tuber shrub, locally known as *Zhombwe*, is now saving many cattle from death in periods of drought, thus reducing livestock keeping households vulnerability to drought. This thesis shows the anthelmintic properties of *Zhombwe*; its distribution in the field was quantified. Crop experiments explored adaptive strategies which can be used by the households of the crop-based livelihood type to increase food self-sufficiency. Results show that by making better use of different landscape units in the area food production can be increased, both in good and bad rainfall years. By applying a method like FCM and by analysing quantitatively different options for increasing the resilience of the local households, this thesis shows that it is key to take into account the heterogeneity of rural households in an area, as adaption options differ strongly between them.

Key words: vulnerability; resilience; livelihood; drought; Great Limpopo Transfrontier Conservation Area; south eastern Zimbabwe.

Contents

Chapter 1

General introduction

1. Livelihoods in the domain of sustainability science

The vulnerability of coupled human-environment systems has become one of the central elements of sustainability research. 'Being focused on understanding complex local realities, livelihood approaches are an ideal entry point for participatory approaches to inquiry, with negotiated learning between local people and outsiders' (Scoones, 2009). Growing concern in 'sustainable science' led to the understanding of coupled human-environment systems as key to 'understanding dual objectives of satisfying societal demands while maintaining the life-support systems of the planet' (Turner *et al.*, 2003). Under the concept of 'a new sustainable science'(Walker *et al.*, 2004), attention is being drawn to such notions as robustness, vulnerability and risk because it is these characteristics of socio-ecological systems that determines peoples' ability to adapt to and benefit from change. Exploring coupled human-environment systems helps to reveal many dimensions of vulnerability (Turner *et al.*, 2003) but analysing complex systems is not an easy task. The development of social-ecological systems thinking since the late 1970s (Gunderson and Holling, 2002) provides a framework for understanding human-environment interactions but our comprehension of the complexity of such interactions is still in its exploratory phase (Folke, 2006). One of the major setbacks is the unavailability of appropriate tools capable of dealing with feedback mechanisms that are frequently, a characteristic of social-ecological systems. In this thesis, livelihoods at the 'edge' of a nature conservation area in a semi-arid environment in southern Africa were explored within the context of social ecological systems thinking. In my work, I follow the definition of livelihoods as the ways in which households make a living (Ellis and Biggs, 2001; Scoones, 2009).

1.2 Dry-land areas and food production

Global population is growing faster than food production (RS and NSA, 1992; Kendall and Pimentel, 1994). Global food production is seriously threatened by climate change (IPCC, 2002). Global poverty rates are falling but the number of people living in poverty in sub-Saharan Africa is increasing (Kundhlande, 2005). Despite increasing uncertainty that comes along with climate change, 268 million people live in dry land areas of Africa. Excluding deserts, dry lands cover 43% of Africa (UNEP, 1997). They are found between 63^{o}N and 55^{o}S of the equator (MA 2005) and include all areas with an aridity index less than 0.65 (UNEP, 1997). Aridity index is the long-term average of mean annual precipitation over mean annual evaporative demand, so it follows that water scarcity is an important characteristic of dry land areas. People in dry land Africa depend on maize, sorghum and millet for staple food, grain production of these crops is constrained by moisture stress (Dixon *et al.*, 2001). Climate change assessment data gives no relief to the plight of farming households either, for example, during last 100 yrs. the global mean surface temperature increased by 0.6^{o}C (Lean and Rind, 2009) and projections from 1990 to 2100 shows an increase in global mean annual temperature as ranging from 1.4 to 5.8^{o}C, and this will be accompanied by heat waves and changing precipitation patterns, with most arid and semi-arid areas becoming drier and increasing incidences of floods and droughts (MA, 2005). Water scarcity constraints primary production and nutrient cycling making dry land areas prone to desertification. Seasonality of precipitation is known to have dramatic impacts on vegetation life forms, diversity, sensitivity to invasion, and productivity of arid and semi-arid ecosystems. It is widely accepted that livelihoods in African dry lands are a major challenge to attainment of Millennium Development Goal number one – to eradicate extreme poverty and hunger. Therefore, considering semi-arid areas as important food production areas cannot be avoided.

1.3 Africa, the continent of technology failure

Failure of Africa to benefit from long-term research gains has been attributed to blanket recommendations that are often employed without properly understanding the diversity and context of African farming systems (Smaling *et al.*, 1996; Schnier *et al.*, 1997; de Rouw, 2004; Tittonell *et al.*, 2005; Tittonell *et al.*, 2006; Tittonell *et al.*, 2007; Ebanyat *et al.*, 2010). Most organisations funding agricultural development talk of poverty alleviation within the context of increased yield using improved germplasm that respond positively to good management practices and proper application of external inputs like fertilisers and pesticides. If it fails then blame the farmer! Or maybe equip the development agent with better skills to convince the farmer to adopt the technologies. We fail because we are stubborn with facts and realities. Worse still, farmers are always taken as 'final destination' of technology, their collective wisdom on judicious use of natural resources depending on situation is often not considered. Europe claims poor adoption of conservation farming to lack of appropriate technology for implementing it, but the African smallholder farmer and his single hoe is expected to bear conservation agriculture and implement it successfully. In an open letter signed by 816 people and Non-Governmental Organisations to the Director General of FAO dated 16 June 2004, it is written that:

'*If we have learned anything from the failures of the Green Revolution, it is that technological 'advances' in crop genetics for seeds that respond to external inputs go hand in hand with increased socio-economic polarization, rural and urban impoverishment, and greater food insecurity. The tragedy of the Green Revolution lies precisely in its narrow technological focus that ignored the far more important social* *and structural underpinnings of hunger. The technology strengthened the very structures that enforce hunger*'.

Examples of technologies developed elsewhere and unilaterally applied on farmers with failure are many. Many technological interventions link crop or livestock production to the biophysical environment, totally forgetting market, investment and policies on input supply systems. In African context, smallholder farmers' strategies are employed within and outside of the cropping system based on social organization, locally-specific knowledge and calculated risk-taking that influence yield. Improved understanding of the adaptive strategies employed in semi-arid areas and their impact on food production would enable us to identify opportunities for innovative design of agricultural systems technology and policy in the face of political, social and environmental changes (Stringer et al., 2009). Institutions (such as property rights) govern use of natural resources creating incentives for sustainable or unsustainable use. Institutions can be broadly defined to include habitualised behaviour and rules and norms that govern society as well as the more usual notion of formal institutions with memberships, constituencies and stakeholders (Adger, 2000). Institutions are central components linking social and ecological resilience. The role of institutions (just as the role of adaptive strategies by people) is usually ignored in traditional research, resulting in model outcomes that are too pessimistic (Mendelsohn and Dinar, 1999). Analysis of vulnerability of different social groups and the institutional architecture which determines resilience in the context of environmental change is an emerging research issue (Adger and Kelly, 1990). To understand more about livelihoods and their vulnerability of people to different hazards, a heterogeneous social-ecological system in semi-arid south east lowveld of Zimbabwe was studied.

1.4 New developments in semi-arid southern Africa

Dry-land areas of southern Africa are often earmarked for livestock and wildlife production (Vincent and Thomas, 1961; Dixon *et al.*, 2001; Cumming, 2005). With increases in catastrophic droughts, wildlife farming is increasingly becoming considered better than livestock. In Zimbabwe for example, there was a transformation of many cattle ranches into game ranches after the 1991-1992 drought. Increasing awareness on climate change has led to a global drive on conservation of natural resources in parks to merge with objectives of creating employment opportunities for local people through tourism related activities. In southern Africa, there are new initiatives to increase conservation while improving livelihoods in same locations. Thirteen Transfrontier areas are formalized to date in southern Africa. Our study area forms part of one of these Transfrontier conservation areas known as the Great

Limpopo Transfrontier Conservation Area (GLTFCA) (Figure 1). Work reported in this thesis focuses on one of the major Transfrontier parks in this region, The Great Limpopo Transfrontier Park (GLTP).

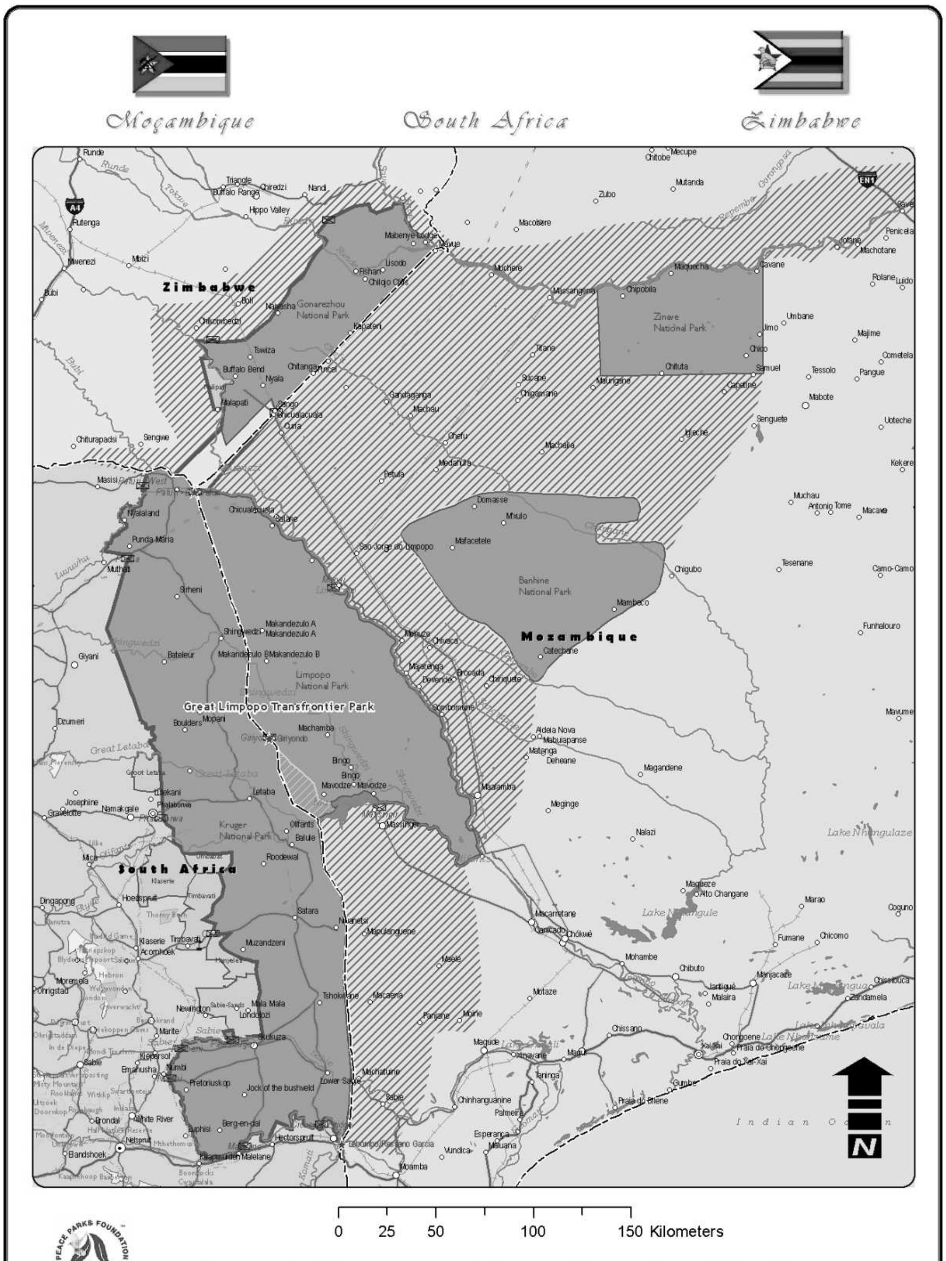


Figure 1: Protected ‘park’ areas (dark coloured - known as The Great Limpopo Transfrontier Park (GLTP)) and community areas (strip shaded), known as Transfrontier Conservation Area (TFCA), both combined forms the Great Limpopo Transfrontier Conservation Area (GLTFCA). Source: Peace Parks.

Key elements of the people-natural resource system of this region are shown in Figure 2 below.

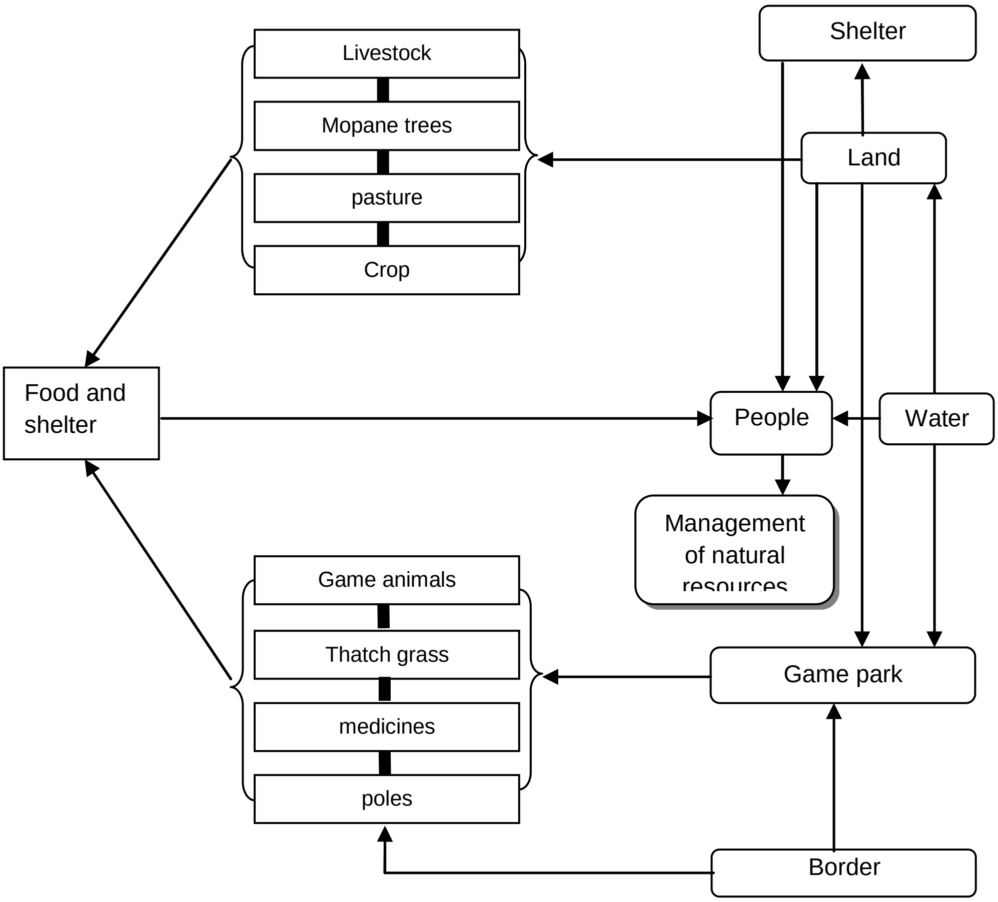


Figure 2: Key elements affecting management of natural resources in semi-arid south eastern Zimbabwe.

Recent efforts focused on management of the proposed 99,800 km^2 conservation area at ecosystem level under the theme of transboundary natural resources management program, a build-up to communal-based natural resource management program. The GLTFCA was formally established in November 2000 between Zimbabwe, South Africa and Mozambique. In 2001 a smaller area containing only the core protected areas was recognized as the Great Limpopo Transfrontier Park (GLTP) (Wolmer, 2003). A formal treaty for the transboundary area was signed in November 2002 as a first phase towards the wider, and reframed, Great Limpopo Transfrontier Conservation Area (GLTFCA), now including certain parts of communal land outside the GLTP. These included areas outside park are known as the Transfrontier Conservation Areas (TFCAs). The GLTFCA has potential to become one of the largest conservation areas in the world and can conserve the widest variety of wildlife on earth, with areas of great cultural and historical value: making it an area of global conservation significance (Katerere et al., 2001). Current debate is on how to include local people within the GLTFCA along with development initiatives targeted on increasing conservation of wild resources by strengthening tourism? These new initiatives creates uncertainty because there is a possibility for relocation of some people. Some stakeholders are worried about exclusion of communities and how these communities are expected to depend upon livelihood portfolios (ecotourism) that they have no experience with (Katerere et al., 2001). In reality, the general state of economic decline and political isolation of Zimbabwe has substantially reduced the potential for tourism.

The institutional framework driving the implementation of the GLTFCA in Zimbabwe is based on a three-tier system, the ministerial, joint management board and transboundary area local committees. The three-tier system was adopted to ensure representation of stakeholders at all levels. However, there are no village-level structures in place to facilitate dialogue amongst villagers and to enable information to flow from the villages through to the highest levels. At district level there is a steering committee (Public-Private-Partnerships), which has representation from all sectors meant to provide a platform for planning and even to start negotiations. It is helpful for planners to understand factors relating to resilience, and the basic resilience characteristics of the ecosystems for which they are responsible before embarking on such development (Colloff and Baldwin, 2010). Exploring current and future constraints and opportunities can lead to empowerment of communities and associated stakeholders on ways to cope better can be helpful (Cooper et al., 2008).

2. Objectives

The goal of this thesis was to contribute to the knowledge base needed for developing sustainable projects aimed to increase food security and reduce poverty of people living in semi-arid rural Africa. The purpose was to develop a methodological approach that helps understanding the vulnerability of rural livelihoods to change resulting from drought conditions, environmental factors like damage causing animals, and policy issues like crop breeding or conservation and relate this to adaptive mechanisms employed by people to cope with the resulting change. The outputs of this research include a tested tool that takes into account feedback mechanisms when analysing livelihood systems, hazards of importance to rural people living in semi-arid areas of southern Africa, vulnerability of main livelihoods to identified hazards as they are assessed in scenarios developed from knowledge of local people and their stakeholder, adaptive mechanisms employed by different households to cope with change, role of manure in semi-arid cropping systems, performance of different crop varieties in different landscape position of interest to farmers and opportunities available for people to improve on their coping capacity while improving household food security. Various activities were employed to make these outputs possible. These activities include interviews, surveys, livestock and crop experiments and modelling exercises. Specific objectives were:

1. To identify and describe and explain key elements and relationships of the main livelihood systems of semi-arid south east lowveld of Zimbabwe

2. To develop and apply a framework for analysing functioning of different livelihoods and their vulnerability to external changes

3. To explore factors determining resilience of main land-based livelihoods to change in the face of hazards

4. To reveal opportunities available for enhancing household food self-sufficiency at local level by assessing activities contributing to household food availability

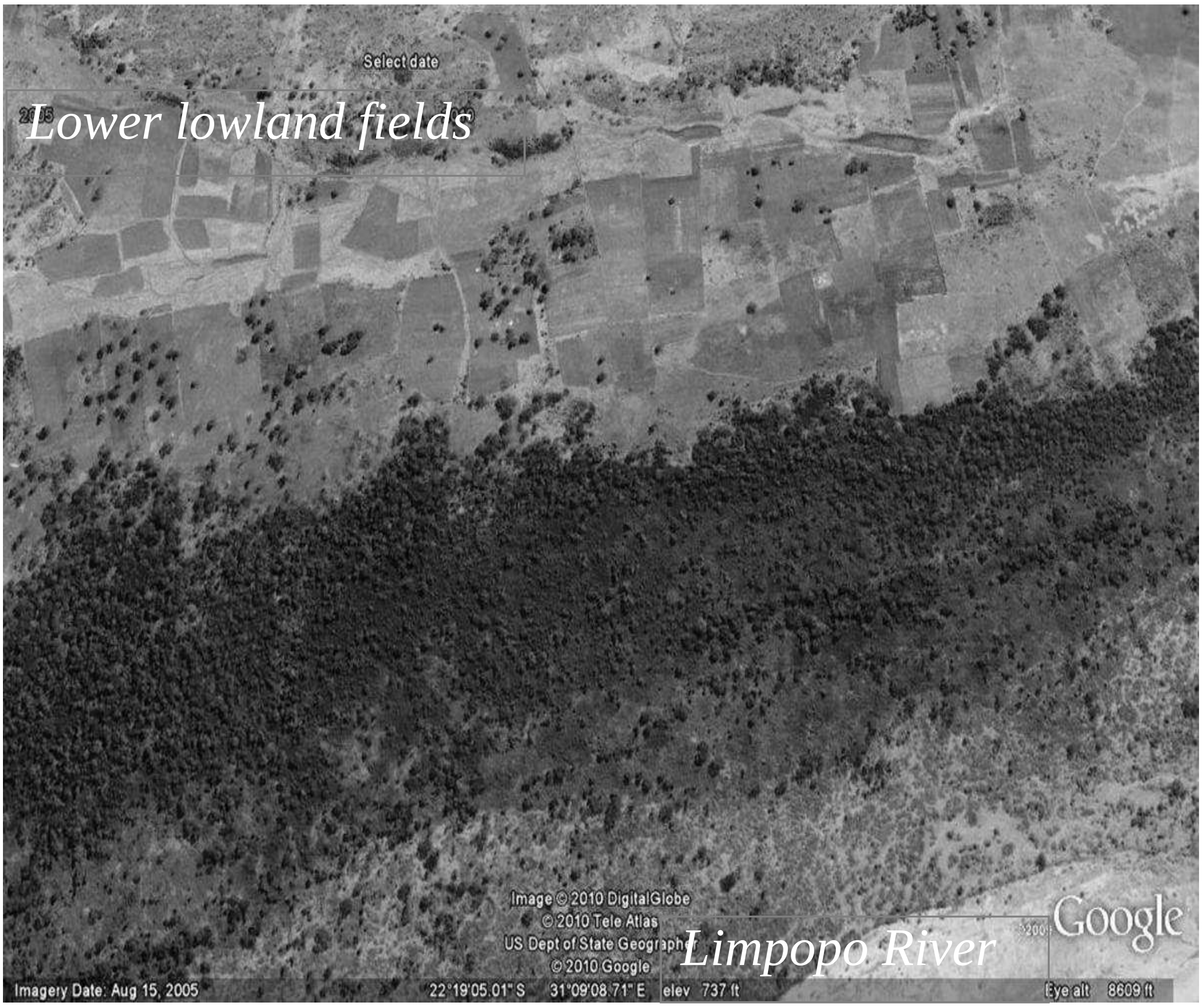
5. To determine implications of various strategies employed by people living in semi arid areas to alleviate poverty and food insecurity.

3. Thesis layout

Diversity in livelihoods results from differences in resources endowment and how people apply these resources in pursuance of a living. In the process of resource application, various feedback mechanisms result from coping strategies employed as a way to smoothen consumption and food access due to supply changes. In Chapter 2, various activities forming livelihood systems of people in the south-east lowveld of Zimbabwe are quantified per livelihood type. This was done in order to assess household food self sufficiency in different households between contrasting years (good and bad in terms of grain harvest). Other hazards exacerbating effects of drought are identified and described in this same chapter. Coping mechanisms employed by different people are explored (Chapter 2) and the outcome sets the foundation of vulnerability assessment of the different households in Chapter 3. Analysing complex livelihood systems is a challenge that requires tools capable of dealing with feedbacks. In Chapter 3, one such a tool (Fuzzy Cognitive Mapping) was employed and the setbacks and opportunities provided by this tool are discussed. Fuzzy Cognitive Mapping was used to explore main livelihoods of the rural semi-arid south east lowveld of Zimbabwe. Hazards faced by different households were used to build scenarios that made it possible to explore vulnerabilities of the identified main livelihoods to change. It is now common knowledge that cattle is the mainstay of land-based livelihoods in most semi-arid areas (Kinsey *et al.*, 1998; Cumming, 2005; Mavedzenge *et al.*, 2008) and almost all rural households do farming. Drought is the major threat to peoples' livelihood because many cattle die and crop production is hampered (Tobaiwa, 1993; Oba, 2001). 'Statistically in a semi-arid region, severe crop reductions caused by a dry spell occur l-2 out of 5 years, and total crop failure caused by annual droughts once every 10 years'(Rockstrom, 2000). In a drought year people lose crop, breeding stock, draught power and other products like milk. Despite livestock deaths in cattle, numbers are still increasing in communal areas of south east lowveld (Mavedzenge *et al.*, 2008). Vulnerability and resilience to drought was investigated for the cattle system in Chapter 4 and that for the crop system in Chapter 5. *Neorautanenia amboensis* (SCHINZ) – a tuber- is a newly discovered medicinal feed keeping cattle alive and survive drought. Some feed, medicinal and growth characteristics of this tuber are explored in Chapter 4. In Chapter 5, vulnerability and resilience of crop farmers is explored with the aid of two year crop experiments. Farmers spread risk by cropping drought tolerant varieties across different landscape positions without manure. Best fit practices are explored (Chapter 5) in order to access food production potential of the region (Chapter 6). In Chapter 6, hazards, vulnerability and adaptation to different hazards are discussed in a wider context (from household to livelihood to regional food security).

Chapter 2

Linking adaptive livelihood strategies to sustainable household food self-sufficiency in semi-arid rural Africa



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Abstract

Rural households in semi-arid areas of southern Africa are confronted with numerous hazards such as livestock predation, crop destruction by wild animals and, most notably, recurrent drought conditions. All of these are threatening their household food production. Transboundary natural resources management programmes that are currently being implemented, are considered to be additional threats to peoples' livelihoods in this region. We used the vulnerability approach to assess how these hazards affect food systems of different households in order to gain insight on how the affected people address critical questions of food self-sufficiency. Livelihood types were identified on the basis of interviews with representative members knowledgeable of the area; councillors, local teachers, extension workers and traditional leaders. They identified the main characteristics of livelihood diversity and these were used to construct an initial classification of rural livelihoods later refined by focus groups of household heads. Three types of livelihoods were identified – cattle based, crop-based and non-farm based livelihoods. Respondents to an initial explorative survey were classified into these three main livelihood types. We found that cattle-based households generally cope with hazards by selling cattle, but cattle face challenges from lack of feed and outbreak of disease which negatively affects markets. Crop-based households strive to spread the risk of crop failure by cropping across the landscape. Access to flood plains reduces the vulnerability of their food production system to drought but the implementation of Transfrontier conservation area threatens their access to flood plains. They cope with drought by relying on food aid distributions. Non-farm households rely for their survival on paid employment outside the study area, mostly of households' members working in South Africa, and they fear more restrictions at international borders. We conclude that vulnerability concepts bring more insights to manifestations of hazards; prior disaggregation of systems facilitates process. Factors aggravating effects of hazards are specific to the different household types.

Keywords: Risk; hazards; food self-sufficiency; transboundary natural resources; rural livelihoods; Adaptive strategies.

1. Introduction

Vulnerability is a useful entry point to assess people's needs in terms of adaptation or improvements in their ability to cope with existing threats (Adger *et al.*, 2004a). Current vulnerability, determined by past adaptation and the current availability of coping options, provides a baseline from which a system's future vulnerability will evolve (Adger *et al.*, 2004b). Understanding the trajectory of vulnerability from knowledge of current adaptive capacity helps in selecting appropriate parts of the system to enhance in order to increase the resilience of people to undesirable change. Current predictions of vulnerability to climate variability often appear to be too pessimistic (Dyson, 1999) because they do not consider learning and adaptation (Folke *et al.*, 2002; Walker and Salt, 2006). In addition, such predictions tend to ignore positive effects of climate change such as the powerful fertilizing effect of carbon dioxide that can increase yield in some areas (Mendelsohn and Dinar, 1999; Eldridge, 2002).

In semi-arid areas, vulnerability due to climate variability is poorly understood because adaptive strategies employed by people are often excluded (Simelton *et al.*, 2009; Easdale and Rosso, 2010). Understanding adaptive strategies results in the prospects for the future looking better than speculated (Dyson, 1999), because by enhancing different mitigating factors (some of them non-agricultural), climate change will not increase poverty levels dramatically as is currently predicted for semi-arid areas. Adaptive strategies are site specific (Osbahr *et al.*, 2010), they depend on available resources, knowledge and experiences, social and institutional organisation in addition to the nature of hazard. In semi-arid areas drought is the main component of climate variability. Drought affects many more people than any other natural disaster (Wilhite, 2000). By looking at climate variability in terms of what changes in peoples' food systems and what people do to cope with these changes enables us to understand the resilience of social ecological systems to climatic change (Adger, 2003). In this paper, adaptation will be defined as the changes people make in response to a changing environment, within a defined response space.

With increasing climate variability due to climate change, predictions are that poverty will increase in semi-arid Africa. Looking at food availability from the perspective of food self-sufficiency as an explicit policy objective by national governments has normally been criticized by economists as an unnecessarily costly way of meeting national food needs (Jayne and Rukuni, 1993). However, pursuing food self-sufficiency becomes a sensible strategy where food markets are missing or failing as often is the case in the poor semi-arid rural areas of southern Africa (Devereux, 2009;

Rufino *et al.*, 2009). In order to understand the state of household food security better, adaptive mechanisms employed by different people will be explored.

Studies on adaptive strategies have been carried e.g. Mendelsohn and Dinar (1999); Adger, (2003); Coles and Scott (2009) but generally fail to consider diversity among populations. However, as Reidsma and Ewert (2008) demonstrated, diverse farm management strategies can be important in reducing the responsiveness of a region to climate variability. When diversity is acknowledged, some form of classification makes sense in order to effectively understand a system. This study is on the effects of climate variability and other environmental hazards on vulnerability. It builds on people's own classification. We studied adaptation to climate variability at a scale of livelihood type, considering a household as the unit of analysis. In order to understand the coping capacity of different people, we explored change in contribution by different sources to livelihood in a good and in a bad year. Such an assessment reveals opportunities available for enhancing household food self-sufficiency. The aim of this work was to explore diversity in order to understand adaptive livelihood strategies employed by people in semi-arid areas for the purpose of evaluating impact of these strategies on household food self-sufficiency. Our specific objectives were to quantify the contribution of different livelihood components to household food self-sufficiency, and to explore coping strategies employed by households of different livelihood types during bad years in relation to food self-sufficiency.

2. Materials and methods

2.1 Study area

This research was carried out in rural areas forming part of the Great Limpopo Transfrontier Conservation Area (GLTFCA) in the south-east lowveld of Zimbabwe. The GLTFCA is one of the 14 such areas in southern Africa which strive to combine resource use and conservation.

2.2 Data gathering

A household survey was carried out in four wards located on the south-western side of Gonarezhou national park in the south-east lowveld of Zimbabwe (Figure 1). A multi-stage sampling procedure was used, based on a three-stage design with four ward segments, eight villages per ward and twenty households per village. Villages were initially listed according to their proximity to national park.

Closeness to the park was defined as villages with households benefiting from the communal area management programme for indigenous resources (CAMPFIRE) which is a local community based natural resource management programme (CBNRM).

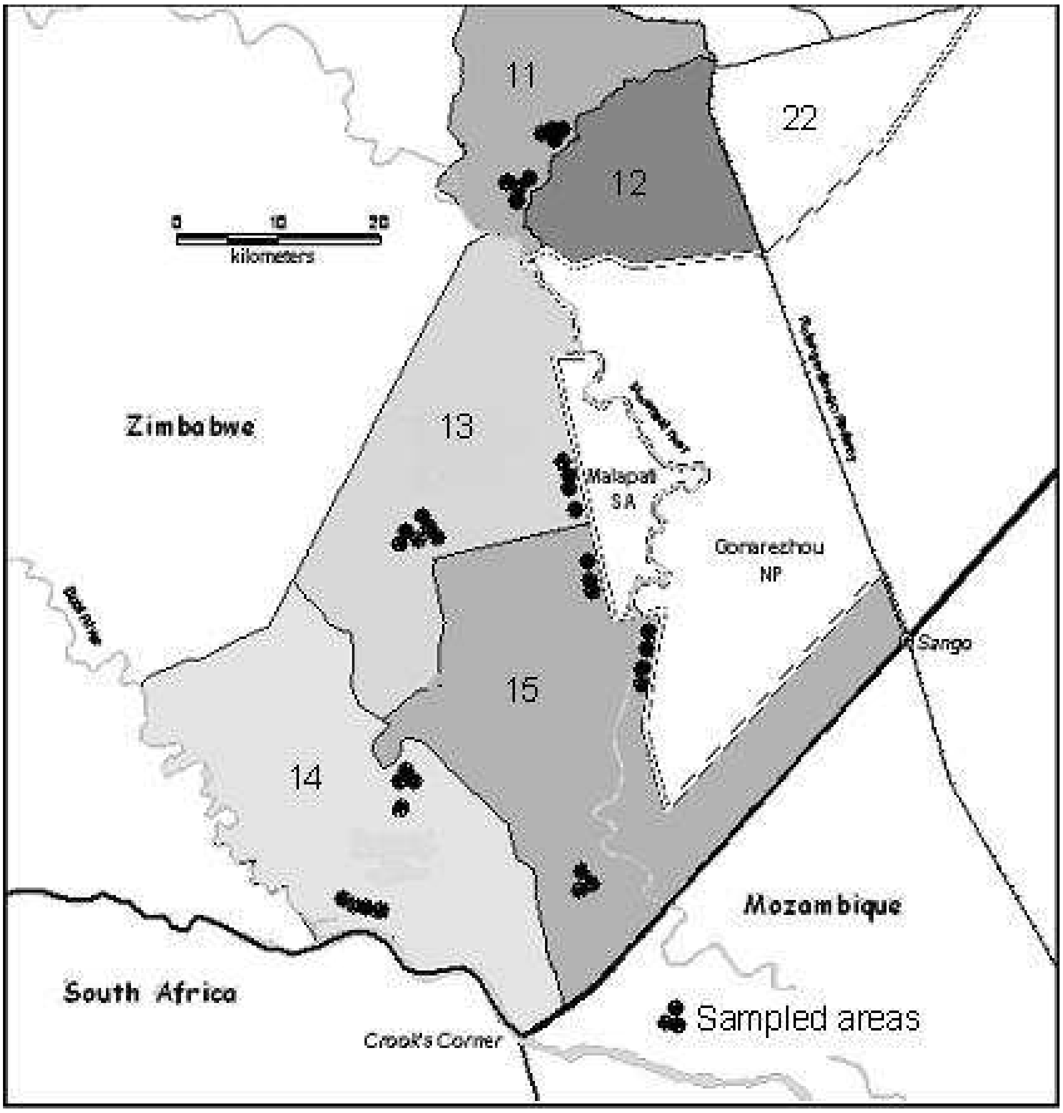


Figure 1: Rural areas (Wards 11, 13, 14 and 15) surrounding Gonarezhou National Park and within the Great Limpopo Transfrontier Conservation Area in the south east lowveld of Zimbabwe.

This close-far separation defined as beneficiaries and non-beneficiaries of CAMPFIRE was informed by land-use planners who use the same classification as they consider villages close to park to be worse affected by wildlife than those away. However, communities further away from the park – non-beneficiaries of CAMPFIRE – claim that they are affected by wildlife in the same way as those living close to the park. Household heads to be interviewed were randomly selected from household lists of the randomly selected villages. A household was defined as all people living in the same compound, contributing and/or making decisions on food and income. Data were collected on household characteristics, household assets, livelihood activities, hazards, livestock management, crop harvest (good and bad year), food self-sufficiency and coping mechanisms in bad years.

Livelihood types were identified on the basis of: (1) interviews with locally residing people deemed knowledgeable about the livelihoods of people in the area, such as councilors, local teachers, extension workers, traditional leaders, etc. The main defining characteristics of livelihood diversity they identified were used to construct an initial classification of livelihoods. (2) This initial classification was refined during group interviews with household heads in focus-group meetings. (3) Three types of livelihoods were thus identified – cattle based, crop-based and non-farm based livelihoods – and respondents to an initial explorative survey (n = 156) were classified into these three main livelihood types. This livelihood classification will be used throughout this study. The surveyed households were distributed as follows: 12% of all households are cattle-based, 41% are crop-based and 47% are non-farm based.

2.3 Data analysis

Quantitative data were analysed using non-parametric tests in order to determine level of importance among the eight activities defining farmers' livelihood systems. Where differences were observed, mean separation was done pair-wise controlling for Type 1 error using the Bonferroni approach in the multtest procedure of SAS 9.2 (SAS, 2008). The Rao-Scott modified Chi-square test was applied to analyse multi-response qualitative survey data using the design correction form that uses the proportion estimates. The design effect for an estimate is the ratio of the actual variance (estimated based on the sample design) to the variance of a simple random sample with the same number of observations.

3. Results

Analyses showed no differences between people living close to the park and those living further away in the way they are affected by wildlife (results not presented). This result is in agreement with local people's claim that there is no distance-related difference in how people are affected by wildlife, and this finding is contrary to the current method used by policy makers to define the beneficiaries of the CBNRM programme in the south east lowveld. The findings presented here do, therefore, not distinguish on the basis of the variable 'distance from the park'.

3.1 Demography and wealth distribution

Informants described six age categories following major functions particular to a certain age group. Children up to five years of age do not do any work. The age group 6 to 18 is school-going age whose labour is available. The 19 to 30 age group is made up of newly married people, mostly staying with their parents. Their livelihood decisions are largely influenced by the parents of newly wedded husband, and they are still part of the pool of labour in those parents' households. The 31 to 40 age group consists mostly of married couples now living on their own. They are in what may be typified as the resource accumulation phase, and most are independent from parents. The 41 to 60 age group is made up of settled couples that have the additional responsibility of paying school fees for school-going children of themselves and possibly, younger siblings and nephews and nieces. The above 60 age group is defined as 'the elderly', since sixty is the retirement age in Zimbabwe.

The age distribution of household heads of the different type of livelihoods is shown in Table 1. Cattle acquisition is a long-term investment reflected by stability that comes with age as reflected in Table 1. Households of the cattle-based livelihood type are only headed by people above 40 years of age.

Table 1: Age distribution of household heads in different livelihood type by age group.

	(n)	up to 18 years	19 - 40 years	41 - 60 years	Above 60 years	Total (%)
Cattle based	19	0.00	0.00	73.8	26.2	100
Crop based	64	3.20	20.2	64.1	12.4	100
Non-Farm based	73	1.50	43.8	47.9	6.80	100
Total	156	1.90 (1.1)	28.8 (3.6)	57.7 (4)	11.5 (2.6)	100

The sex-age distribution in households of the cattle-based livelihood type is expanded at the top and boys aged from 6 to 18 form the largest proportion (Figure *2*). As the total number of households of the cattle-based livelihood type in the sample was relatively small, this could have contributed to the overall structure of the population pyramid. Household heads of the crop-based livelihood type are mainly within the 41 to 60 age group and the overall shape of the pyramid is close to being symmetrical (though less women than men).

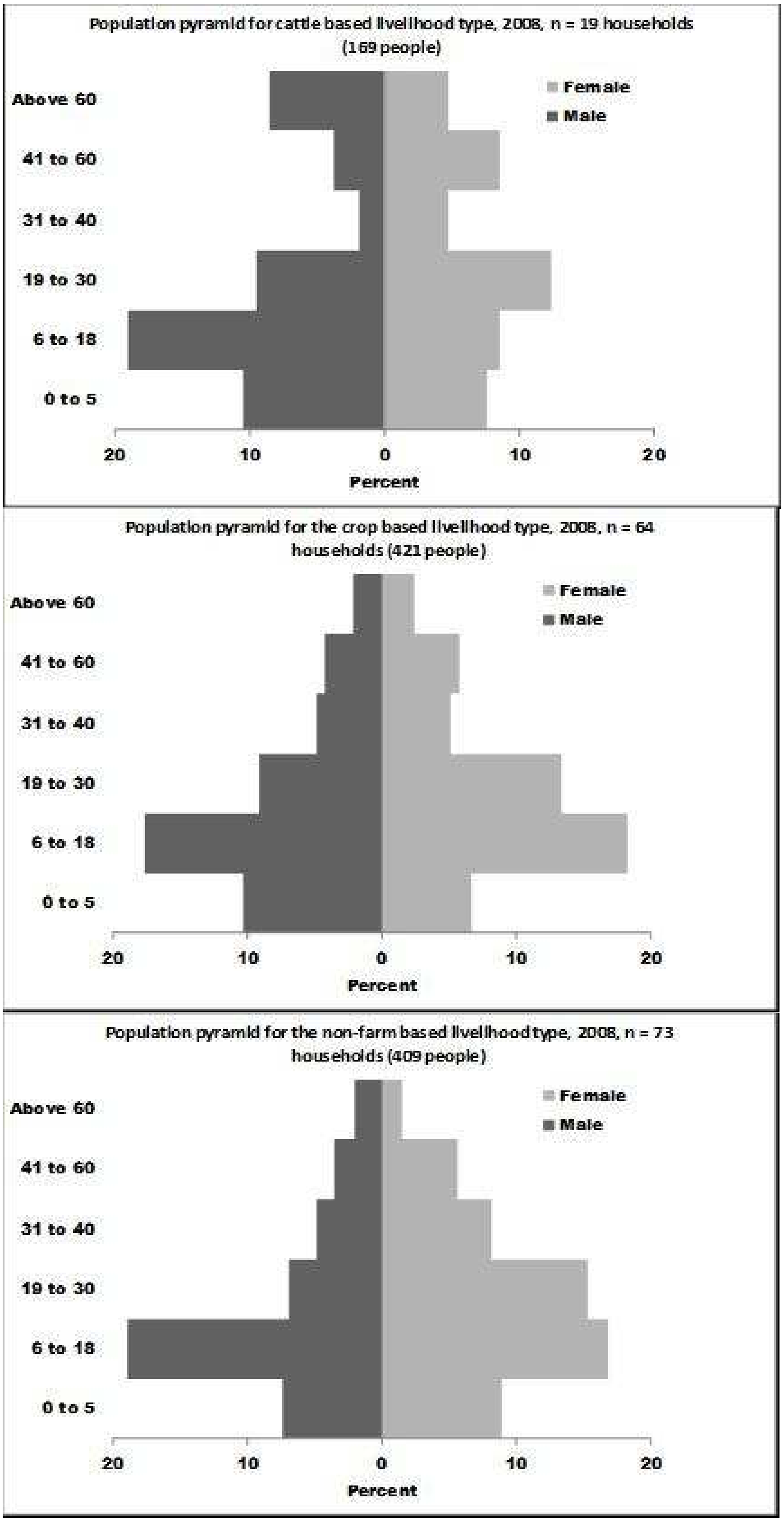


Figure 2: Population pyramids of main livelihood types in the south-east lowveld of Zimbabwe

Household heads of the non-farm livelihood type are spread over a wider age bracket from 19 and 60 years (see Table 2). There are far much less men than women especially so for the 19 to 60 age group (see Figure 2). On average household heads of the cattle-based livelihood type have 1.8 (SD = 1.3) wives, while household heads of crop-based and non-farm based livelihood types have 1.3 (SD = 0.6) and 1.2 (SD = 0.5) wives, respectively.

3.2 Household Assets and their distribution

On average, the cropping land of households of the cattle-based livelihood type is 7.5 ha (SD = 1.3). Households of the crop-based and non-farm livelihood types have land areas of size 6.5 ha (SD = 1.4) and 6.3 ha (SD = 1.4), respectively. Livestock plays an important role in the study area; cattle are a source of draught power, a source of instant cash, and a source for bride wealth payments. Donkeys are used for transport, while sheep, goats and chicken are sold for cash or bartered for food or other necessities. The distribution of livestock among households belonging to different livelihood types is shown in Figure 3 below.

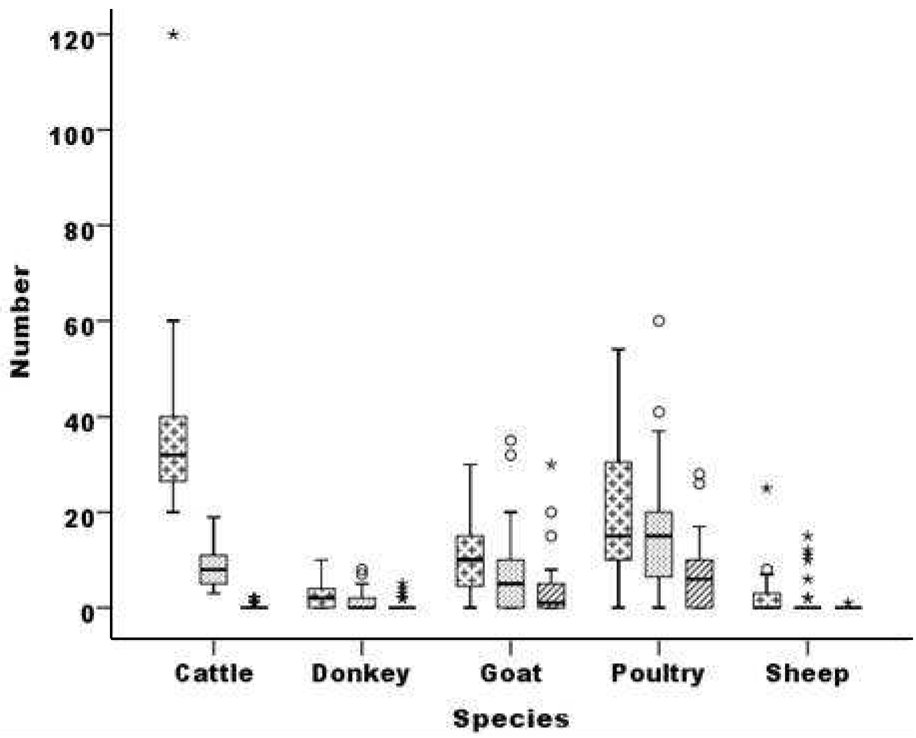


Figure 3: Number of livestock in the main livelihood types for people living in the semi-arid south east lowveld of Zimbabwe.

Households of the cattle-based livelihood type own the greater proportion of cattle and goats. They are well-endowed with farming implements (Table 2). The plough is the most important asset even for households of the non-farm type. Scotch-carts and wheel barrows are used when collecting food from the field and are also important for taking produce for sell at their monthly organised local markets.

Table 2: Ownership (%) of farming assets by people of different livelihood types in the south-east lowveld of Zimbabwe.

	Frequency (N)	Plough	Cultivator	Wheel barrow	Scotch-cart	Handling pen	Granary
Cattle-based	19	94.3	58.2	78.7	89.3	78.7	94.3
Crop-based	64	89.0	12.4	62.4	39.0	7.80	70.2
Non-farm based	73	50.6	0.00	37.0	10.9	1.30	38.2
Total	156	71.8	12.2	52.6	32.1	13.5	58.3

3.3 Major activities contributing to livelihood

People in the south-east lowveld of Zimbabwe diversify their livelihoods basically within the eight activities as represented in Table 3 below and described in Table 4. These activities were identified in the survey data (n=156) and confirmed by interviews with informants. It was difficult to separate cross-border activities from non-farm activities. Non-farm activities can be both on-farm and off-farm, and include (among other things) trading outside the locality but within Zimbabwe, Often such activities are combined with or linked to cross-border activities such as trade and migration.

Table 3: Proportional contribution of different livelihood activities to household food self-sufficiency in rural south-east lowveld of Zimbabwe.

	Cattle-based		Crop-based		Non-farm based	
	Good year	Bad year	Good year	Bad year	Good Year	Bad Year
Activity						
Livestock farming	41.4	56.8	30.0	22.9	16.4	16.2
Crop Farming	38.2	12.6	47.6	12.9	41.2	10.1
Outside farm activities	5.30	7.70	8.90	14.0	18.4	24.3
Remittances	7.00	10.2	5.20	13.8	10.1	14.1
Gardening	5.60	9.50	6.40	12.4	10.6	10.5
Cross-border	2.50	2.50	0.30	5.70	1.00	10.0
Donor assistance	0.00	0.70	0.90	17.4	1.50	12.3
Wild-fruit collection	0.00	0.00	0.70	0.90	0.80	2.50

In a good rainfall year (that is, well distributed rainfall), at least 75% of food in households of the cattle-based and crop-based livelihood type comes from two activities and from three activities in households of the non-farm livelihood type (see Table 3). In a bad rainfall year, at least 75% of the food in the cattle-based livelihoods comes from three activities, and from at least five activities in households of the crop-based and non-farm livelihood types.

Table 4: Description of activities contributing to livelihoods of people in the south-east lowveld of Zimbabwe.

Activity	**Description**
Livestock	Include cattle, donkeys, goats, sheep and fowl. Cattle help with timely ploughing and are a source of cash and food for cattle based households. In a good year, households of the Crop-based type sell goats and chickens at the local shows, in a bad year they sell in Mozambique. Most non-farm households borrow cattle for draught power and milk. Households of the non-farm type trade livestock in Mozambique. They also link prospective local livestock sellers to buyers in Mozambique.
Crop farming	Involve grain production for household food with extra being exchanged for livestock. Variability of crop production within same area is appreciated because it enables internal trade in livestock and food. In a bad year, people from non-farm households source for food from nearby towns like Beitbridge, Chiredzi and further away towns like Masvingo in exchange with baskets, beer and mopane worm. The grain will be exchanged for livestock at the local markets; the livestock will be sold for more cash in Mozambique.
Outside farm	Brick molding, fishing, beer brewing, mopane worm harvesting, art and crafts making, trading products and off-farm employment within Zimbabwe.
Remittances	Money sent to family by relatives living and working outside the study area. Most of this money comes from relatives working in South Africa and Mozambique.
Garden	An off-season activity done from April to November. Vegetables and Maize are consumed as food in household or sold at nearby townships for cash. In bad years, maize is left to dry and kept to supplement household grain.
Cross border	Seasonal work in South Africa and Mozambique, bringing products from outside borders to sell in Zimbabwe.
Donor	Food and seed packages from donors.
Wild fruit	People living close to Limpopo river harvest fruits along a band of fruit trees called '*Pfungwe*', found within 5 km of the Limpopo river in Sengwe ward 14. People in ward 15 also value fruits for food in a bad year

3.5 Impact of Drought – the major hazard

Current food production in the south-east lowveld do not meet household food needs levels for the larger part of the population (Figure 4).

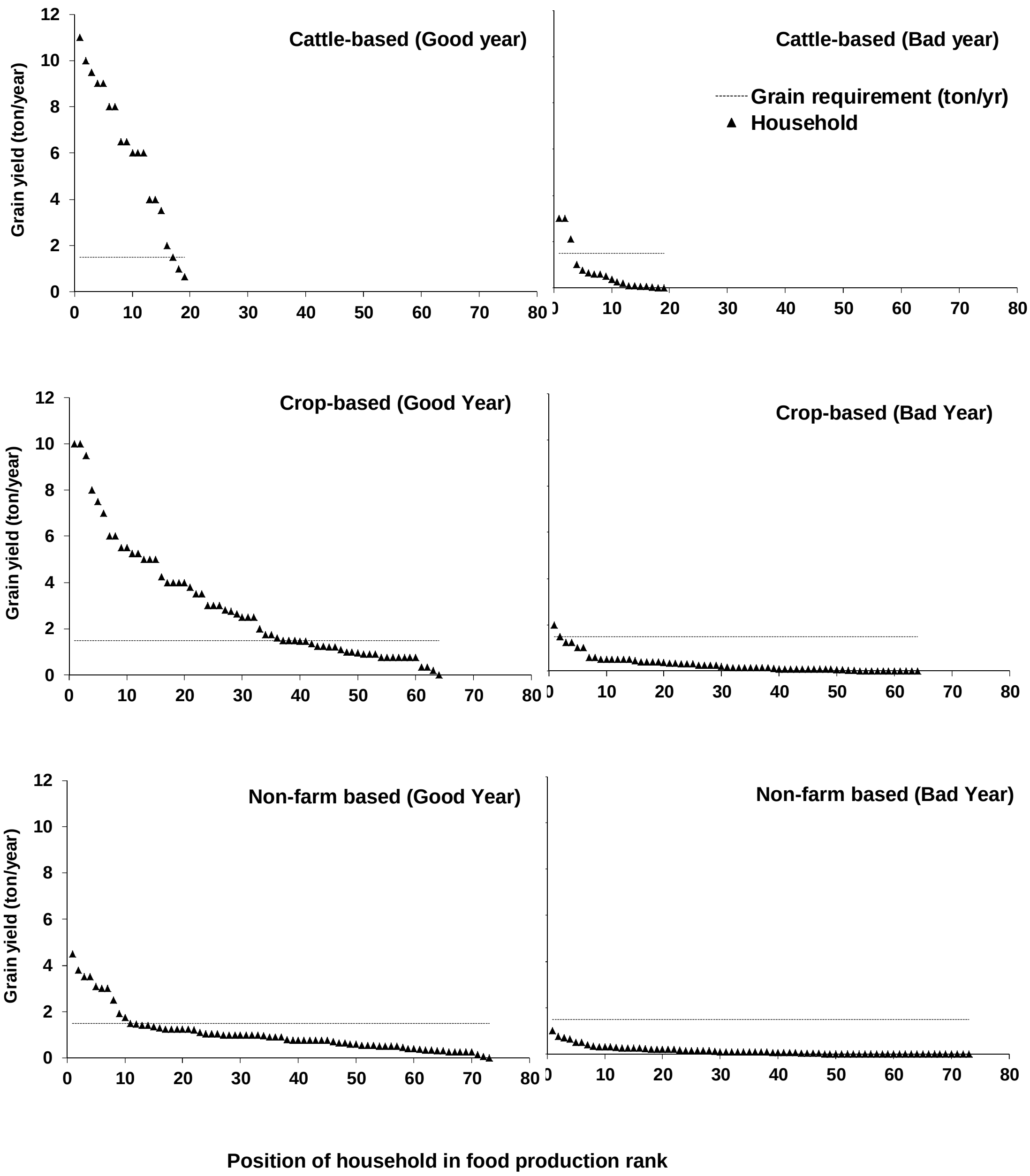


Figure 4: State of food availability (grain yield – ton/year) by household in cattle-based (n = 19), crop-based (n = 64) and non-farm-based (n = 73) livelihood types. A household of 6 people needs 1.5 ton/year of grain.

The situation is worse in bad rainfall (distribution) years. The survey data shows that bad years occur 6.7 (SD = 2.2) years in every 10 years (i.e. 2 times every 3 years). Survey data also shows that the average harvest among all households lasts less than a year, i.e. 0.93 (SD = 0.59) years, making multiple year saving of food uncommon. Current local food production is insufficient for the whole population of the south-east lowveld. Although households of the cattle-based livelihood type are relatively more food secure than households of the crop-based and non-farm livelihood types, only 12% of the south-east lowveld population are cattle-based. During bad years, the contribution of livestock to food availability in households of the cattle-based livelihood type increases significantly ($Z = 3.5$, $P < 0.001$) in order to complement the significant loss ($Z = 3.9$, $P < 0.001$) in crop production (Figure 5).

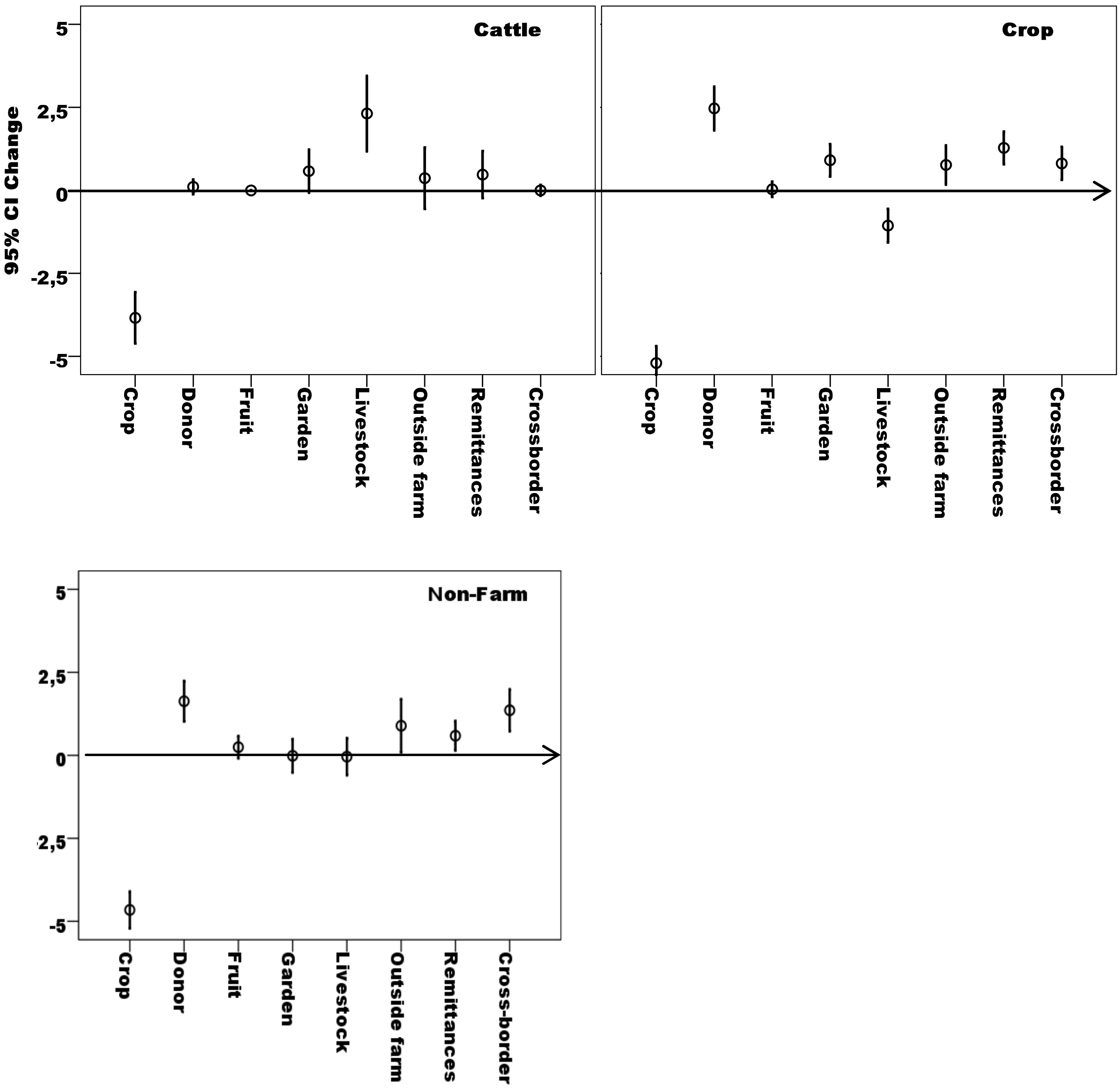


Figure 5: Confidence interval (CI) changes in contribution from good to bad year, by different household activities to total household food in different households of the three main livelihood types in the south-east lowveld of Zimbabwe assuming a livelihood to be a total of 15 food value points.

Table 5: Adaptive strategies employed by rural people to ensure household food self-sufficiency in semi-arid south east Zimbabwe.

Hazard	Adaptive strategy	Cattle-based households	Crop-based households	Non-farm based households
Drought	Flexible cropping strategy	Prepare land in time and dry plant sorghum. They also crop relatively large upland fields (mean 7.5 ha). They substitute part of sorghum with maize when season promises to be good in rain (This happens after receiving two good rains within a space of two weeks in December)	Spread cropping evenly across different landscape positions. They complement dry-land cropping with 1 ha plots in various irrigation schemes across study area. The 1 ha irrigation plots are used for growing vegetables and maize corn to sell for cash in a good year, for growing maize for grain in a bad year	Crop mainly in vlei areas with fields usually fenced as gardens, average size 1.3 ha. Most dig wells or have boreholes in these gardens to irrigate part of crop in order to reduce excessive moisture stress at critical plan growth stage. They intensify their cropping system
	Diversified cropping system	Grow both hybrid and open pollinated varieties of maize, short and medium season varieties of sorghum. They also grow sorghum varieties sponsored by national breweries for cash. Smaller crops like watermelon, cowpea, pumpkin and cucumber are intercropped with maize and sorghum. Sweet sorghum and groundnut are allocated about 0.5 ha each.	Grow mostly open pollinated local variety of maize (known as Gopane) as well as short and medium season varieties of sorghum. They grow sorghum in drier landscape positions and maize in wetter areas. Smaller crops like watermelon, cowpea, pumpkin and cucumber are intercropped with maize and sorghum. Sweet sorghum and groundnut are allocated about 0.5 ha each.	Grow mostly open pollinated local variety of maize and some hybrids like ZM 513. They also mix sorghum varieties. They have relatively less number of different crops in their fields.
	Broader networks of seed systems	Store seed from previous harvest and buy hybrid seed developed for drier areas (SC 513 in most cases). In a bad year they buy seed imported from South Africa/Mozambique at local market	Store seed from previous harvest. After a drought year, they are offered seed by donors or they buy seed from non-farm based households	Buy seed from Mozambique and South Africa
	Multiple year grain saving in the form of grain and of livestock	Harvest grain that lasts 1.5 yr (SD = 1.2 yrs) in a good year. They preserve grain in large granaries using grain preserving chemicals	Harvest grain that lasts 1 yr (SD = 0.5 yrs) in a good year. They increase their grain stores by working for grain at cattle farmers fields. Grain in excess of household's annual needs is exchanged for livestock. The livestock will be used to source for grain in a bad year	Buy grain. Grain lasts 0.8 yr (SD = 0.4 yrs) in a good year

Extension of Table 5

	Migrating with cattle to areas with grazing/springs, redistributing cattle among the poor (kuronzera)	Migrate with cattle to faraway uninhabited vast grazing places for grazing (and water). Many households offer cattle to poorer households for them to look after while using them	Use Zhombwe for ruminant livestock feed, some take their cattle to Mopane woodlands where ruminant livestock would survive on dry Mopane leaves. Some people living close to the park 'illegally' graze their livestock inside park	Graze livestock along gardens and wetter areas close to their homes
Unreliable Markets	Locally organised monthly 'shows', held in each ward in rotation during last week of every month. 'Illegal' cross border (to Mozambique) livestock sales	Exchange cattle for grain at local markets (1 beast for 2.5 tons in a good year and for as low as 600 kg for a beast in a bad year), If they want more money they sale cattle in Mozambique for cash between USD 700 and USD1 200 per beast depending on size	Sell art and craft or exchange these items for food at local markets, during a drought they exchange art and craft for food in nearby towns (Chiredzi, Masvingo and Beitbridge). Some brew beer and make ilala palm wine for sale. Some mould bricks and sell firewood also	Exchange clothes (bought in South Africa and Mozambique) with grain, chickens and small ruminants which they then sell in Mozambique and South Africa. They link cattle households in Zimbabwe to cattle buyers in Mozambique
Damage causing animals and thefts	Increase security measures	Hyenas, crocodiles and lions are their main problem. Those close to the park herd their livestock and pen them in kraals. They make special type of kraals using tall poles with sharp tops pulled close together. They pen animals in the night even though it reduces grazing time	Elephants and birds are the major problem. They feed on crop during harvest. People sleep in fields and use metallic objects to create noise that scares away the elephants. They stay in fields also to scare away birds, some use long shiny tape (2cm thick) around fields. Some plant red sorghum	Buffalos are their main worry. They encounter buffalos during times they cross international borders. Most have specific 'safe' routes that they use to avoid contact with wild life. During travel, they make fire in the evening to scare wild animals
Livestock diseases	Traditional medicines, donors and dip-tank committees	They have functional dip-tank committees who work closely with local veterinary services on which medicines to buy, when and to use them. A disease that results in many deaths of livestock is what farmers consider most important. Lumpy skin is considered more important than foot and mouth but foot and mouth is more widespread than Lumpy skin.	They use mainly traditional medicines, the park acts as a preserved area for these medicines (for those living closer to parks). They benefit from donors and research organisations like CIRAD which provide them with dipping chemicals and vaccines	Most households don't own cattle; they are keeping other people's cattle in return for milking and draught power. If the cattle owner asks for assistance, the recipient of cattle usually gets a heifer every year as payment.

Households of the cattle-based livelihood type increase cattle sales, while households of the other livelihood types sell small stock and chicken to survive. As selling cattle results in larger sums of money, the sale of cattle attracts better deals in grain procurement. In 2008, cattle prices ranged between 400-1000 US dollars, depending on size. Cattle in the south-east lowveld have a large frame, often Brahman crossbreeds and average mature weight of 400 kg. In a drought year households of the cattle-based livelihood type make use of 2 (±1) cattle (either selling of exchanging with food) to alleviate drought effects.

Households of the crop-based livelihood type significantly increase cross border ($Z = 3.2$, $P < 0.001$), remittances ($Z = 2.9$, $P < 0.01$) and gardening ($Z = 2.1$, $P < 0.05$) activities in bad rainfall years, in order to cope with drought. These three activities complement donor assistance ($Z = 6.1$, $P < 0.001$) (Figure 5). Hence, these households do not depend only on one activity during drought as households of the cattle-based livelihood type do. As the cropping season encompasses the Christmas holidays – when many household members working away from home return to their families/rural homes - the visible impact of drought may prompt working relatives to increase support in the form of remittances. In order to boost food production during drought, households of the crop-based livelihood type also plant more maize than vegetables in gardens. Some people trade small ruminants in Mozambique and bring food and medicines for use and for resale. The permeability of the border makes trading options wider for locals to survive drought. In order to cope with drought, households of the non-farm livelihood type increase their cross-border activities ($Z = 4.5$, $P < 0.001$) and the lucky ones get additional assistance from donors (Figure 5). Donors are often biased against households that receive remittances from family member(s) working elsewhere. These households often cope by finding seasonal jobs in South Africa.

3.6 Adaptation strategies employed by different households

Several coping mechanisms are employed by people for smoothing their consumption pattern (Table 5). How these coping mechanisms are employed depends on household type. Whereas households of the cattle and crop-based livelihood types mobilize locally available resources, households of the non-farm-based livelihood type depend more on the wider economy.

4. Discussion

Although most households in the study area keep livestock, practice arable farming, and receive remittances, they differ in terms of their dependency on cattle, cropping, and non-farm and off-farm activities, especially in years of drought. Households have different poverty status and their ability to depend on land for food production depends on their asset base (see Table 2 and in Figure 4), social and organisational capacities, shared belief systems and motivational capacities. Anderson and Woodrow (1991) attributed the importance of level of asset base to the differences in households to survive environmental pressures. The roles of assets in smoothing consumption during bad years were described by other researchers such as Babington (1999) and Kinsey et al. (1998). An important result of our study is that not only differences in asset base are important but functioning of a household as determined by its type is very important. Cattle-based households generally cope with hazards by selling cattle. Their main problem is an unreliable livestock marketing system. They deal with market issues by selling illegally across international borders or at monthly self-organised local markets. Crop-based households spread the risk of crop failure by cropping across different landscape positions, ranging from flood plains to uplands on the interfluves. They cope with drought by relying on food aid distributions and, to a lesser degree, by increasing gardening and non-farm activities such as labouring for food, moulding bricks, beer brewing, and selling chickens and small stock. Non-farm households practice land intensive agriculture because of labour constraints and poor asset base. They rely on paid employment outside the study area, mostly of households’ members working in South Africa.

4.1 Contribution by different activities to household food self-sufficiency

A large proportion of households in the south-east lowveld are not food self-sufficient, even during a good year. The local food base is poor and the available informal markets are unpredictable in terms of food availability for those with cash to buy see Mavedzenge et al. (2008). Households belonging to the non-farm livelihood type appear to be the worst-off, but although they are not food self-sufficient, they can be food secure: they get their food from across borders and sometimes exchange other goods for grain. The international border plays a key role in their survival. Devereux (2009) reduced all legal sources of food acquirement to ‘production, exchange (barter or purchase) and transfers (including food aid) and indicated that failures of all three can lead to famine. Establishment of the Transfrontier conservation areas in southern Africa is seen as a threat to all sources of food acquirement by local people. Drought affects production more if access to flood plains and other lower lying areas is restricted; restrictions at international borders affect exchange and transfers negatively by reducing food access and exchange.

Strategies used by people to cope with climate variability in the semi-arid south-east lowveld of Zimbabwe are livelihood type specific. Households not only differ in terms of how different livelihood activities contribute to a household's food situation, but also in coping strategies and how these are employed for smoothing food availability. Cattle and available labour determine timely execution of cropping activities, flexibility in adapting a cropping calendar to undesirable events like poor germination of crop and the capacity to hire labour during peak labour demand periods, see Dercon and Krishnan (1996). In the south east lowveld of Zimbabwe, households of the cattle-based livelihood type harvest more grain than households of other livelihood types even in a bad year. Their capacity to harvest more is enhanced by timely execution of activities and by their capacity to plant larger areas. In a bad year, cattle are sold or exchanged for food. On average, three cattle are sold to be able to buy food in a bad year where one will suffice in a good year. When selling within the local area, farmers realize 200 to 300 USD per steer, while they could get USD 500 to 900 if they sell in Mozambique. Also, if exchanged for grain locally, one cow can be exchanged for as little as six 50-kg bags of maize grain in a drought year. Garden and outside farm activities compliment livestock as shown in Figure 5. However, gardening is possible only to households that are located close to big rivers.

Unlike households of the cattle-based livelihood type, the contribution of cattle to food security in households of the crop-based livelihood type is smallest in a bad year (see Figure 5). Households of this livelihood type do not sell cattle to cope with food shortages and they do not milk the cows either. This is contrary to findings by Kinsey et al. (1998) who generalize that people in low rainfall areas sell cattle to survive drought. Our results show the importance of disaggregating livelihoods before making an analysis. Local people believe that less than 20 cattle is not a good enough number to effectively rebuild their herd after a drought and that the risk of losing all cattle decreases with an increase in the number of cattle that one owns. They are therefore very reluctant to sell cattle in a moderately dry year. Most households of the crop-based livelihood type have less than 20 cattle, explaining why cattle off-take is very low in households of this type. Small stock and poultry are traded instead. In the south-east lowveld, people cross the border into Mozambique with chickens and goats to exchange for food or cash. Small stock and poultry forms the basic framework for trading, therefore, the security level of international borders define the level of reliability of their market. Besides trading in small stock, crop based households depend more on donor food than the other two livelihood types. Donor food is beyond control of the households making the crop-based vulnerable to multiple hazards, for example, in June 2008 the Zimbabwean government restricted operations of donors on political grounds, and many recipients of donor food were left exposed to hunger. In addition, the poor road network hinders transportation of drought relief food and floods make most areas inaccessible. To increase their adaptive capacity, most farmers try to increase their cattle numbers. Risk spreading based on such beliefs partly explains the reason why cattle numbers are increasing in the south-east lowveld of Zimbabwe, thereby posing serious problems to the carrying capacity of the grazing land. Alternative feed sources will need to be identified. The risk of losing all cattle during droughts in certain areas is spread by lending some to the poor in different areas as a way of spreading the risk posed by high spatial variability of rainfall and to gain access to other grazing land. Cattle lending is not common in a household with less than 20 cattle.

In a good year, households of the non-farm based livelihood type practice an intensive form of agriculture on the usually fenced pieces of land in vlei areas close to their homes (on average 1.3 ha). In a bad year, they increase their cross border and non-farm activities. Remittances remain fairly similar as compared with good years possibly because remittances already form part of the basic framework of their livelihood system.

4.2 The socio-cultural dimension of adaptation to climatic variability

The study area is composed of Shangaan speaking, Shona speaking and Ndebele speaking people. The Shangaan people form the largest and oldest ethnic group in this area. Among them a large herd of cattle and a large cropping area are valued as indicators of wealth. Having many cattle defines the potential to cope with drought and a large field signifies the capacity for mobilising available resources to produce food. A preference for drought tolerant sorghum over maize befits this value pattern. Generally, a very large field is likely to belong to a Shangaan speaking household. Ndebele and Shona speaking people in the area often balance maize and sorghum production, although they prefer maize. They prefer to grow many other minor crops such as groundnut and cowpea in order to diversify their diet. Such preferences may be interpreted as adaptation through diversification (risk-spreading), as opposed to the Shangaan who put more emphasis on drought tolerant crops. Such different socio-cultural orientations are both the result of and reinforcing diverse farming systems and even livelihood types. Disaggregation by ethnicity may thus be needed when new developmental programmes are to be implemented.

4.3 Adaptation to climatic variability

Households of the cattle-based livelihood type face the challenge of reduced feed and water for their cattle during periods of drought. As pointed out by Gallopín (2006), vulnerability is not always an undesirable property. In the south-east lowveld of Zimbabwe, Cattle-based households facing the danger of losing many of their cattle during a drought year redistribute some of these cattle to the poor for keeping. They save on labour for herding and watering when the recipient also benefits from draught power and milk. People with smaller herds (largely of the crop-based livelihood type) and located close to the national park graze their cattle 'unofficially' inside the park. In the short run they gain in terms of feed for their livestock but in the long run they lose production because of disease. Inside the park cattle usually mix with buffalo and pick-up the blue-ear tick resulting in increased incidence of the disease theileriosis. Buffalo are also carriers of foot and mouth disease and those cattle grazing inside become exposed to this disease. When they come out of the park, they inter-mix with other cattle thereby increasing the risk of spreading the disease. The park fence is therefore an important component for reducing the vulnerability of households to livestock disease and respondents said that they understand this reason for fencing. However, respondents argued that local authorities hire people from outside their area to repair fences causing retaliation by local people who would then excessively remove the fence and use parts of it for making snares inside the park. Some local people cut the park fence in order to get some food supplement of game meat. On the other hand, local authorities think that the local people do not understand that the reason for fencing is to keep buffalo in the park, not to keep local people out. If there is no well-developed platform for sharing and informing the local communities why certain conservation measures are taken, these measures will always face stiff resistance from local people; see for example Fabricius et al.(2007). In terms of feed resource, mopane tree leaves are important. But with increased cutting down of trees for making fences to protect fields and livestock from wildlife, mopane resources are dwindling. Recently (during the 1991-1992 drought), farmers discovered value in using a tuber plant that is widely spread in their area. This plant is called *Neorautanenia amboensis* Schinz, locally known as Zhombwe (see Chapter 3). Many farmers are now using this tuber with claims that it is a 'God given medicinal feed resource' that sees cattle through drought. They dig this tuber and feed their cattle every alternate day.

Households of the crop-based livelihood type spread their cropping across landscape positions as a way to spread risk posed by both drought and floods. Cropping in uplands takes place at the start of rains whereas cropping of wetter areas like flood plains takes place a month or two later, usually after flooding. This allows the households to spread their limited labour resource across time. In drought years they get more food from wetter areas and in flood years they harvest from uplands hence reducing their vulnerability to total crop failure. Limited access to some landscape positions will reduce the capacity of crop-based households to cope with climate variability. Policies adjustments that can facilitate the enhancement of farmers activities are required under such circumstances (Duncan, 1998). They also diversify crops across the landscape positions as a way of spreading risk. Most employ multi-planting regimes as a way to cope with unpredictable dry spells.

Training animals for ploughing and the actual ploughing exercise is work for men, weeding and threshing of maize is mostly done by women, while the youth perform both cropping activities and livestock management. The population pyramid of non-farming households is skewed to the left especially between 19 and 60 years. Most men (19 to 60) are in South Africa, and only visit their families in the research area during major holidays like Easter and Christmas. Where cattle are not available or fewer men are available, crop management is jeopardized. In such cases (as with non-farm households), intensification of agricultural activities on smaller areas takes place.

4.4 Enhancing coping capacity through community level networks

Cattle are redistributed among the poor (*kuronzera*) during drought in order for cattle households to cope with increased labour demand for feeding and watering cattle. To ease labour bottle-necks, people organise ploughing/cropping programmes where the household in need prepares food and beer and invites neighbours for help. As many as 5 to 10 spans of cattle are involved and the activity usually lasts half a day but a large area can be ploughed and sown during this time. At chief and headmen fields there is a large field cropped by all households in one day, the food from this field is reserved for distribution among the hungry where necessary. This program is locally known in Zimbabwe as *zunde raMambo*. Other supporting programs include working in other people’s fields for food, cash or draught services. This system increases vulnerability of poorly resourced households because they will fail to perform cropping operations such as ploughing and sowing on time.

4.5 Implications of adaptive strategies on development and planning

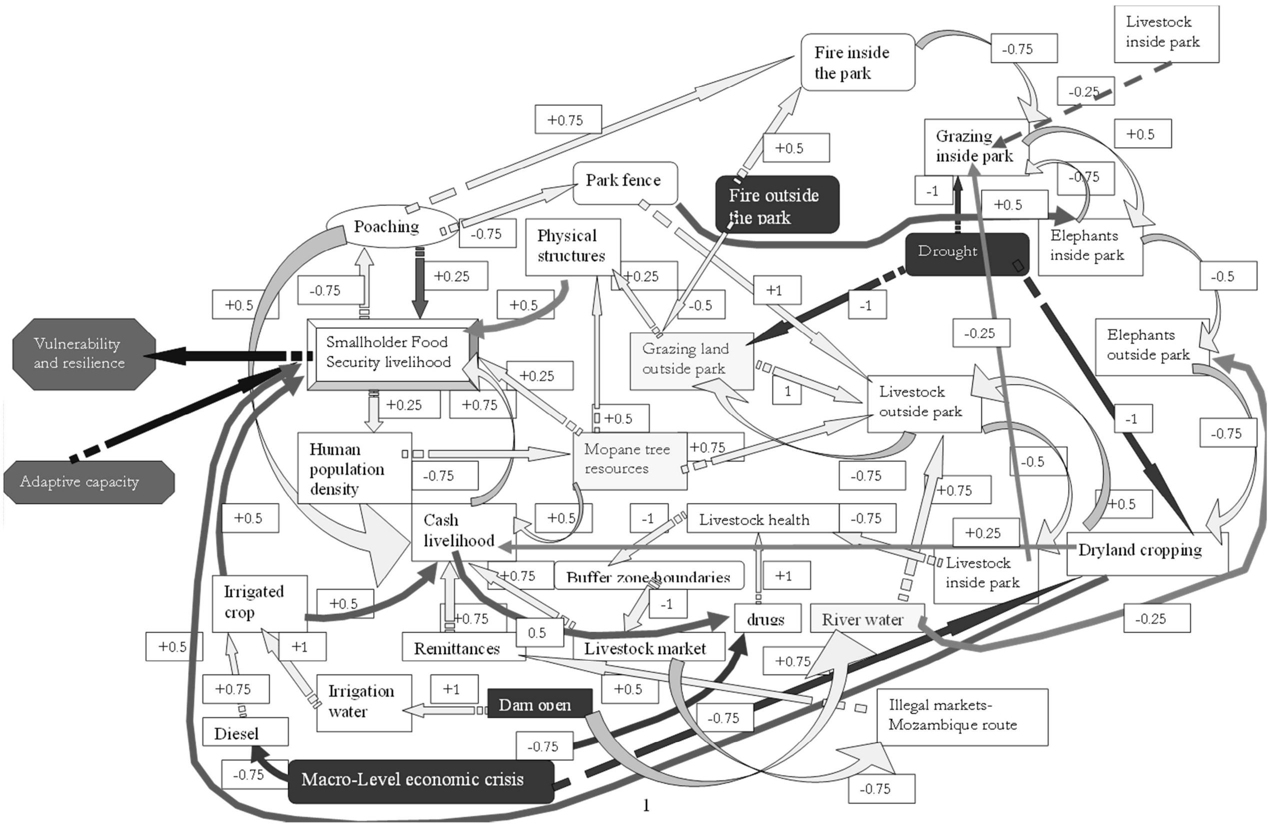
Livestock is not immediately impacted by drought conditions as crops are. Households of the crop-based livelihood type respond by intensifying other activities. Livestock dependent households take more time to employ adaptation strategies during a drought. But when their cattle finally succumb to drought, it also takes a longer time before they come back to original capacity of function than is the case with other activities. This means that drought manifests itself differently in different households resulting in different responses that need proper understanding before implementation of new development programmes. In most drought relief programmes, old people are often considered vulnerable. However, those that fall within the cattle livelihood type cannot be considered vulnerable to food shortages. What they need are markets for their livestock and access to food. In terms of adjusting to climatic variability, cattle households have more source of labour in the number of boys between 6 and 18 as shown in their age pyramid. They have sufficient resources for a better adaptive capacity at the local level than other households. However, it is important to realise that cattle are important for households to adapt but without markets their value cannot be realised. Poor performance of the Zimbabwean beef sector is often blamed on poor cattle off-take (2-3%) in smallholder areas and the smallholder sector holds 70% of all livestock at a national scale.

5. Conclusion

Our findings show the importance of disaggregating systems before studying livelihood systems. This will make it possible to bridge organizational functions of different livelihood types and link them across institutional scale, while combining different sources of knowledge to promote social learning pathways (Olsson *et al.*, 2006). Existence of different livelihood types helps facilitating trade between different households in addition to semi-specialisation by different households on certain activities (e.g. creation of food networks by non-farm households). Because of limited market access, food self-sufficiency should be considered first. It is positive that the current developments in southern Africa (establishment of TFCAs) has food security agenda on its broad-based development aim but it is important to consider food self sufficiency in its short to medium term objectives if both natural resources conservation and poverty alleviation is to be achieved. Cultural practices on livestock and crop production to meet household food self-sufficiency need to be explored. In this research, we linked adaptive livelihood strategies to household food self sufficiency, that way, we were able to expose constraints and opportunities for creating win-win situations where increased biodiversity conservation strategies are being proposed in areas close to people vulnerable to climate variability. Analysis of the vulnerability of different livelihood types to hazards of greater importance will give more in under different scenarios.

Chapter 3

Application of fuzzy cognitive mapping in livelihood vulnerability analysis



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Abstract

Feedback mechanisms are important in the analysis of vulnerability and resilience of social-ecological systems, as well as in the analysis of livelihoods, but how to evaluate systems with direct feedbacks has been a great challenge. In this paper we applied Fuzzy cognitive Mapping (FCM), a tool that allows for analysis of both direct and indirect feedbacks and can be used to explore vulnerabilities of the livelihood types to identified hazards. We studied characteristics and drivers of rural livelihoods in the Great Limpopo Transfrontier Conservation Area in southern Africa in order to assess the vulnerability of inhabitants to the different hazards they face. The process involved four steps: (i) survey and interviews to identify the major livelihood types, (ii) description of specific livelihood types in a system format using fuzzy cognitive mapping, a semi-quantitative tool that models systems based on people's knowledge, (iii) linking variables and drivers in fuzzy cognitive maps by attaching weights, and (iv) defining and applying scenarios to visualize the effects of drought and 'moving' park boundaries on cash and household food security. FCM successfully gives information concerning the nature (increase or decrease) and magnitude (large increase or small decrease) by which a livelihood system changes under different scenarios. However, it does not explain the recovery path in relation to time and pattern (e.g. how much time it takes for cattle to come back to desired numbers after a drought). By FCM, we found that issues of policy like changing situations at borders can strongly aggravate effects of climate change, e.g. drought. FCMs can reveal hidden knowledge and insights that improves an understanding of the complexity of livelihood systems in a way that is better appreciated by stakeholders.

Keywords: Feedback mechanism; hazards; scenarios; resilience; vulnerability; Great Limpopo Transfrontier Conservation Area; livelihood.

1. Introduction

Over the past decades livelihood analyses have emerged as a powerful participatory approach in poverty analysis and poverty reduction strategies. By integrating different disciplinary perspectives and challenging sectoral approaches, these approaches link the particularities of local-level situations of people trying to make a living to wider institutional and socio-economic dynamics. While livelihood analyses, with their focus on ‘assets’ and ‘capitals’ have nevertheless ‘remained largely focused on a fairly instrumental poverty reduction agenda, framed by economists’ (Scoones 2009), environmental concerns have been influential in these analyses since the late 1980s, as is evidenced by the well-known Sustainable Livelihoods Framework (Rahman *et al.*) (Chambers and Conway 1992). SLA methods have been criticised because of the difficulty to assess pathways of change or trajectories of vulnerability and resilience within households (e.g. Toner, 2003).

Sustainability implies that livelihoods are relatively stable and resilient to be able to cope with shocks and stresses. Assessing the (possible) impacts of such shocks and stresses on different livelihoods at the local-level remains an important challenge in the face of wider processes such as climate change and new land use policies. Resilience thinking, with its origins in ecological systems thinking (Adger 2000, Folke et al. 2002), is increasingly applied to the study of what are commonly known as social-ecological systems (Folke et al. 2002). Integrating such resilience thinking into participatory livelihood approaches has been labelled a ‘work in progress’ (Folke 2006, Scoones 2009). This article aims to contribute to this integration by evaluating a simple participatory ‘reasoning-scheme’ methodology – Fuzzy Cognitive Maps (FCM) – that enables local people and scientists jointly to assess the impacts on different local livelihoods of different future scenario’s that people identify themselves.

A wide range of tools and approaches have been used as analytical and participatory tools in livelihoods analysis: Agent Based Modelling (ABM) (Eakin and Luers 2006, Castella et al. 2005), Dynamic Systems Models (DSM) (Dougill et al. 2010), Bayesian Belief Networks (BBN) (Newton et al. 2006) and more recently also Fuzzy Cognitive Maps (FCM) (Kok 2009). ABM and DSM typically encounter problems with lack of information to describe the processes they include, are often case specific in their structure and the underlying assumptions of both methods are often hidden in the implementation details (e.g. O'Sullivan and Haklay 2000). BBN and FCM have the ability to combine quantitative and quantitative information and have some similarity in the way they use a transparent, graphical representation of the functioning of the system, which can supplement existing, less transparent, frameworks that analyse vulnerability (e.g. Fraser 2007, Ericksen 2008).

BBN has been used in livelihoods analysis (Newton et al. 2006, Martínez-Santos et al. 2010), evaluation of management of forests (Haas 1991, Crome et al. 1996) and environmental policy studies (Wolfson et al. 1996). A BBN is a graphical model for probabilistic relationships among a set of variables (Pearl 1993, Heckerman 1999) and gives a compact representation of reasoning under uncertainty by making reference to Bayes' rule for computing probabilistic inference (Smid et al. 2010). Bayesian Belief Networks offer many advantages. They readily handle incomplete data sets (Heckerman 1999), they represent probabilistic relationships concisely (Cooper 1990, Pearl 1993) and their graphical user interface makes the approach simple to use for non-experts (Smid et al. 2010). Their drawback is that they do not allow for inclusion of direct feedbacks in their analysis which limits their use in vulnerability assessments. Feedback mechanisms are important in the analysis of vulnerability and resilience of social-ecological systems, and equally in the analysis of livelihoods, particularly if policy makers are to develop options that are well-adapted to local conditions (Folke et al. 2002). In this paper we use Fuzzy Cognitive Maps (FCM), a tool that allows for analysis of both direct and indirect feedbacks and goes on further to explore vulnerabilities of the livelihood types to identified hazards.

Fuzzy Cognitive Maps are fuzzy-graph structures that represent causal reasoning, allowing systematic causal propagation, in particular forward and backward chaining (Kosko 1986). (Tolman 1948) introduced cognitive maps and their use has origins in politics (Axelrod 1976, Hermann 1978). Kosko (1986) extended their use which later spread to various fields such as forestry management (Mendoza and Prabhu 2006), biological processes occurring at cellular level (Weinreb *et al.* 2006) and scenario development (Kok 2009). Özesmi and Özesmi (2004) compared FCM with a dynamic model and found FCMs to be useful in evaluating complex systems. To develop a FCM, a qualitative understanding of how elements of a larger structure are related to one another is required (Carley and Palmquist 1992). Relative weights are then used to quantify strengths of causal relationships between the elements (Kosko 1986). The weights are included in a matrix which is subsequently used for scenario analyses.

In this paper, we use FCM based scenario analysis to understand the vulnerability of poor rural households to events perceived as hazards. The scientific use of 'vulnerability' has its roots in geography and natural hazards research (Turner et al. 2003, Janssen 2006). This term is now a central concept in a variety of other research contexts such as ecology, public health, development studies (Adger 1999), famine analyses (Watts and Bohle 1993), disaster risk studies (Swendsen and Norman 1998, SDR 2003), and notably, social-ecological systems thinking (Berkes 2007). Vulnerability is used here as an attribute of livelihoods, and thus puts people and the way they manage their lives at the centre.

The goal of this study was therefore to assess the usefulness of FCMs in livelihood analysis, and we developed and applied a framework in which the functioning of different livelihoods and their vulnerability to external changes can be analysed. We analysed a livelihood system at the human-wildlife interface of a semi-arid region in south-east Zimbabwe. This area is part of the Great Limpopo Transfrontier Conservation Area, which includes renowned protected areas such as the Kruger, Gonarezhou and Limpopo National Parks in South Africa, Zimbabwe and Mozambique (Peace-Parks 2001). Proposals for land use change have been made to include more space for wildlife and ecotourism in smallholder farming/livestock areas surrounding these national parks (Dzingirai 2003, Spenceley 2008).

We used four steps to generate FCMs, each guided by a question:

1. What are the defining variables of different types of livelihoods that local people and other stakeholders distinguish?

2. How can we understand the structure of each distinguished livelihood type; the relations between the main assets, activities and outcomes, as a simple model of interrelated variables?

3. How do local people and other stakeholders perceive the impact of particular hazards on the defining variables of specific livelihood types?

4. Where do particular hazards (drought, unclear boundaries) impact the constituting variables of the different livelihood types, and what consequences does this have on the assets, activities and outcomes?

2. Materials and Methods

2.1 General description of the case study area

The case study area is located to the south-west of Gonarezhou National Park in the south-east lowveld of Zimbabwe (Figure 1). South-eastern Zimbabwe is a drought prone region more suitable for both livestock and wildlife than for cropping. Local communities depend on livestock as their main source of livelihood, yet economists believe tourism with wildlife makes a lot more sense. This situation presents a conflict of interest between several stakeholders on best land-use options and natural resource conservation strategies. Already there are complex relationships between various sub-systems in the area: communal grazing, park grazing or smallholder grazing; water for cattle, for people and / or wildlife; sorghum cropping and or maize cropping; and other issues related to migration, cattle rustling and hunting or poaching, etc. In this region the formation of the Great Limpopo Transfrontier Conservation Area, with on the Zimbabwean side Gonarezhou National park, has brought many new challenges to local populations living in or adjacent to this park. Our study focuses on developing and applying a framework to analyse the vulnerability of the local livelihoods to changes in external drivers while taking into account of the difficult environment in which the people are living.

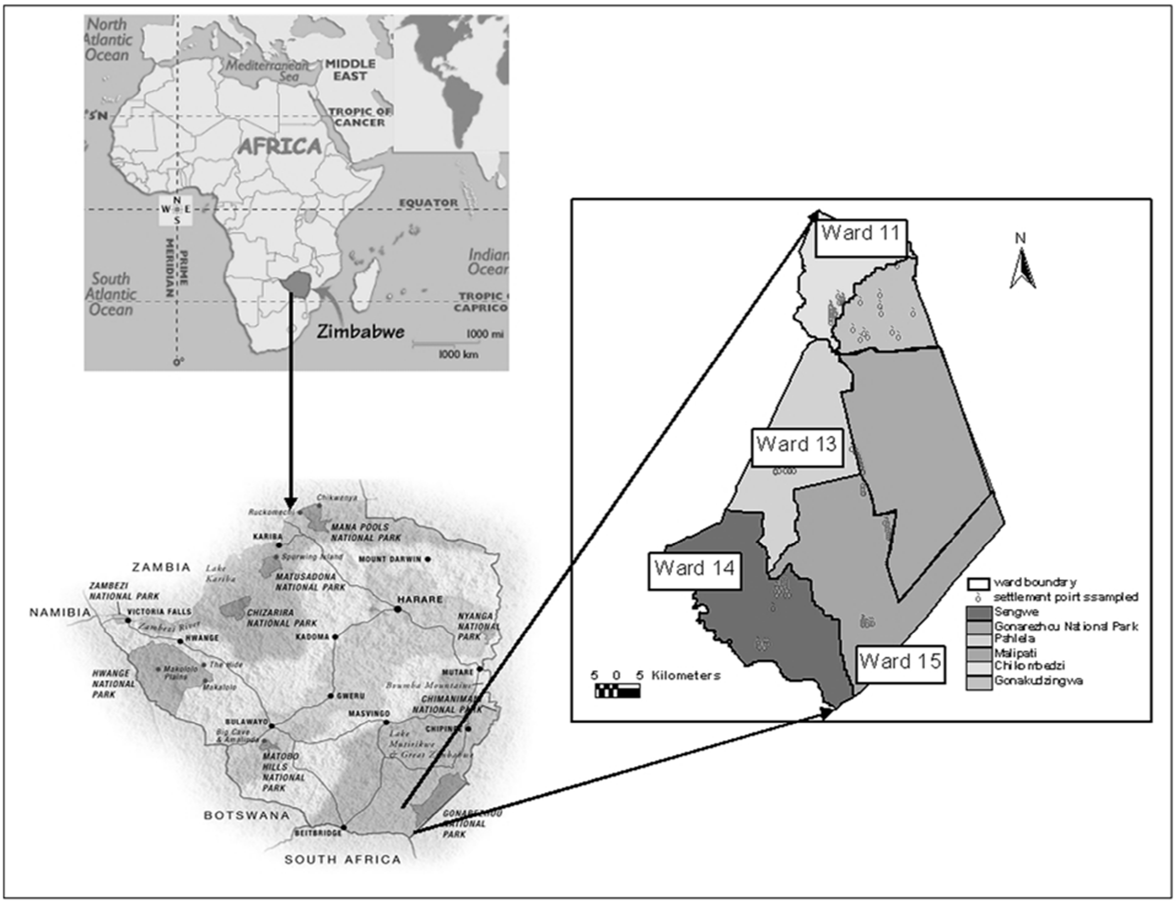

Figure 1. Wards 11, 13, 14 and 15 are the communal areas surrounding Gonarezhou National Park and Gonakudzingwa small scale commercial farms in south eastern Zimbabwe. Representative members who identified livelihood types and constructed corresponding Fuzzy Cognitive Maps reside in the communal areas shown. Wards overlap with ward names given in legend.

Gonarezhou National park is not only seen as a threat, but is valued by local people for the following resources: forage, game meat, roofing poles from *Androstachys johnsonii* (Musimbiti in local language), mopane worm (*Gonimbrasia belina*; Imbrasia belina), thatch grass, controlled fish ponds and traditional medicines e.g. *Xeroderris stuhlmannii* (Murumanyama in local language) used for malaria treatment. The case study area covers 2750 km2 of communal land divided into four wards with a total of 6400 households made up of 15,940 men and 20,550 women (CSO 2002). Mean annual rainfall is 400 mm, but highly variable in time and space with a coefficient of variation of 35% (Cumming 2005). Local vegetation of the area is dominated by lowland Mopane (*Colophospermum mopane*) within eutrophic savanna (Cunliffe 1993) in this region where Shangaan-speaking people predominate, with Shona and Ndebele speaking minorities. This research was carried out in rural areas forming part of the Great Limpopo Transfrontier Conservation Area (GLTFCA) in the south-east lowveld of Zimbabwe. The GLTFCA is one of the 14 such areas in southern Africa which strive to combine resource use and conservation.

2.2 Definition of the livelihood types

Four main stages of the research process are shown in Figure 2. Four groups of individuals were interviewed, i.e., local people: those who have a home and live in the study area; informants: people who are knowledgeable about livelihoods in the area but do not necessary live there; focus group: a group of local people with knowledge on and interest in the particular topic of livelihood research and; stakeholders: organizations and individuals with an interest in natural resources and local livelihoods, working for public (Govt., NGO, traditional leaders) or private interests (conservancies, safari companies). Current livelihood types were identified based on a preliminary survey (n=156) and two interviews with informants (n=5) and stakeholders (n=17) (Figure 2, stage 1). During the preliminary survey, stakeholders and informants identified the characteristics that determine different livelihood types. The informants were randomly selected from lists of local people considered typical representatives who were deemed knowledgeable about the livelihoods under investigation. The characteristics identified led to an initial classification of livelihoods which was later refined through group discussions. Based on the initial livelihood classification, representative households (n=9) of each livelihood type identified (n=3) were selected for further study.

2.3 Development of FCMs

The general livelihood types were refined (Figure 2, stage 2) by focus groups chosen randomly from lists of household heads of each livelihood type. Each focus group (n=9) drew an FCM to define the structure of their livelihood system. The facilitator showed the groups how to draw an FCM, and then each participant drew an individual FCM on their own without interruption. They then discussed and combined their individual FCMs to make one FCM representative of their particular livelihood type. Input by stakeholders from local authorities, NGOs, government officials and private organisations was used to refine the FCMs in iteration with each group and in the end the whole group decided on the final structure of the FCM.

The variables and relationships of the FCM were entered into a matrix. The relative weights given to relationships (Figure 2, stage 3) constitute the elements of the matrix. This means the matrix is filled with numbers between -1 and 1, where -1 means a very strong negative effect, 0 means no change in effect and +1 means a very strong positive effect.

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2.4 Scenario analysis

Following the finalised FCMs, stakeholders and focus groups came together to add strengths to the relationships in their maps and to define possible scenarios to be analysed using the FCMs (Figure 2, stage 4). Representative members of each livelihood type described the value of relationships between variables in FCMs by selecting the weighting factors for individual relationships (semi-quantification). Weights from -1 through 1 with quarterly divisions were used. Next, stakeholders and focus groups defined four scenarios after quantification of the effects of the drivers on the system. The four scenarios were chosen based current expectations of climate change (possible increase in the occurrence of extreme drought events) and policy options in the region, the latter especially related to migration issues.

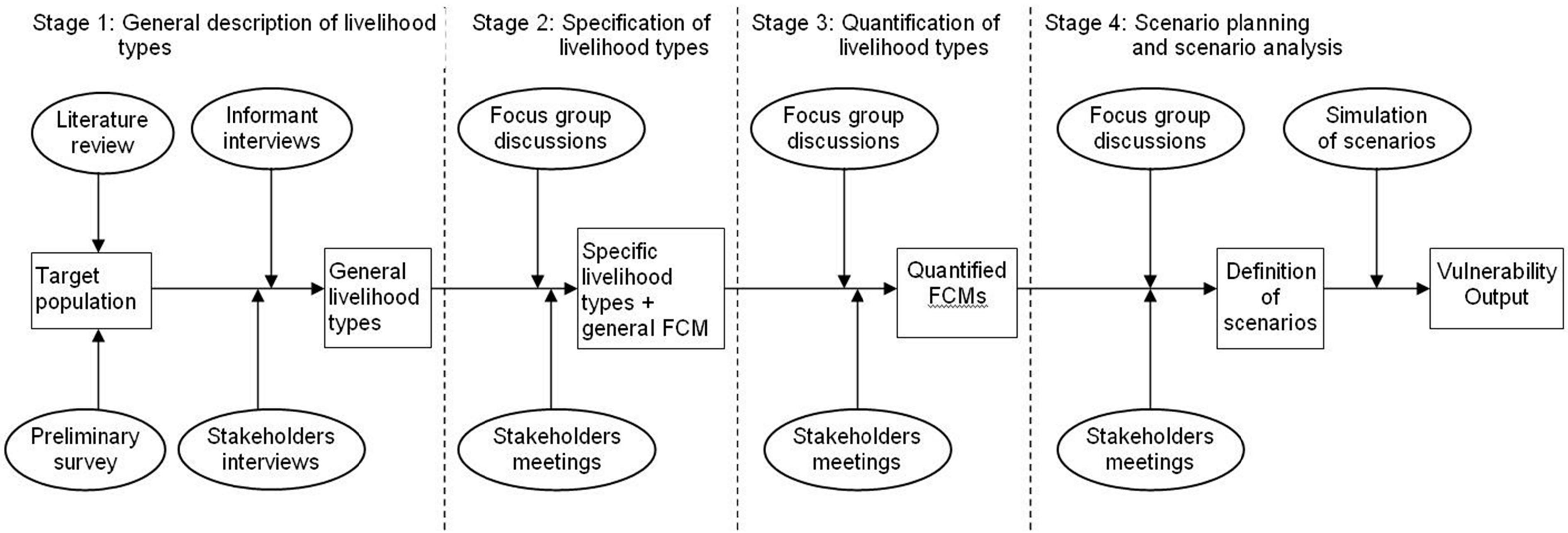


Figure 2: Four main stages of the research process to understand vulnerability of different rural livelihoods to hazards of southeastern Zimbabwe. FCM stands for Fuzzy Cognitive Maps.

The scenarios were:

1. Baseline scenario: normal rainfall according to area standards, few cases of damage by wildlife from the park, possible and negotiable system allowing local people to cross boundaries to access resources, weaker institutions due to prevailing political and economic challenges. Political affiliation, for example, is determining food access and cattle rustling have become a complex issue with no solution in sight. In addition, there are few cattle dying, at least half of crops planted reach harvesting stage, remittances are making a recognisable contribution to household cash and food.

2. Drought scenario: rainfall is insufficient for cropping. There is a high degree of uncertainty on when it will rain next. No harvest from upland fields, many cows die, crossing of boundaries increases, remittances are increasingly important and food is obtained from across boundaries. Effects of institutions, damage-causing animals outside the park and unclear boundaries are represented in the same way as in the baseline scenario.

3. Border scenario: many restrictions and monitoring of movements across boundaries (boundaries less unclear). There is drought, all crops die, many cows die, crossing of boundaries is strongly restricted so there is less inflow of remittances and less food coming from across boundaries. Institutions and damage-causing animals retain same strength as in the baseline scenario.

4. Desire Scenario: Rainfall is sufficient for crops. There is low degree of uncertainty on when it will rain next. There are fewer cases of damage by wildlife from the park; there is a properly defined and targeted compensation strategy for households affected by damage causing animals. Institutions become stronger in supporting households' access to food. Crops grow well and all crops that are managed properly gives a good harvest, household cattle ownership is increasing, boundaries have an acceptable priority window and mechanism for local people to access resources from either side (boundaries - unclear) and there is increased flow of remittances and food from outside the system boundaries into the household.

After defining scenarios the FCM models for the identified livelihood types were run in order to generate graphs quantifying relative changes in the important livelihood outcomes (cash and food in this case). The influence matrix defined by the focus groups and the stakeholders is the basis for the scenario analysis. To begin this process, an input vector, in which all variables and drivers are given values representing a certain scenario, is multiplied by the matrix. The values of the new output vector are rounded between -1 and 1 (here our approach deviates from the approach used by van Vliet et al. 2010 and Kok (2009)), and constitute a new input vector that is multiplied by the matrix. This process continues until the outcomes of the multiplication and rounding have stabilized. The changes of the variables compared with their starting value (=0) can now be interpreted as increase (if positive) or decrease (if negative) compared with the original situation. In this way the importance of different feedbacks within the system under different scenarios can be analysed.

Total food and available cash in the household were chosen by the focus groups as good indicators of the functioning of each livelihood type. Relative change in total food and available cash was compared with the baseline scenario (set at value 0) and quantified. It must, however, be noted that these two indicators (cash and food in household) are not independent of each other. Families generate cash for buying food and sometimes sell food to get cash. 0 means no change in effect and +1 means a very strong positive effect.

2.5 Sensitivity analysis

The relative weights given to the relationships between variables of the FCM are by definition uncertain. It is therefore important to assess how robust the outcomes of the scenario analyses are, taking into account this uncertainty. To make this assessment we performed for all scenario analyses a sensitivity analysis in which we randomly varied the values of all weights in the three livelihood matrices within 20% of their value. In the sensitivity analysis in this way 1000 new FCM matrices were generated and were run for the scenario analysis of interest. The range of output values at each number of vector-matrix iterations generated in this way were summarized by calculating the standard deviation of the 1000 values. In the results section the outcome of the original FCM matrix are presented together with the standard deviation, and thereby we gain insight in the robustness of the outcomes, and how strong the outcomes can be affected by changes in the weighs of the relationships.

3. Results

3.1 General description of livelihood types

Based on the discussions with stakeholders and informants three key factors were defined which determined the classification of livelihood types:

1. Value of cattle and relevance of cattle numbers to a household

2. Value of cropping and relevance of vlei areas to a household. Vlei is a common term used in southern Africa meaning low-lying, gently sloping, treeless land that is seasonally waterlogged with seepage from high ground and rainfall and which contains drainage channel for the removal of excess run-off (Rattray et al. 1953, Ivy 1981). In many parts of central and southern Africa, vlei areas are also known as dambos.

3. Value of off-farm activities and relevance of remittances to a household

As a result, three livelihood types were identified: cattle-based, crop-cattle based, and non-farm based. The general characteristics of the livelihood types, following from stage 1 in Figure 2, are presented in Table 1. The livelihood types constitute 12 % (cattle-based), 41 % (crop-cattle based) and 47 % (non-farm based) of the total local community (n =156). The relative weights given to the relationships between variables of the FCM are by definition uncertain. It is therefore important to assess how robust the outcomes of the scenario analyses.

3.2 Specification of livelihood types

Focus group discussions defined four building blocks that determined the structure of the different livelihood types. These were: number of cattle in the household, total harvest, available cash and fees (Figure 3A). Fees are a variable that defines all payments that the household has to meet in order to function properly, and these include payments for hospital, grinding meal, school and transport. After putting in the central building blocks in the overall scheme (Figure 3A), the factors determining these key variables were identified. Figure 3B, 3C and 3D illustrate how the FCM was constructed using the cattle based livelihood as an example. First the variables affecting the amount of cattle in household (Figure 3B) were added, followed by the variables determining total crop harvest (Figure 3C). Finally, drivers determining the functioning of the system were added (Figure 3D).

3.3 Quantification of livelihood types

Perceptions of local people and other stakeholders on strengths of relations defining different livelihood systems are presented in Figure 4, 5 and 6 showing FCMs of the three livelihood types after the weighting process (Figure 2, stage 3).

Table 1: General description of livelihood types of southeastern Zimbabwe.

Livelihood type	General attributes	Coping strategies during drought
Cattle based	• Large kraal • At least 20 cattle (median 30) • At least one granary • At least 2 ploughs and a scotch cart • Household head usually over 50 yrs. old and present • Education level of household head (primary) • Big homestead with at least one big brick 4 bed roomed house • Family size average 15 • Cropping • Don't have problems with sourcing inputs	• Sell cattle or exchange cattle for food • Keep medicines for common diseases of cattle • Usually rent grazing from commercial farms or migrate with their livestock to certain specific far away areas with better grazing and water points • Loan some cattle to those in need to save on labour demands for watering cattle using buckets • Use *Zhombwe* during drought • Ferry relief food (for a fee) of those benefitting from donors • Hire labour in times of demand
Crop-cattle based	• Average size kraal • less than 20 cattle (median 10) • At least one granary • One to 2 ploughs and a scotch cart • Household head between 40-50 yrs. old and present • Education level of household head (Infant to junior primary) • Average size homestead to small in poor households • Family size average 10 • Balances land size for cropping between dry land and vlei areas • Cash for inputs and how to get inputs to farm is a problem	• Sell other livestock species (besides cattle) in drought years • Exchange food for cattle • Buy livestock with extra cash • Values wetter areas like the Banyeni (Fertile, low-lying flat areas) and the Gumbini (river banks) for cropping • Borrow cattle from some cattle farmers in times of need • Harvest wild fruits (especially around *Pfungwe* - a strip with fruit trees along river Limpopo • Use *Zhombwe* to feed cattle, rent grazing or graze inside park • Donor assisted, plant more sorghum, use traditional seeds
Non-farm based	• Small kraal or no kraal at all • Small thatched round huts to 4 bed roomed houses, in most cases you find long aerials for phone network • Zero to 10 cattle (median 1) • No granary • Receive remittances • Crop in wetter areas and have a permanent gardening activity • Household head, less than 40 yrs. old and away most of the time • Educational level of household head (infant) • Average size homestead Family size average 5	• Rent cattle from those with many • Brew beer (or make traditional dishes) then invite others neighbours to plough, plant and eat together at one function • Increase off-farm activities • Gets a smooth inflow of remittances • Hire-out labour within and outside Zimbabwe • Get food aid (but only if they are on the perceived poorer side of this livelihood type

Zhombwe (*Neorautanenia amboensis* SCHINZ) is a perennial leguminous, mostly erect herb or shrublet producing purple flowers on often trailing stems averaging 0.82m. It forms an underground tuber of up to 35kg (70% water) that has been fed to cattle as feed and medicine during droughts in south east Zimbabwe since the 1991/92 drought.

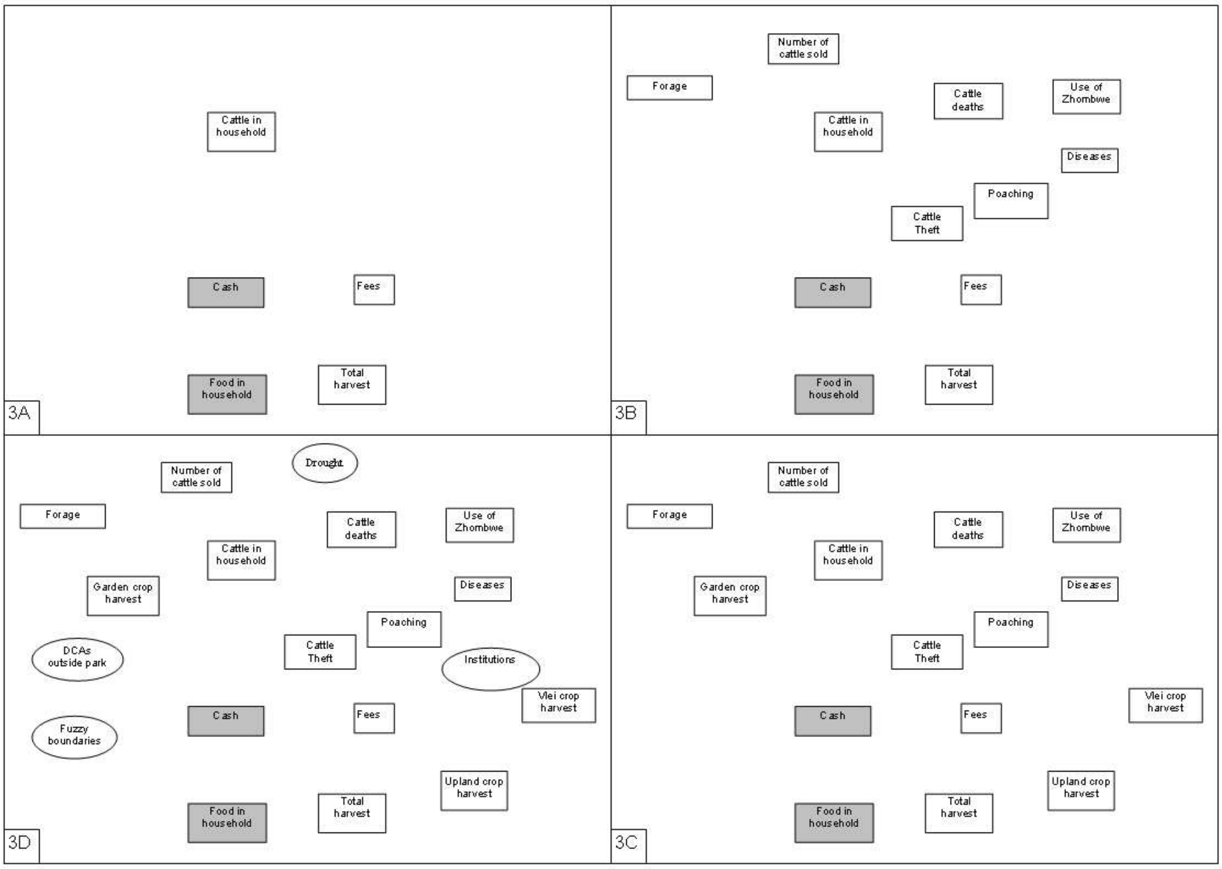


Figure 3. Stepwise construction (3A, 3B, 3C and 3D) of a cattle-based rural livelihood system in south eastern Zimbabwe using method of Fuzzy Cognitive Maps. Grey boxes are key indicators of the functioning of the livelihood, white boxes are variables and white circles are drivers of the system.

3.3.1 Cattle based livelihood system

The cattle based livelihood system (Figure 4) has 19 variables and 42 connections. The sum of all positive connections is 26, and the sum of all negative connections is 22. The density of the matrix (the number of connections in the matrix divided by the maximum number of connections possible) is 0.12 (see Van Vliet et al. 2010). Cash is arguably the most important variable for securing food in household, basically from the sale of cattle. This cash is mostly used to buy food; some is re-invested in cattle through purchases of drugs to keep them in good health and through direct purchases of cattle after a good harvest.

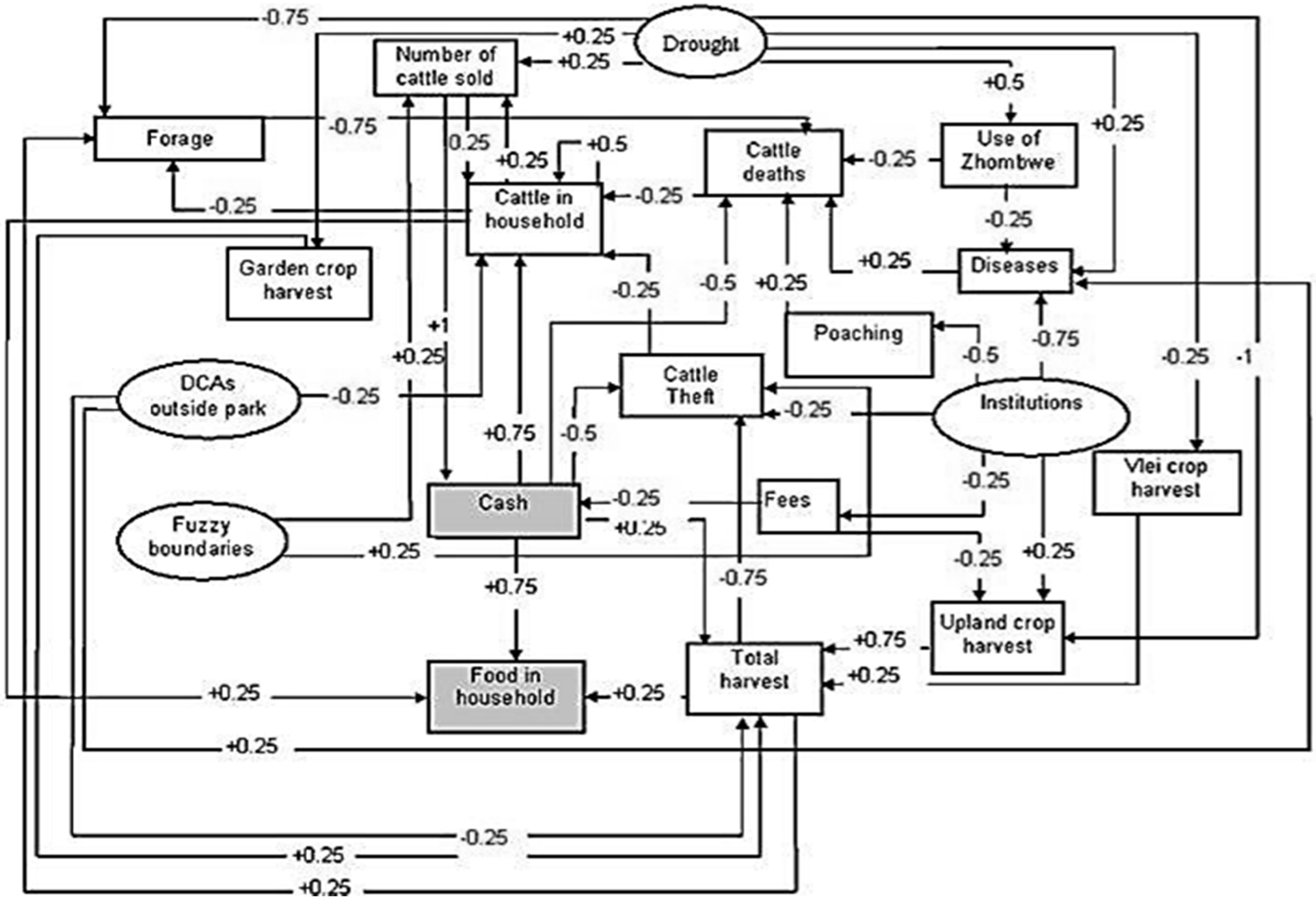


Figure 4: Fuzzy Cognitive Map of cattle-based livelihood type. Grey boxes are key indicators of the functioning of the livelihood, white boxes are variables and white circles are drivers of the system. Numbers given are influences between factors, in light negative relationships, in dark positive.

The positive feedback within the system of more available cash, leading to more cattle in the household, resulting in more cattle being sold and therefore more cash available to buy food during drought years and replacement cattle in a good crop production year keeps the household going. Damage-causing animals outside the national parks reduce the number of cattle directly through preying, and indirectly through disease. Disease affects cattle productivity by reducing growth rate and reproduction potential. Disease incidences increase with increase in drought conditions. Drought reduces forage availability, forcing the already weak animals to graze in contact with soil thus exposing them to infectious diseases. To alleviate loss of cattle due to disease, dip-tank committees (some form of social organisation) facilitate easier and cheaper access to livestock drugs. In extreme drought years, Zhombwe (*Neorautanenia amboensis* Schinz): a perennial leguminous, mostly erect herb or shrublet that forms an underground tuber of up to 45 kg (74% water) used to feed cattle during droughts in south-east Zimbabwe, becomes more important. Zhombwe is used only to feed priority breeding stock because of the labour required to dig the tubers out from ground to save them from dying (Murungweni et al. Unpublished). Most of the household food in cattle-based livelihood type comes from upland fields, which is however, strongly and negatively affected by drought.

3.3.2 Crop-cattle based livelihood system

The crop-cattle based livelihood system (Figure 5) has 21 variables and 51 connections. The sum of all positive connections is 35, and the sum of all negative connections is 21. The density of the matrix is 0.13. Total harvest is the most important variable for securing food in the household. Game meat, garden, crop from vlei areas and small stock especially goats and chicken, become important for cash during drought. External inputs largely include seed, fences and diesel for irrigation. Seed (especially groundnut and sometimes maize) is in short supply after a drought year so people seek seed from outside the livelihood system boundaries. Their cattle are mainly used for draught power so the variable 'number of cattle sold' is secondary. However, cropping is given less attention as the number of household cattle increase. Vlei areas are highly valued for food production during a drought year (Rattray et al. 1953) when upland fields produce nothing. Damage-causing animals outside the park directly reduce total harvest: elephants and wild pigs invade crop fields; pangolin feeds on watermelon and birds (notably quelea) attack small grain crops. The availability of labour determines total food harvest. More labour results in more harvest, but more harvest reduces labour problems of a household: with more food a household can pay labour in exchange with food.

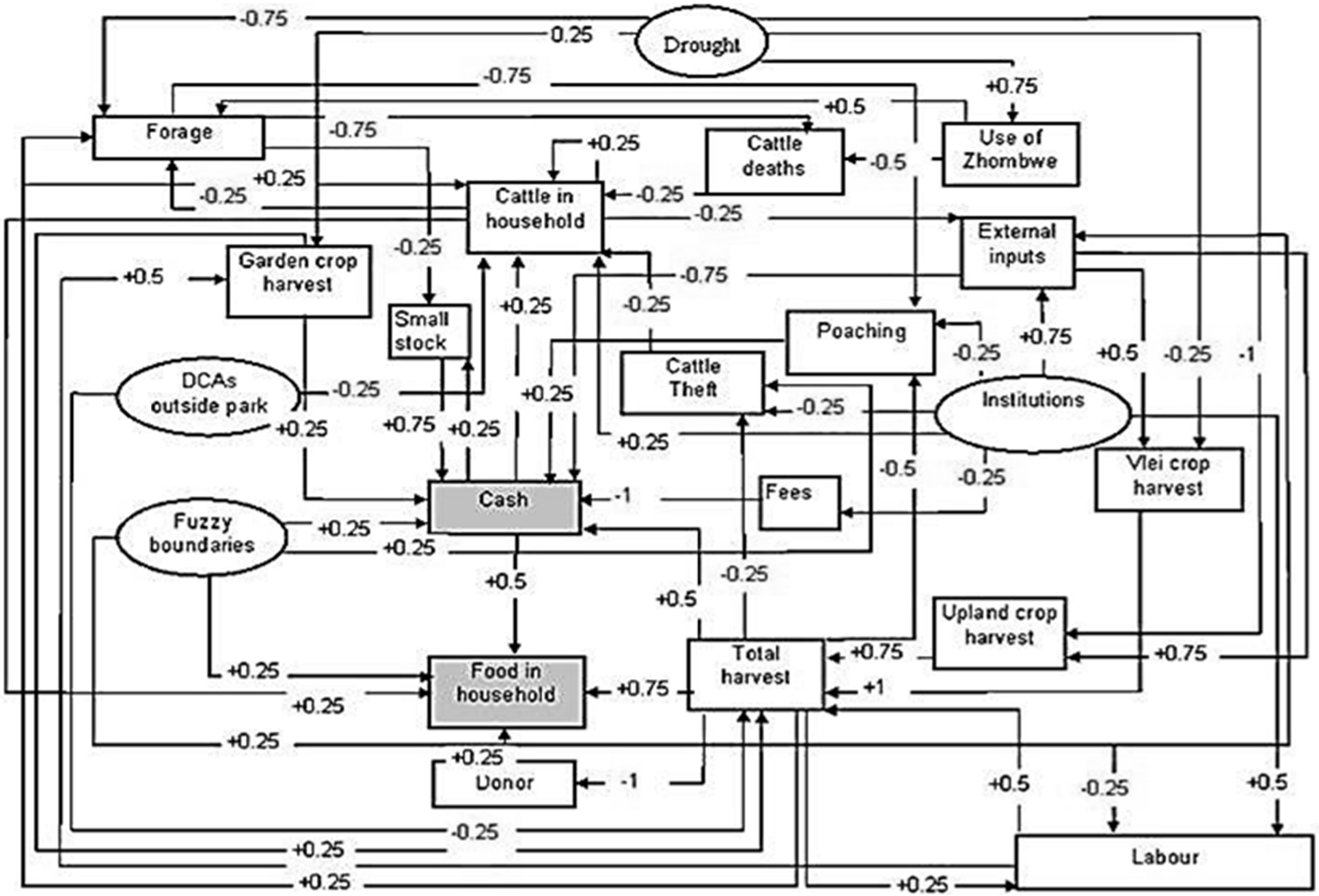


Figure 5: Fuzzy Cognitive Map of crop-cattle based livelihood type. Grey boxes are key indicators of the functioning of the livelihood, white boxes are variables and white circles are drivers of the system. Numbers given are influences between factors, in light negative relationships, in dark positive relationships

After a poor harvest, most household members work for richer families begin season by working for richer families to get food and lose time for their own cropping. This decreases their chances of getting a good harvest during a season that follows a drought year. Their recovery path should be long and complex. *Humwa*, a system whereby a household prepares beer and food and then invites neighbours to help with ploughing, weeding or harvesting, smoothens labour peaks especially for the labour constrained households. Kuronzera/kupfuwisa, a common practice of cattle renting to those in need by those who have many, helps households who lost many cattle during a drought and those with no cattle at all to continue cropping. These two practices are good examples of how social arrangements help to reduce drought effects on labour constraints on crop production. People with more food can use some to hire labour and fewer restrictions at boundaries allows for greater flexibility in accessing food across boundaries. More total harvest results in reduced cattle theft not only because households would have capacity to employ someone to herd cattle but also because fewer people would risk stealing when there is no need.

3.3.3 Non-Farm based livelihood system

The non-farm based livelihood system (Figure 6) has 15 variables and 38 connections. The sum of all positive connections is 27, and the sum of all negative connections is 14. The density of the matrix is 0.18. Available cash and donor food are the most important variables for securing food in the household. People with a non-farm based livelihood system value off-farm activities and remittances, a major difference with the other two systems described above. Drought is the major driver of off-farm activities. Households belonging to this system do not have cattle of their own so do not sell cattle. Number of cattle in the household (that they often get through *kuronzera/kupfuwisa* practice) plays a role in cropping and in bringing food directly into the household. Unclear boundaries determine how remittances contribute to cash and food for the household. Remittances decrease with increase in the amount of food harvested. Fewer people would need to buy food in a good harvest year. Their harvest comes mainly from vlei areas and gardens. Donor food is important as a source of food in the household, but it is largely reduced in a good harvest year in the region and not available to households known to be getting 'good' remittances.

3.4 Scenario analysis

Weights were given to the settings of the different scenarios (Table 2) by turning on the driver full strength to increase effect (+1), or to reduce the effect (-1) or by half strength (±0.5). Graphical output of the FCM models for cash availability in the cattle based (Figure 7A) and crop-cattle based livelihood (Figure 7B) cover the three different scenarios Drought, Border and Desire in relation to the baseline scenario.

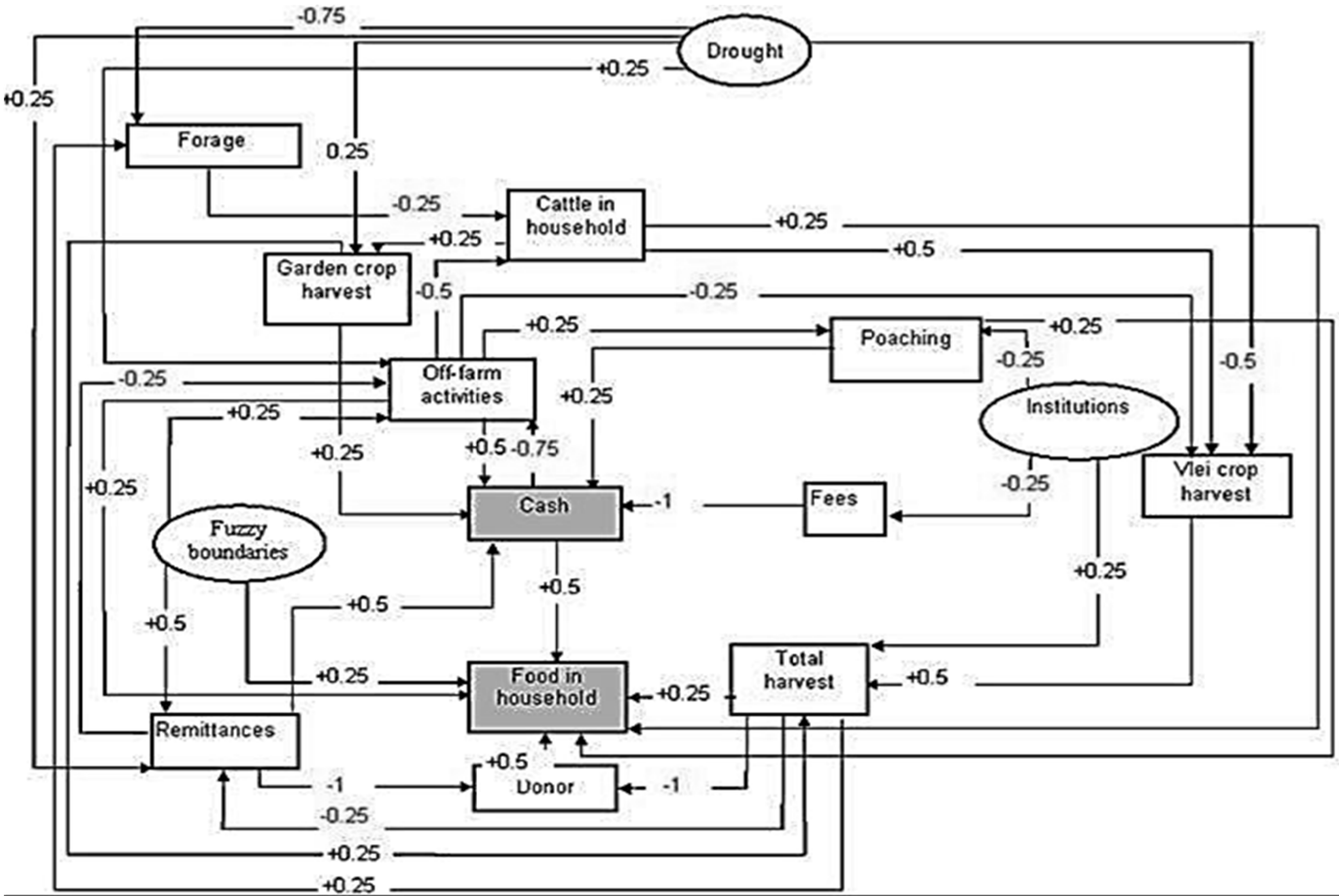


Figure 6: Fuzzy Cognitive Map of non-farm based livelihood type in southeastern Zimbabwe. Grey boxes are key indicators of the functioning of the livelihood, white boxes are variables and white circles are drivers of the system. Numbers given are influences between factors, in light negative relationships, in dark positive relationships.

After an initial transition period the model outcomes stabilise at a certain value, which represents change in the output variable relative to the baseline scenario. The x-axis in Figure 7A and 7B represents the number of vector-matrix iterations, and the length of the transition period therefore shows how many matrix multiplications are needed to take into account all the feedbacks that exist within the system.

Table 2: Strength of the driver of livelihood function (1 = very strong in relation to current situation (0)) by scenario type as identified and described by local people and their stakeholders in south east Zimbabwe.

Driver	Current scenario	Drought scenario	Border scenario	Desire scenario
Drought	0	1	1	-1
Damage causing animals outside park	0	0	0	-0.5
Border restriction	0	0	-1	1
Institutions	0	0	0	1

Note: Current scenario is the reference point all strengths are therefore set at a constant value (0)

The outcomes of all scenarios show a shorter and smoother transition period for the cattle based livelihood type (Figure 7A), and this signifies that the system is less complex and has weaker feedbacks than the crop-cattle based livelihood type (Figure 7B). After the transition period the amount of cash in the cattle-based livelihood type stabilizes at a value of around 0.3 in the Desire scenario, which means a clear improvement in the cash availability compared with the baseline scenario, and a better cash availability compared with the Drought and Border scenarios. Although the uncertainty of the exact value of the variable representing the amount of cash is large (signified here by a wide band determined by the standard deviation of the 1000 runs performed in the sensitivity analysis), it is clear than an increase in amount of cash is a robust outcome of this scenario. Separate sensitivity analyses in which the weights of individual relationships are varied showed, not surprisingly, that the outcomes of the FCM analyses are especially dependent on the relationships with high weights, and that changes in the values of these weights can have significant impact on the outcomes of the FCM analyses (results not shown). In the Drought scenario the amount of cash becomes slightly better than in the baseline scenario because farmers start selling cattle. Whereas the cash situation improves, the number of cattle decreases. In the Border scenario it is more difficult to sell cattle (and prices go down) and therefore the households' cash situation deteriorates (Figure 7A).

For the crop-cattle based livelihood system, the different scenarios resulted in clear differences in terms of cash availability (Figure 7B). The outcomes of the crop-cattle based livelihood system have a longer and haphazard kind of transition period, and this shows that the system is more complex and has stronger feedbacks than the cattle based livelihood. After the transition period the amount of cash in the crop-cattle based livelihood stabilizes at a value of around 0.4 in the Desire scenario, which means a clear improvement in the cash availability compared with the baseline scenario.

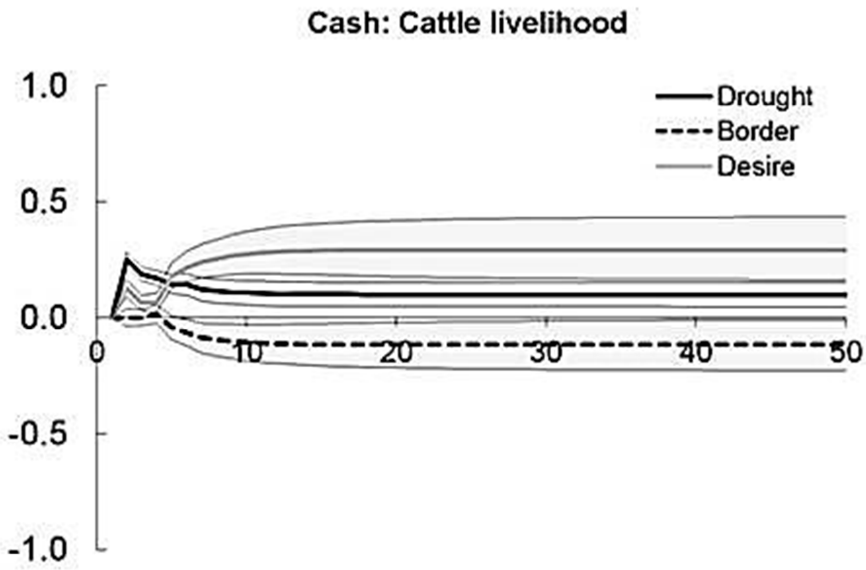


Fig. 7A

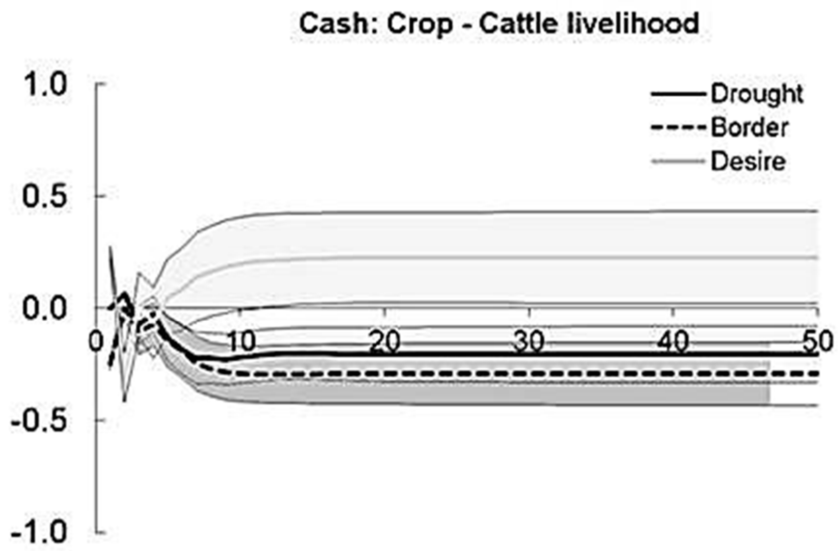


Fig. 7B

Figure 7. Output of the Drought, Border and Desire scenarios relative to current scenario (for explanation see text and Table 2). X-axis: number of iterations; Y-axis: value of Cash for cattle-based livelihoods (A) and cattle-crop based livelihoods (B), relative to current scenario. The light grey bands represent plus and minus the standard deviation of the ensemble scenario simulations in the sensitivity analysis (for explanation see text).

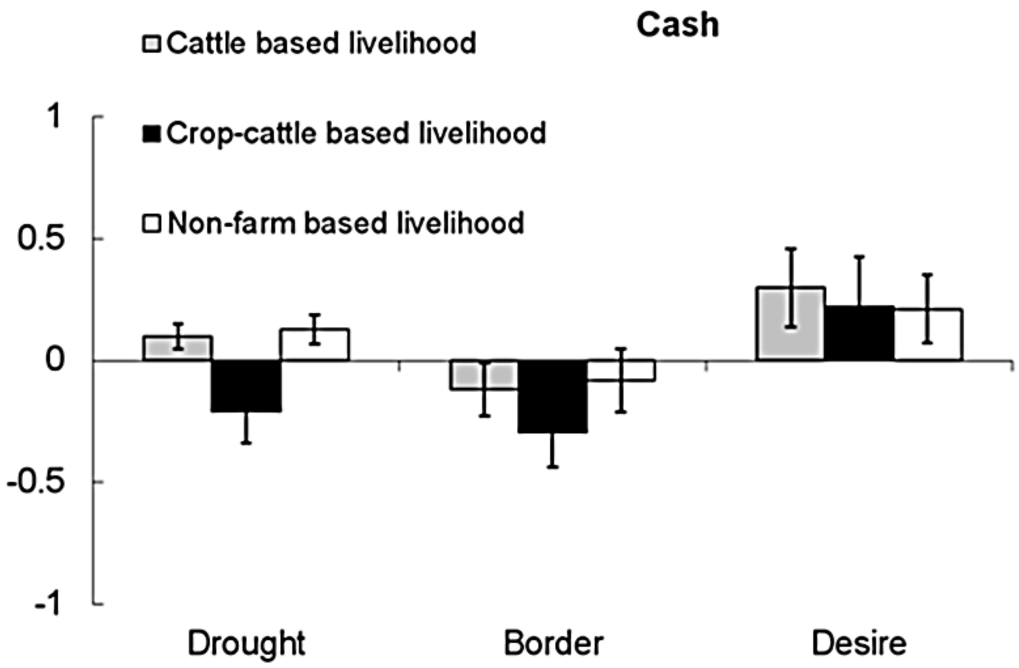


Fig. 8A

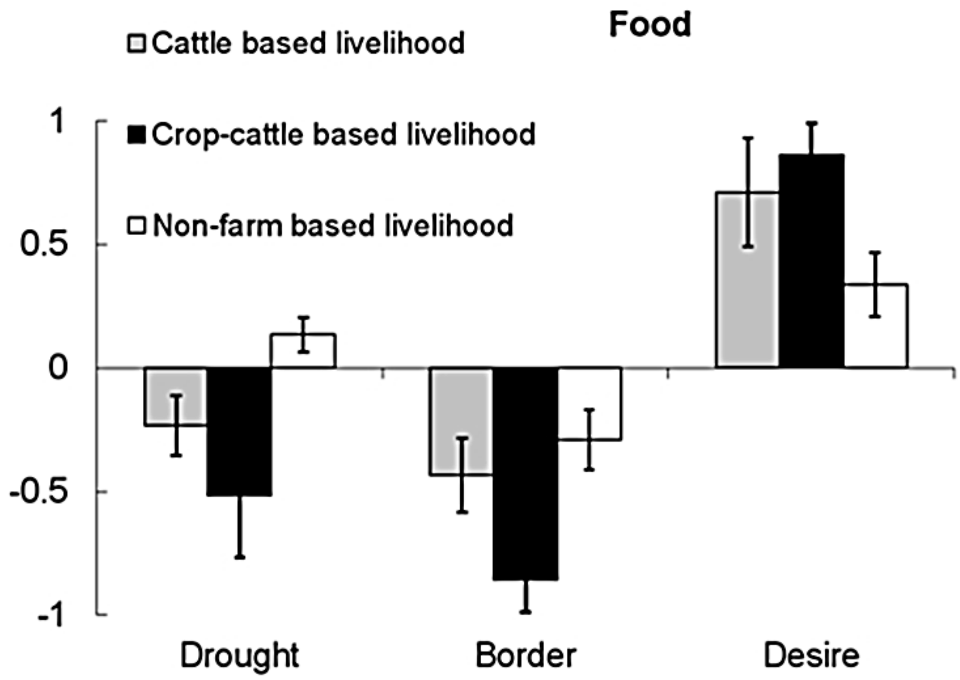


Fig. 8B

Figure 8. Output of the Drought, Border and Desire scenarios (for explanation see text and Table 2) on A) cash situation and B) Food situation of different livelihood types of Zimbabwe's south eastern lowveld. X-axis: Scenario type; Y-axis: value of A) Cash and B) Food, relative to current scenario. Error bars the standard deviation of the ensemble scenario simulations in the sensitivity analysis (for explanation see text).

However, the Drought scenario (stability value of -0.35) and the Border scenario (stability value of -0.45) both show a clear reduction in available household cash. People rely on their garden for food and cash and also sell small stock across the border. So, if the boundaries are closed, cash availability is reduced more. The difference between the stability values shows that the crop-cattle livelihood has a more sensitive cash situation than the cattle-based livelihood.

To assess the overall effects of the scenarios on cash and food availability in the three livelihood types the stabilized FCM outputs are shown in Figure 8A (for cash) and Figure 8B (for food). The cash and food situation of the crop-cattle livelihood type shows the highest sensitivity to changing conditions compared with the other two livelihood types. In all cases, the food availability is strongly reduced in the Border scenario and strongly increased in the Desire scenario. The Border scenario was the worst scenario. The non-farm livelihood type showed the smallest sensitivity.

4. Discussion

4.1 The usefulness of Fuzzy Cognitive Maps in livelihood analyses

The framework presented in this study was able to give a graphical representation of the most important factors within the livelihoods and how these factors interact, and to use this as a basis to analyse the vulnerability of livelihoods to external changes. When using Fuzzy Cognitive Maps (FCMs) the presence of certain factors and relationships have to be made concrete and therefore the consequences of the representation chosen by the researcher based on the input of local people and stakeholders can be quantified. As such FCM can be used as a tool to represent the outcomes of a qualitative study of livelihoods, and is a promising tool for formalising systems knowledge. The process of data acquisition is in itself long and labour demanding due to many steps involved and the wide consultation during early stages of the FCM development. However, the iteration process within and between stages makes the process sufficiently robust to generate a deeper understanding of the underlying factors determining livelihood types and their function, also observed by van Vliet et al. (2010). Furthermore, the process carries researchers and local people along with their stakeholders from beginning to end. This enhances wider acceptance and ownership of the output by the intended users. The approach puts people and stakeholders to task on negotiating what is relevant and what is not. That way, it reveals hidden knowledge and insights that we cannot generate by working with individuals separately. A structured, semi-quantitative understanding of the system perceptions of a group of participants is one of the strengths of FCM (van Vliet et al. 2010). The interaction involved presents an opportunity for knowledge synthesis between different stakeholders. These characteristics and their ability to take into account feedbacks in the analyses makes FCMs a useful tool alongside other methods such as Bayesian Belief Networks (Martínez-Santos et al. 2010), which have the advantage of being more quantitative even though they cannot analyse for feedbacks.

In the scenario analyses FCM gives an idea of the direction in which the system will move given certain changes in the driving variables, and it also gives an idea of the magnitude of system fluctuations after a disturbance. The sensitivity analysis showed how robust each of the outcomes were, and was therefore useful to interpret the outcomes. Using FCM in scenario analysis was powerful because local people and other stakeholders could understand what was meant with each scenario, and could relate to the outputs that were generated by the FCMs. By using peoples' experiences we make use of trends relevant to the affected group targeted for analysis. FCMs also have weaknesses as tools for livelihood analyses. Simulation output of FCM shows values in relative terms according to how large or small without saying exactly how large is large and the reverse. Kok (2009) and Özesmi and Özesmi (2004) described some of these weaknesses in other work. Because it is not a dynamic modelling tool, FCM does not give insight on how long it takes the system to self organise after disturbance, for example when cattle die in a drought or how long does it take the affected household to return to their normal way of life.

4.2 Livelihoods in south-eastern Zimbabwe, their functioning and their vulnerability

In the case study presented, three key livelihood types were distinguished. These were cattle-based (12%), crop-cattle based (41%) and non-farm based (47%). The analyses showed that people in each type are affected by hazards differently and react differently to resulting change: their vulnerability to change differs. For example, drought affects those depending on land resources more than those depending on the wider economy. Climate change is well documented as one of the major stressors of livelihood systems in semi-arid regions but the analysis of vulnerability by FCM method showed us that issues of policy such as changing situations at borders, can result in problems of greater magnitudes than drought as observed in our case study. In their work on assessing vulnerability to climate change of dry-land pastoral systems, Dougill et al. (2010) found that qualitative issues of policy increase vulnerability of poorer communal pastoralists. Assessment of vulnerability of livelihoods indeed brings insights on what policy makers can focus to improve on if win-win situations, as proposed within the GLTFCA, are to be realised.

The general notion in rural livelihood studies in semi-arid regions is that cattle play a central role in livelihoods of people living in marginal areas (Kinsey et al. 1998, Cumming 2005). The results of our study qualify this general statement. We found that in the south-east lowveld the number of cattle owned by a household is especially important. Herd size is not merely a sign of wealth, it is indicative for different production orientations. It is a defining variable for local people when asked to distinguish different livelihoods. Having many cattle reduces a households' vulnerability as it is a source of instant cash (ploughing for cash, transportation, sale) without immediately jeopardizing the households' productive capacity in crop cultivation. The number of cattle spans a household has determines the area that can be planted, and how fast this can be done. Timely planting is a major factor in crop success in these marginal rainfall areas (Nyamudeza 1999). But besides cattle, polygamous marriages and large families are a sign of wealth especially among the Shangaan speaking people where large families are subsequently associated with cattle-based livelihoods.

4.3 Livelihoods' vulnerability and drought

In south-east Zimbabwe droughts are usually associated with outbreaks of livestock disease, especially tick borne, lumping skin and foot and mouth disease (FMD). Limited grazing outside the national park and dried-up water points in the dry season and in drought years result in greater animal concentrations on the limited resources. Consequently, the likelihood of buffalo-livestock interactions and disease transmissions, especially at water points, increases. Buffalo are reservoirs for ticks and FMD, mixing buffalo and cattle increases chances for tick-borne diseases and FMD outbreaks. While the more wealthy households can afford to invest in vaccination and treatment, poorer households rely more on traditional medicines, usually from protected shrubs and trees within the GNP. To reduce FMD outbreaks, movement of cattle into non-affected areas is restricted; however, this depresses cattle sales and prices. Yet, as long as park and international boundary controls are limited, such effects of disease can be mitigated. Both traditional remedies for cattle diseases and cattle markets in Mozambique remain accessible, even though these options are illegal. Increased boundary controls thus increase especially poorer cattle owning households' vulnerability to drought.

Whereas droughts deplete both food resources and cash of cattle-crop based livelihoods as food needs to be purchased, in times of drought we found that cash and food availability tends to increase for non-farm livelihoods. To understand this, one has to appreciate the ways in which these livelihoods' are linked into the wider economy. Their cash situation tends to improve as droughts induces these households to sell home-made crafts in towns like Chiredzi, Beitbridge and Masvingo, or abroad or seek temporary employment in Mozambique and South Africa where often household members already work. The sale of crafts and labour outside the area add to explanation on their improved food situation during drought. Whereas wealthy households with cattle based livelihoods can raise the cash for food purchasing during drought, their food situation usually deteriorates as local supplies run out. Households with non-farm based livelihoods are better positioned to deal with this situation. They purchase and transport food from further away. Truck deliveries of food from relatives working outside the country is but one example of how these livelihoods are embedded in wider networks of economic exchange.

Especially in the analyses of the effects of drought on the functioning of the livelihoods FCM showed that it can be a powerful tool. Due to the incorporation of important feedback mechanisms like the sale of cattle, the tool showed the difference between indicators that are affected directly by drought (e.g. food self-sufficiency) and variables in which the buffering capacity of the household plays an important role (e.g. cash). Without the incorporation of feedbacks like the sale of cattle a livelihood analysis would over-estimate the vulnerability of the livelihoods to drought. In this respect FCM compares favourably to tools like Bayesian Belief Networks. If more quantitative information is available other techniques like dynamic systems modelling can be used (e.g. Dougill et al. 2010), but it is always attractive to start an analysis with a rapid and easily applicable tool like FCM, in which knowledge of both the ‘soft’ and ‘hard’ science side can be incorporated, followed by a more in depth assessment of the individual relationships. We therefore do not see FCM as the final product of a livelihood assessment but rather as a way to quickly get the most important aspects of the functioning of livelihoods on the table, to be followed by further in-depth and more quantitative studies.

In drought prone areas crop cultivation dependant livelihoods are, obviously, most vulnerable. In the south-east lowveld such livelihoods face the additional risk of crop destruction by elephants and other wildlife. Households of the crop-cattle based livelihood type deploy several strategies to reduce these vulnerabilities. They crop larger areas, plant as much as they can in a short period of time and with subsequent rains, grow different drought tolerant varieties of staple crops (maize and sorghum), practice dry-planting of sorghum in order to benefit from the first rains, and reduce labour peaks at the beginning of the season, and replant up to three times if necessary. This happening was also observed and described by Nyamudeza (1999). The practice of continuous planting can, however, cause a shortage of planting material, increasing vulnerability in the next season. Thus one can understand a preference for open pollinated maize varieties and limited boundary controls, the latter allows for purchase of seed from farmers across the border.

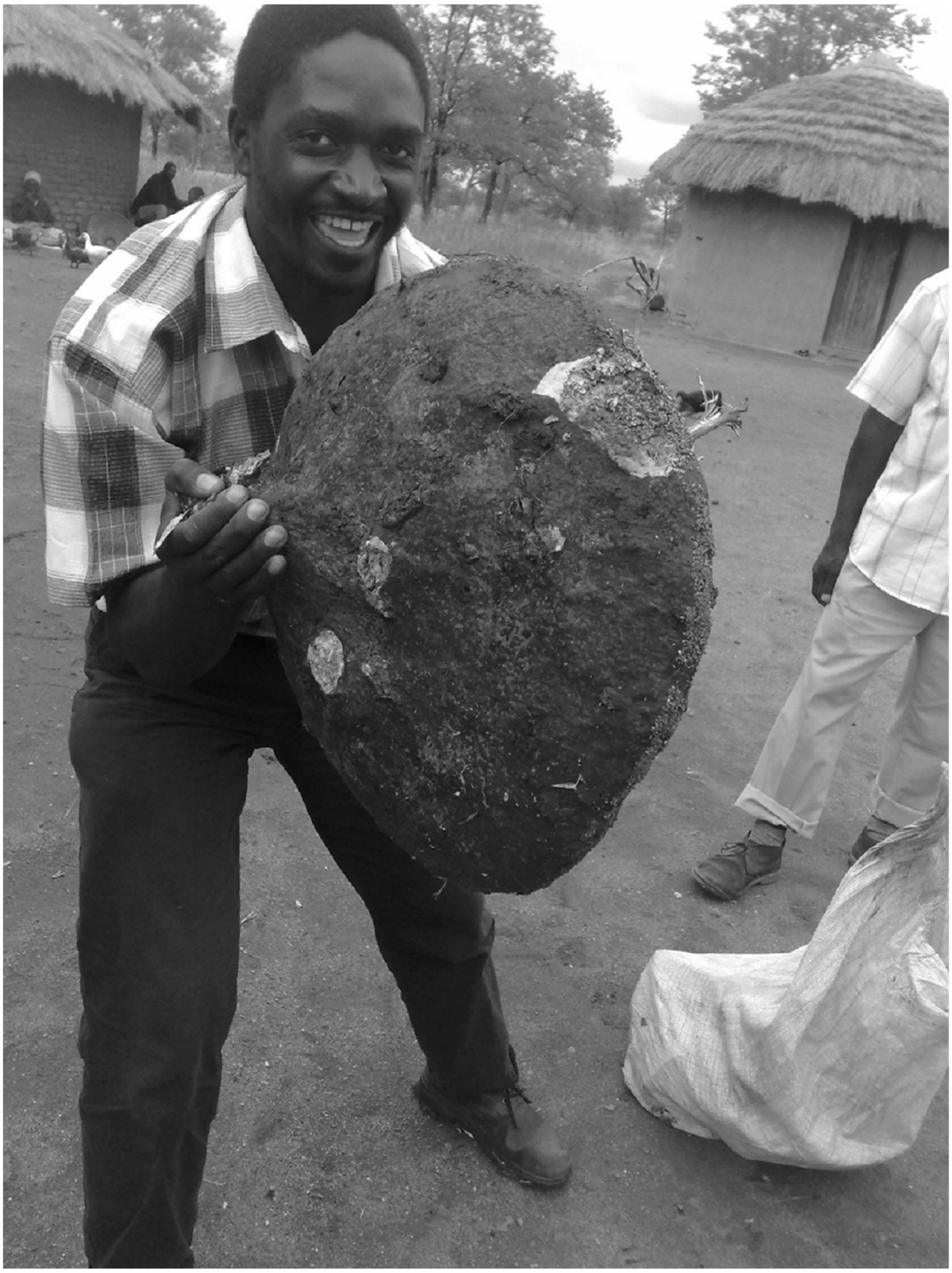
In the context of the development of the GLTFCA there is another reason why boundaries and their control are highly relevant for understanding the vulnerability of, especially crop-cattle based livelihoods. In addition to the above mentioned strategies to reduce the risk of crop failure, crop farmers prefer to plant crops in different locations. Particularly vlei areas are preferred locations as these low-lying areas return moisture longer than the upland areas. When drought wipes out a crop in upland fields, vleis can still produce, and vice versa, when too much rainfall swamps vlei areas, better draining upland areas can still yield. A special kind of vlei area in south-east lowveld of Zimbabwe is the Banyeni or flood plains. In addition to water from rains and run-off (as the vlei areas), flood plains also receives water from flooding rivers. In Sengwe, the area along the Limpopo River, the Banyeni has the added advantage of nutrient replenishment from alluvium when the river floods. This Banyeni area lies within the proposed Sengwe-Tchipise wildlife corridor that is proposed as part of the GLTFCA to connect the GNP directly to South Africa’s Kruger National Park. The wildlife corridor may cause people in Sengwe to be displaced and/or their fields in the Banyeni to be fenced. Even when fields are fenced out, the corridor will increase wildlife presence in the area; people in Sengwe fear its development, as they expect no compensation for wildlife destruction of crops, the same way as the current situation with people living close to the park. Again, crop-cattle based livelihoods appear to be most vulnerable to such redefining of boundaries; although also cattle based and non-farm based livelihoods will be affected. Grazing areas may be reduced and risk of wildlife-livestock disease transmission is likely to increase. As the corridor is likely to reduce access to natural resources such as fish ponds, the fruit belt known locally as pfungwe and bird sanctuaries in addition to constraining (illegal) border crossings, this will negatively impact non-farm based livelihoods’ dependence on non-agricultural sources of food and income in the area and across the border, in South Africa.

5. Conclusions

FCM successfully gives semi-quantifiable information concerning the nature (increase or decrease) and magnitude (large increase or small decrease) by which a livelihood system changes under different scenarios. However, it does not explain the recovery path quantitatively in relation to time and pattern (e.g. how much time it takes for cattle to come back to desired numbers after a drought). We found that the interactive nature of FCMs reveals hidden knowledge and insights that improves our understanding of the complexity of livelihood systems in a way that is better appreciated by stakeholders. Analysis of vulnerability by FCM method showed us that issues of policy like changing situations at borders, can strongly aggravate effects of climate change, for example the drought sensitivity component of the vulnerability of livelihoods. Various literatures reveals that the current debate on development within the GLTFCA is taking place at higher levels without proper understanding of different needs of different people to be affected by decisions. FCMs can assist in effective communication platforms to involve communities in project participation and benefit sharing.

Chapter 4

Zhombwe (*Neorautanenia amboensis* Schinz) – A Recent Discovery for Mitigating Effects of Drought on Livestock in Semi-arid Areas of Southern Africa



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Abstract

In semi-arid areas drought results in cattle death making people vulnerability to poverty. People in southern Africa recently discovered *Neorautanenia amboensis* as an important medicinal feed that they now use to help cattle survive drought. There is no literature on use of *N amboensis* by people. *N. amboensis* was evaluated with the aim of providing scientific substantiation of peoples' claims by determining extent of its use, feed and anthelmintic value and the ecological characteristics that explain its distribution. Information on characteristics and use of *N amboensis* was gathered from focus group discussions and the semi-quantitative survey that employed structured interviews with both closed and open questions. Survey data were analysed in PASW Statistics 18 software. Feed value of *N amboensis* was evaluated using proximate analysis and digestibility assessment. Its anthelmintic value was evaluated in feeding trials with cattle and goats naturally infected with strongyloid. The results showed that *N. amboensis* is used during drought by 59% of cattle owners, 14.5% do not use it because they have alternative grazing and 26.5% did not know it can be used as cattle feed. *N. amboensis* contain adequate nutrients for maintenance of ruminant livestock. Infected animals fed on *N. amboensis* ended with less strongyloid worm infection in small ruminants ($P < 0.05$) and in large ruminants ($P < 0.01$) similar to animals dosed with recommended drugs. In the natural environment, *N. amboensis* was more commonly found in Eutric vertisols and Chromic luvisols than in Ferric arenosols and Leptosols, more in open spaces than in closed forests and more in cultivated areas than in naturally vegetated areas. *N. amboensis* is a useful medicinal feed for ruminant livestock especially in semi-arid areas that are prone to cyclic droughts. It grows in a range of different types of soils and management affects its abundance. *N. amboensis* can play a central role in promoting the resilience to drought for cattle keeping households.

Keywords: anthelmintic; strongyloid; drought; ruminant livestock; vulnerability.

1. Introduction

The catastrophic two-year drought in southern Africa from 1991 to 1992 resulted in death of 1.03 million cattle in Zimbabwe alone, more than 23 per cent of the national herd (Tobaiwa, 1993). Semi-arid areas were the worst affected, 75% of cattle in one ward (Matibi 11), south-east lowveld of Zimbabwe, died during this period (Cumming, 2005). During the drought, a local farmer in the south-east lowveld was surprised to see two of his cattle eat tubers of *Neorautanenia amboensis* Schinz (*N. amboensis*) that were exposed by ploughing. Tubers of this shrubby legume are known locally to be poisonous; they are used by some to harvest fish from dams. Pigs have been observed to develop serious health complications when they eat this tuber. So, the farmer expected his cattle to die, but to his surprise they showed no signs of illness. Since no other feed was available, and cattle in the area were dying, the farmer dug up more tubers of *N. amboensis* and fed them to his other cattle. Only cattle he fed with the tubers survived the drought, and since then many more farmers started using *N. amboensis* as a feed during droughts. Livestock keepers reported that intestines of slaughtered animals fed on the tubers had much less worm infection in their intestines when slaughtered, and no signs of parasites in their dung. Such information from local people, has been appraised by researchers as Scott and Hewett (2008) and Toledo et al. (2009) to be valuable if properly structured.

Parasitic worms, collectively referred to as helminths are very common in cattle herds and their control using chemicals is recommended. Helminths are a general term applied to multi-cellular worms that can be divided into three forms, namely: Nematodes (e.g. strongyloid, pinworm, hookworm, ascaris and trichuris), Cestodes (e.g. tapeworms) and Trematodes (e.g. intestinal flukes). Parasitic infections, notably of nematodes have little impact on cattle mortality especially in drier regions, but they have a high economic impact because they cause retarded growth, weight loss, disorder in fertility and loss in milk production (Loyacano *et al.*, 2002). In recent years, resistance to broad spectrum anthelmintic has been of major concern in veterinary parasitology (Waller, 1997). This resistance has been reported with products like Benzimidazoles and macrocyclic lactones e.g. Avermectins and Milbemycins (Mejia *et al.*, 2003; Suarez and Cristel, 2007) and Levamisol (Waller, 1997). Alternative sources for making new anthelmintic are needed. To our knowledge the use of *N. amboensis* as feed or anthelmintic has not been reported previously. This prompted us to investigate: 1) the use and characteristics of *N. amboensis* tubers, 2) its feed value and anti-helminthic properties, and 3) its distribution in the natural environment using the south-east lowveld of Zimbabwe case study.

2. Materials and Methods

2.1 The Study Area

The south-east lowveld of Zimbabwe lies below 600 m above sea level. Rainfall is highly variable (CV of 35%) with an annual average of 400 mm mainly falling between November and April, and only rare showers the rest of the year (Cumming, 2005). The wooded savanna developed on fertile soils is referred to as 'sweet veld[†]' because it remains nutritious and palatable for livestock throughout the long dry winter season. This veld is described as 'Aristida-Dactyloctenium-Eragrostis other species grassveld' and has a carrying capacity of 0.084 to 0.14 tropical livestock units per ha (Rattray, 1957). Common grasses are *Aristida adscensionis*, *Dactyloctenium giganteum*, *Eragrostis viscosa*, *Chloris virgata* and on deeper soils with more moisture Urochloa spp., Panicum spp., *Cenchrus ciliaris* and Digitaria species (Rattray, 1957).

Cattle occupy a central position in livelihoods in the semi-arid regions of rural Africa, (Kinsey *et al.*, 1998; Mavedzenge *et al.*, 2008). In addition to problems of lack of water and feed during drought periods (Oba, 2001), the transmission of diseases is promoted by increased contact between cattle herds with wildlife around the remaining watering holes (Foster, 1993; Dragon *et al.*, 1999). Cattle exhibit annual live weight gains of 15 kg per ha in well-managed grazing systems, but the grass biomass disappears rapidly in drought years or when the start of the rainy season is delayed (Elliott and Folkersten, 1961; Sibanda, 1984). The abundance of a variety of trees and shrubs with leaves and twigs relished by cattle, such as *Colophospermum mopane* (Mopane), *Grewia monticola* (Donkey berry), and species of Combretum and Acacia extends the availability of feed into the dry season. But during drought such options become limiting due to early and increased dependence on browse.

2.2 Interviews with livestock keepers

In order to understand how cattle farmers use *N. amboensis*, two types of interviews were conducted. The first one involved two focus group discussions. One group consisted of six household heads each with more than 50 cattle and residing in Gonakudzingwa small-scale commercial farms. The other comprised of nine heads of households in Chikombedzi Ward 11, Sengwe Communal Area who own cattle. In these focus group discussions, questions were asked relating to uses of *N. amboensis,* who uses it, how it is used and when it is used. Second set of interviews were semi-

[†] Veld is a term used to describe the savanna grasslands of southern Africa

structured with both closed and open ended questions conducted on randomly selected cattle owners (n=83) from the rural area. These interviews were meant to gain more insights and to quantify use of *N. amboensis* by local people.

2.3 Determination of the feed and anthelmintic value of *N. amboensis*

Tubers of *N. amboensis* were dug up in the Sengwe communal area, south-east lowveld of Zimbabwe and transported to Grasslands Research Station, Marondera, Zimbabwe for analysis and use in feeding trials. Grasslands Research Station is located on Latitude 18° 11'S and Longitude 31°30'E, at an altitude of 1200 m above sea level. Mean annual rainfall ranges from 600 to 900 mm with at least 80% falling between November and March. Mean maximum temperatures of 31.1^{o}C occur in October and the mean minimum of 8.4^{o}C in July. Management of experimental animals was in accordance with the internationally accepted principles for laboratory animal use and care as found in the European Community guidelines (EEC Directive of 1986; 86/609/EEC).

2.3.1 Chemical composition of tubers

Tubers were first peeled (i.e. farmers' practice) and cut into small slices to facilitate processing for analysis using standard methods (AOAC., 1990). The water content was determined after oven drying fresh samples of eleven tubers randomly selected from 35 tubers dug out from different sites in the study area. Crude protein was determined as 6.25 x total N using the Kjedahl method. Crude fat was determined by Soxhlet extraction. Samples were ashed in a furnace at 600^{o}C. Neutral detergent fibre (NDF) and acid detergent fibre (ADF) were determined by the method of van Soest (Goering and van Soest, 1970). Digestibility was determined in vitro (Tilley and Terry, 1963) as described by Forejtova et al. (2005)

2.3.2 Evaluation of the anthelmintic value of *N. amboensis* in goats

Twelve female Boer goats were weighed and dipped before being randomly allocated individual pens (5 m x 3 m). Dung samples were collected from the rectum of each of the goats and analysed for helminths load (number of eggs/g of faeces) using flotation and sedimentation methods. Helminths load was used to stratify individual goats into uniform groups before randomly assigning them to two treatments. The treatments were: 1. the control treatment with six goats placed on recommended drug treatment 'Closavet' (active ingredient sodium closantel – a benzimidazole). These goats were fed a basal diet of 800 g hay of *Cynodon nlemfuensis* cv. No. 2 (9.5 % CP) ad libitum with free access to clean water. 2. The test treatment with six goats feeding on 300 g of *N. amboensis* tuber on alternate days with the basal diet of 800 g hay of *Cynodon nlemfuensis.* This was done to ensure that the goats received an adequate supply of roughage for proper rumen functioning. To encourage intake, goats on the tuber diet were initially given 300 g of *N. amboensis* and cottonseed cake in equal mixed proportions. The cottonseed cake was gradually replaced until the diet was solely 300 g *N. amboensis* by the end of the week. Animals were fed once a day at 08.00 hrs. Daily feed intake was estimated by weighing refusals each morning before new feed for the day was weighed and offered. Dung samples were collected for analysis at the end of the trial after 30 days. Differences between treatments in helminths load were tested using the non-parametric Mann-Whitney U Test.

2.3.3 Evaluation of the anthelmintic value of *N. amboensis* in cattle

Eighteen 13 month-old steers weighing 290 ± 22 kg on average were dipped before being randomly allocated individual pens (10 m x 4 m). Dung samples were collected from the rectum of each of the steers and analysed for helminths load (number of eggs/g of faeces). Helminths load was used to stratify individual steers into three uniform groups and the members of each group randomly assigned to three treatment groups, each with six steers. These were then treated as: 1. Control group not treated against helminths and fed a basal diet of hay of *Hyparrhenia filipendula* (5.5% CP) ad libitum, plus a protein supplement of 1 kg cottonseed cake (40.2% CP). 2. Recommended drug treatment against helminths drenched with Rafasol (active ingredients Rafoxanide 3% m/v and Levamisole 3% m/v) and fed on the basal diet. 3. *N. amboensis* treatment group fed tubers or the basal diet on alternate days. The tubers were initially chopped into 1 cm^3 pieces but with time cattle ate 3 to 5 cm^3 pieces. Intake was poor for the first few days but increased gradually from 2 kg per day to maximum of 6 kg fresh matter at the end of the second week. *N. amboensis*, hay and refusals were weighed, and new feed weighed and put into feeding troughs at 08.00 hrs each day. Helminths load was analysed at the end of the trial.

2.4 Distribution of *N. amboensis* in the study area

Sampling points at the center of a 5×5 km grid generated by GIS were mapped across the whole 3 077 km^2 area of Wards 11 to 15 bordering Gonarezhou National Park (Mabalauta sub-region). At the center of each grid square, *N. amboensis* plants in a 30 m $\times$ 30 m quadrant were counted. Altitude, land use (crop field or natural veld) and vegetation cover in the quadrant were measured. A soil Map of Zimbabwe was overlaid on the study area map in order to analyse if there were any differences in the abundance of *N. amboensis* between soil types. Analysis was done using the Kruskal Wallis test.

3. Results

3.1 *Neorautanenia amboensis* and its uses

Neorautanenia amboensis, known locally as 'Zhombwe' by Shona speaking people who dominate Wards 11 and 12 and 'Pombwe' by Shangaan speaking people who dominate Wards 13 to 15 is now seen as a 'God-given life saver' – (Mr. Zanamwe, Figure 1. A).

Figure 1: A. Mr. Zanamwe a farmer from Farm no.1 Gonakudzingwa elaborating on importance of *N. amboensis* that saved his 45 cattle during the 1997 drought. B. leaves and flowers of N. amboensis. C. Pods. D. An ox-cart full of harvested tubers. E. A large tuber. F. Size of tuber pieces fed to cattle.

N. amboensis is a perennial, mostly erect herb or shrublet that produces purple flowers and pods (Figure 1. B,C) on often trailing stems averaging 83.3 cm (SD=14.5 cm), n=35. The underground tubers have an average weight of 15 kg (SD=6.8 kg)), n=35 and horizontal circumference up to 86.4 cm (SD=12.5 cm), n=34. In eutric vertisols, large tubers can weigh up to 45 kg (Figure 1D, E). Traditional uses of *N. amboensis* are summarised in Table 1 below.

Table 1: Uses and users of *N. amboensis*, how and when the tuber is used in south-east lowveld of Zimbabwe.

	Cattle keepers in rural areas	Cattle keepers in Gonakudzingwa smallscale commercial farms
Output from focus group discussions		
1. Feeding animals	*N. amboensis* is commonly used during critical feed shortages e.g. drought, or sometimes during dry season (often August to October). April to July of the dry season, cattle feed on dry leaves of *Colophospermum mopane*	Only farmers with poor grazing in their farms (Those farms on poorer soils) use *N. amboensis* but only during critical droughts like the 1991-1992 and 1997. If there is shortage of grazing during dry seasons they rent grazing in other commercial farms with excess
2. Dosing animals	Not a common practice, but some people do that around February. Dosing before the rainy season is not necessary because the cattle were feeding on *N. amboensis* anyway	Common only during years of national economic crisis when medicines are not available or are inaccessible for example in 2007 to 2010.
3. Treating bad wounds on cattle	Common practice now	Not a common practice, they buy medicines
4. Harvesting fish	Not very common but few people do this. They cut the tuber into small pieces and spread in pools of water to stun fish for harvesting especially during dry seasons and drought years	Not a common practice, they would rather kill an impala or another small animal for food
Output from focus informal interviews with local people		
5. Habitat	Most people interviewed said *N. amboensis* is found mainly in black soils that crack; more so in farmers' fields than in grazing areas. We observed that only people in areas where grazing is in short supply had knowledge on use of *N. amboensis* as cattle feed. The extent of knowledge on these uses decrease as we move from Chikombedzi (Ward 11) and Gonakudzingwa (Ward 12) which are further north of Limpopo to Chibhavahlengwe (Ward 13) and upper part of Xini-Maose (Ward 14) which are somewhere in the middle, to no knowledge at all in lower parts of Wards 14 and 15 close to Limpopo river	
6. Other uses	Few people between Limpopo and Chikombedzi areas use *N. amboensis* for dosing cattle only. Towards Limpopo river hunters use to prepare mixture (with food) for their dogs to improve their tracking abilities (personal interview with Mr. Mathosi of Sengwe ward)	

Livestock feeding is the major use in the south-east lowveld of Zimbabwe. The use of *N. amboensis* as a livestock feed began during the 1991-1992 drought and spread to other areas afterwards, especially to areas with poor grazing. Of the 83 cattle farmers interviewed, 59% use *N. amboensis* during drought, 14.5% don't use it because they have alternative grazing and 26.5% don't know it can be used as cattle feed.

All farmers who use *N. amboensis* to feed their cattle during drought reported that animals feeding on the tubers can go without water for more days than when reliant on grass or browse. The joints of cattle feeding on the tubers are always strong no matter how thin the animal will be. This means animals feeding on *N. amboensis* can walk relatively longer distances than others and can still pull a plough as some farmers explain. They also observed that animals feeding on *N. amboensis* produce dung that is thinner. They consider thinning of dung as helping to flush worms from the animals' guts and also helping digestion of dry and fibrous roughages when fed together. Farmers further observed that slaughtered animals that had been fed with the tubers had cleaner intestines, and worms were not seen in their dung. Some farmers began experimenting with the tuber, they applied dry slices of the tubers to bad wounds on their animals and discovered that the wound remains clear of infection and heals rapidly. Negative effects were also observed, farmers say milking cows feeding on *N. amboensis* produce milk that does not turn sour as fast as they would expect, and the milk will not have the 'normal' milk taste.

3.2 Chemical composition and digestibility of *N. amboensis* tubers

The fleshy tuber of *N. amboensis* had a crude protein content of 104 g/kgDM. The water content of the tubers was 74 % (SD=4.3%)) (n = 11). The neutral detergent fibre (NDF) contents of the tubers of 241.5.2 g/kg DM was below the minimum expected mass fraction of 250 g/kg DM whereas the ADF content of 192.4 g/kg DM for was above the minimum 160 g/kg DM recommended for fibre in ruminant diets. The fat content of the tubers was low (8.4g/kg DM) which is far below the maximum recommended 6% after which can cause laxative effects during passage. Gross energy of the tubers was (17.3 kJ/g). Dry matter digestibility of the tubers was high at 83.1% (SD=10.7%), n = 9.

3.3 Anthelmintic value of *N. Amboensis*

N. amboensis reduced the load of strongyloides in infected goats similar to dosing with Closavet (z=1.3731, not significant). Within one month, both Closavet and *N. amboensis* reduced the load of strongyloides in goats to an infection level below that likely to cause major economic losses (Figure 2).

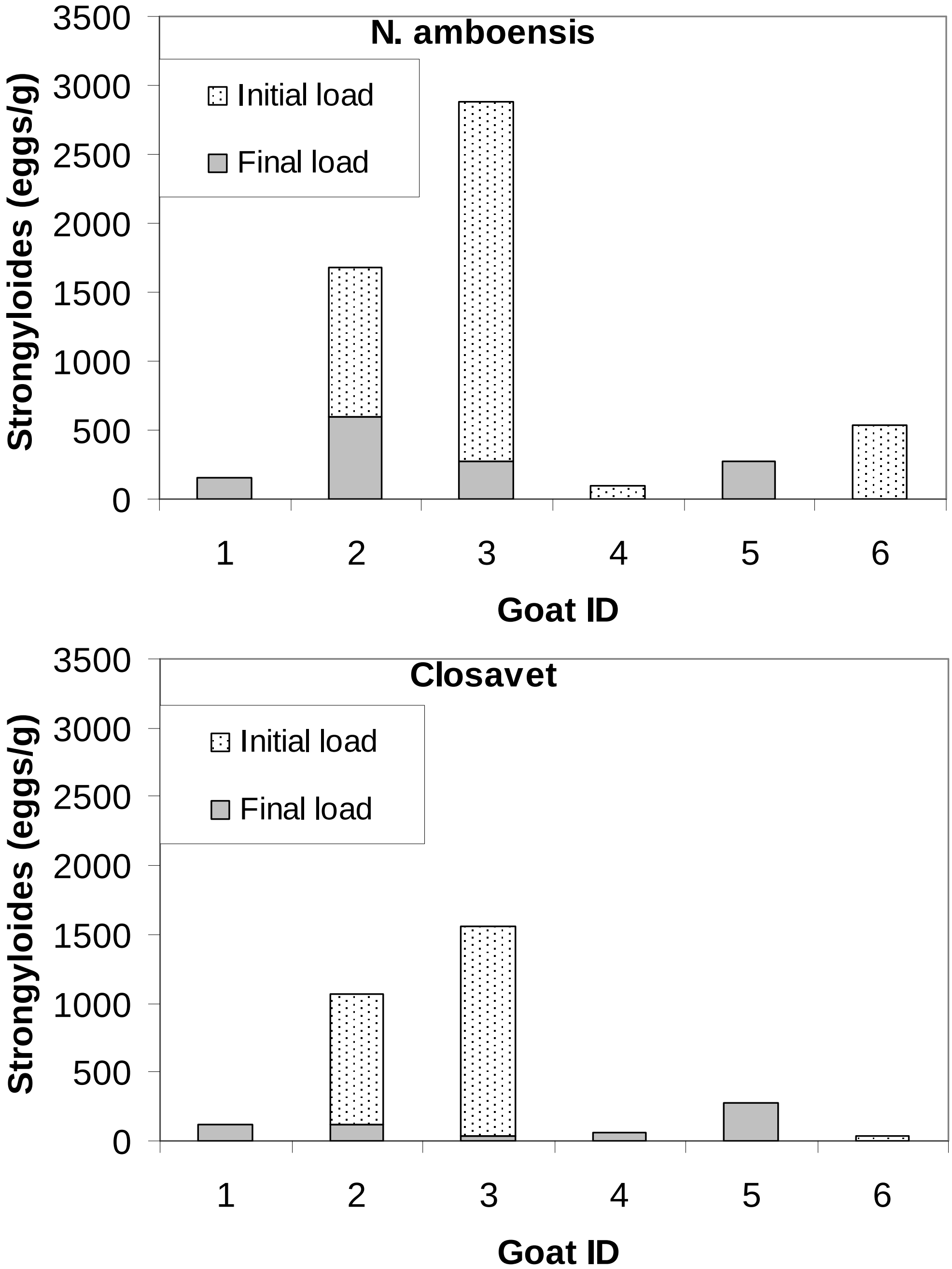


Figure 2: Load of intestinal strongyloid worms at the start and at the end of the goat feeding trial with A. *N. amboensis* and B. Closavet after 30 days. Meaning of worm counts in goats: 0 to 100 (Good Result), 100 to 200 (considered low to drench), 200 to 500 (medium range, productivity loses and scouring), 500 to 1000 (High, production loses and scouring becoming significant), 1000 to 2000 (very high, some animals become anaemic), >2000 (too high, death may occur)

Similar results were observed with cattle where reduction in worm load of strongyloides resulted in different rank distributions across the three categories of treatment groups ($\chi2$ =11.4, P <0.005).

Reduction caused by *N. amboensis* in cattle was similar to that observed after dosing with the Rafasol (Figure 3).

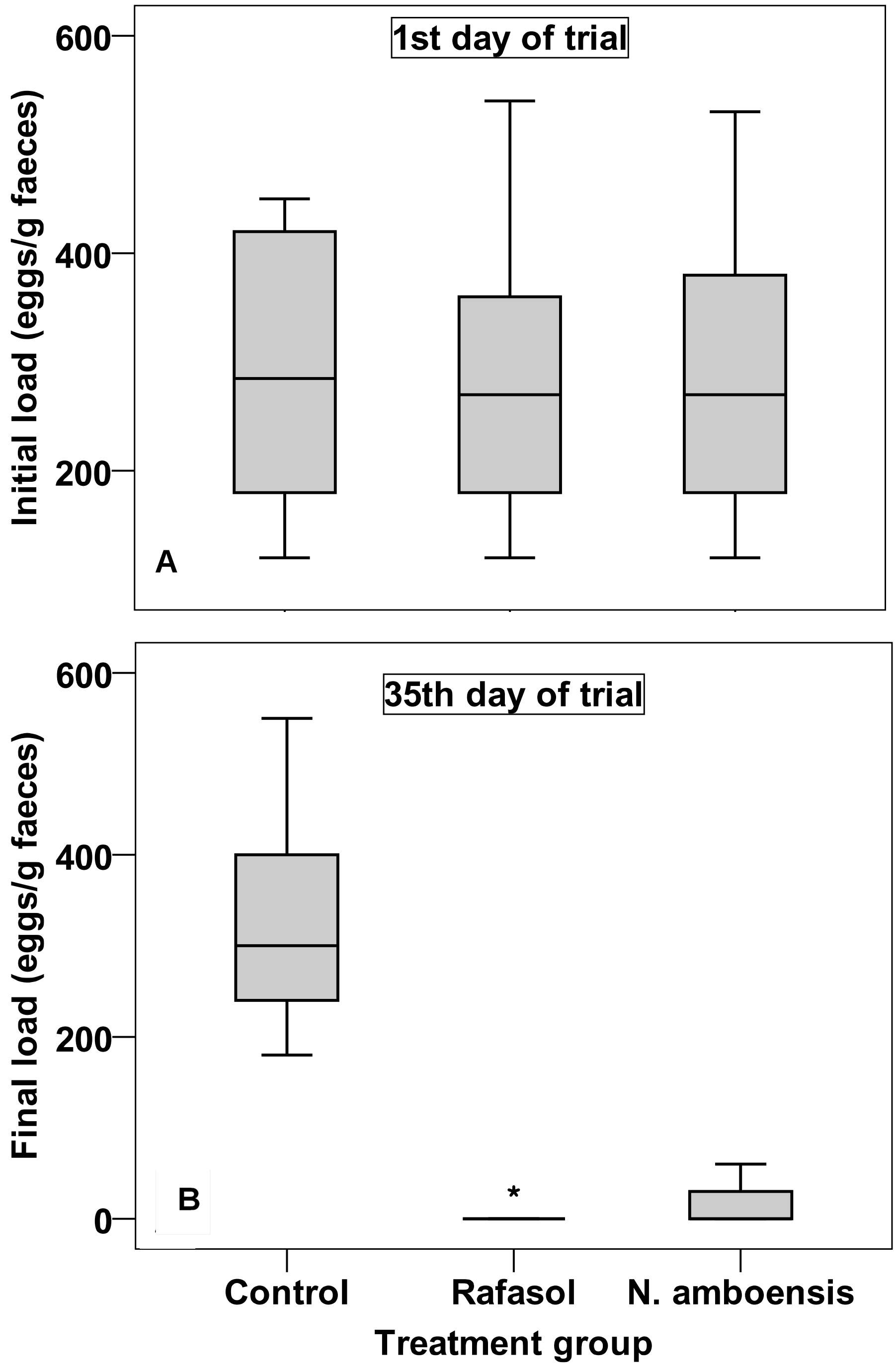


Figure 3 Load of intestinal strongyloid worms at (A) the start and (B) at the end of the cattle feeding trial after 35 days. Meaning of worm counts in cattle: 0 to 100 (Good Result), 100 to 200 (considered low to drench), 200 to 500 (Consider drenching), 500 to 700 (High levels, economic losses may occur), All animals should be drenched >700, mortality may occur if drenching is not done.

3.4 Distribution of *N. amboensis* in the study area

N. amboensis was not evenly distributed across the study area (Figure 4) raising the question in which habitats it is most commonly found.

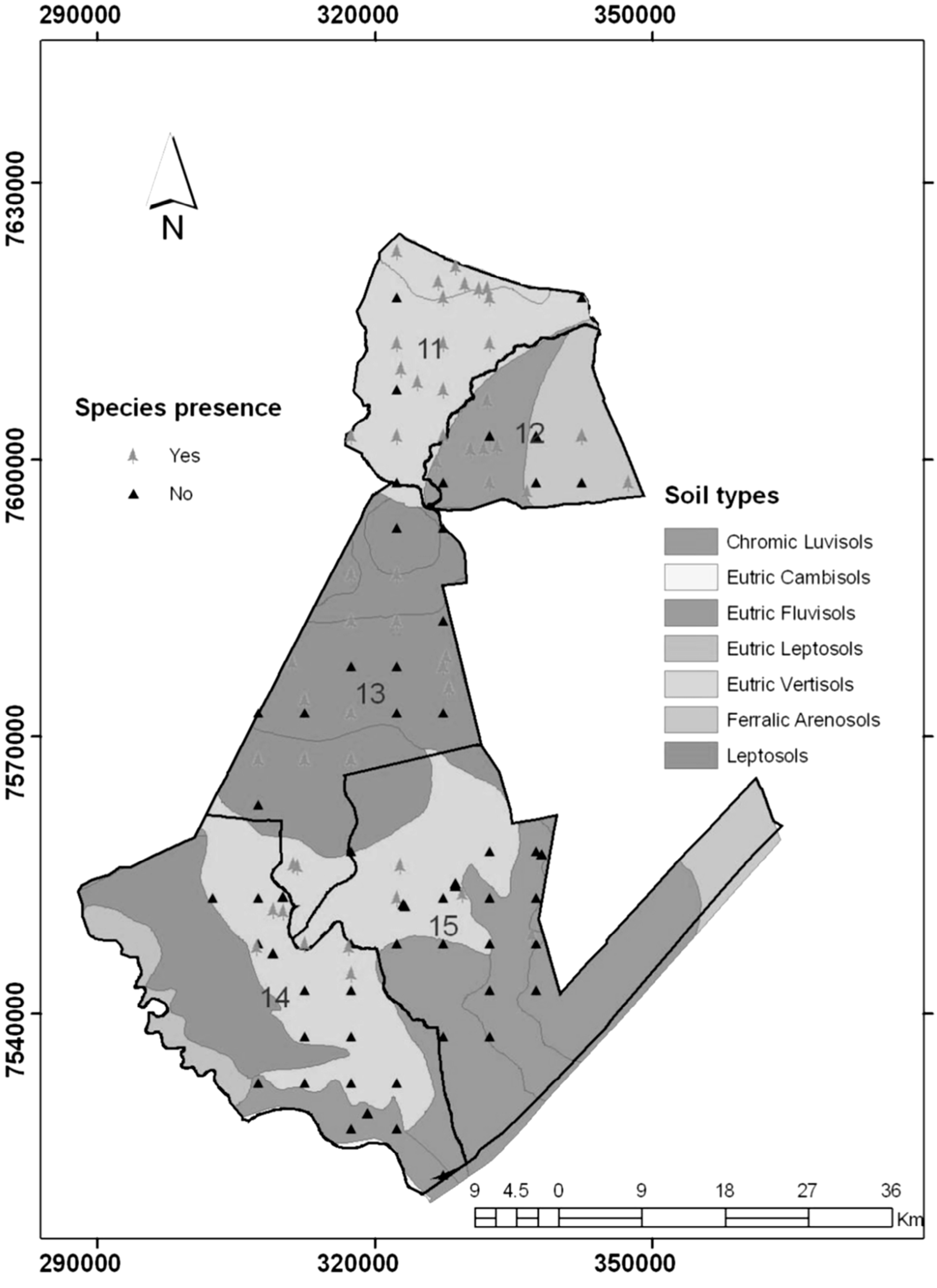


Figure 4 Distribution of *N. amboensis* in relation to soil type in the south-east lowveld of Zimbabwe

We recorded more counts in Eutric vertisols and Chromic luvisols than in Ferric arenosols and Leptosols (Figure 5). *N. amboensis* was not observed in Eutric fluvisols, no sampling was possible in Eutric leptosols because of inaccessibility of the area. Cultivation correlates with counts, more counts were observed in crop fields than in the natural veld. *N. amboensis* can be propagated both by vegetative means and by seed. Its pods shatter when dry, so, cultivation may facilitate: 1. covering the seed with soil during ploughing or weeding thereby facilitating germination and 2. Splitting the tuber into many vegetative fragments that would act as new vegetative planting material. However, we observed that coarseness of soil impacts negatively on numbers and size of *N. amboensis* tubers. Counts increased as we moved from rocky soils, through gravelly to 'normal' soils.

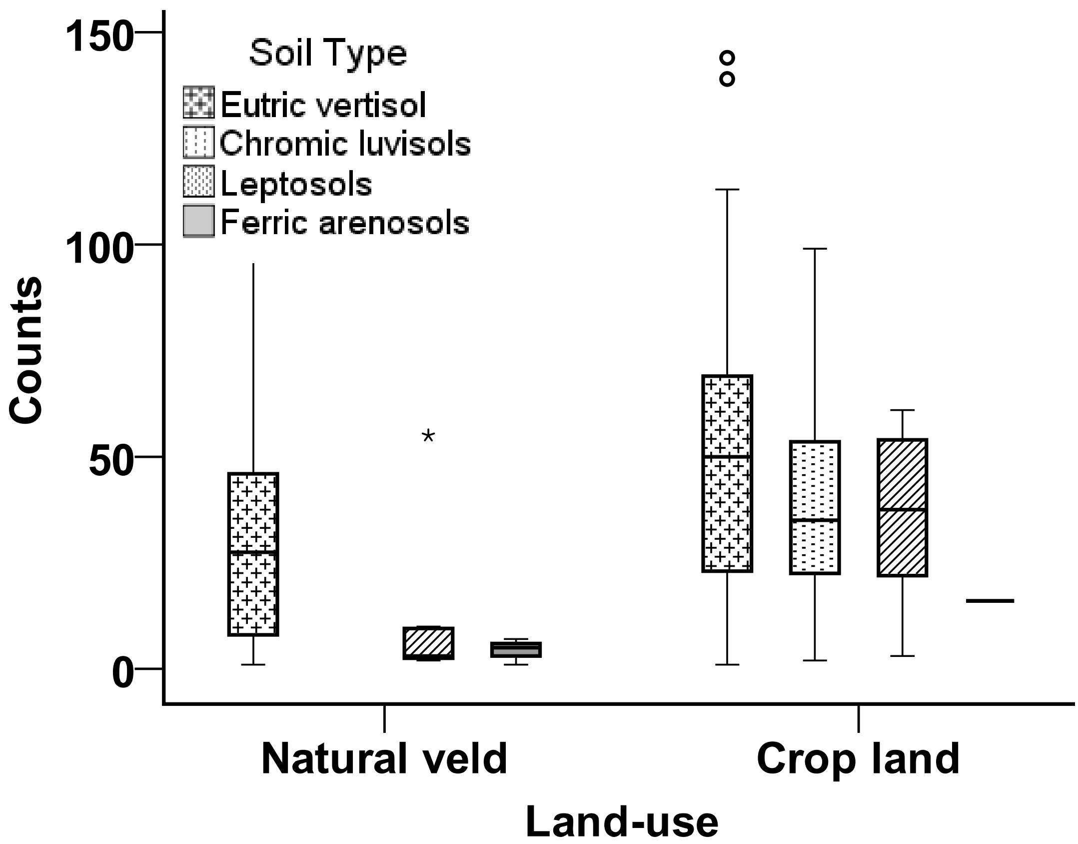


Figure 5. Counts of *N. amboensis* plants in 30 m x 30 m quadrats within 5 km x 5 km grid squares in natural veld (n=31) and crop land (n=20) on different soil types in south east lowveld of Zimbabwe.

Farmers agreed that there is no clear indicator on the plant characteristics that can lead someone to say the tuber is large in size or small, but generally, they agree that there are better chances of getting a larger tuber in black soils that crack and more in cultivated or previously cultivated areas where the tuber is mostly found closer to the surface. We found no correlation between the size of these tubers and above ground height of plant.

4. Discussion

4.1 Traditional uses of *Neorautanenia amboensis*

N. amboensis has generated lots of interest among cattle households in the south east lowveld of Zimbabwe. Its feed and anthelmintic properties provide hope for surviving the negative effects of climate change on the food production system of semi-arid areas. After the initial discovery that *N. amboensis* can keep cattle alive during a drought, more farmers started harvesting tubers to save their cattle from death (see Figure 1D). The high moisture content of *N. amboensis* makes it suitable for drought feeding strategies. If animals eat 6 kg as in the controlled experiments, then the gross moisture content that they will get is 4.4 litres. In reality and from experience, farmers advised that once cattle become used to eating *N. amboensis*, they can eat even 20 kg of the tuber (about 15 litres of moisture). Considering the fact that water requirements depend mainly on dry matter intake and temperature (NRC, 1996), feeding tubers will reduce water requirements for cattle during drought. Presently, *N. amboensis* tubers are the sole diet for cattle in times of acute feed shortages as during drought. Thinning of dung could be a result of the non-fibrous nature of *N. amboensis* when given as a sole diet.

4.2 Feed and anthelminthic value of *N. amboensis*

The nutrient level of *N. amboensis* meets minimum nutrient requirements of ruminant livestock. Livestock feed of protein content above 7% is adequate for maintenance if intake is good (Topps and Oliver, 1993; Van Soest, 1994). Dry matter digestibility was high, and is an important indicator of good nutritive value of the feed (Forejtova et al., 2005). NDF and ADF levels of the tuber are low. NDF levels are negatively correlated to intake and ADF levels are negatively correlated to digestibility (Ball *et al.*, 2007). The detergent fibre contents do not limit usefulness of the tuber as a feed but low fibrous level suggests that *N. amboensis* should ideally not be fed as a sole diet to cattle for many days without extra roughage, poor fibre diets suppress rumen function and depresses feed intake. However, farmers have no option than to feed tubers as sole feed at times especially in years of severe drought when no forage is available. The strength possessed by animals fed *N. amboensis* could mean possibility for anti-oxidant factors that needs further investigation. Dragland *et al*.(2003) reported on several culinary and medicinal herbs that are important sources of dietary antioxidants and that phytochemicals results in health benefits. The thinning of dung observed by farmers could be a result of this poor fibre levels of the tuber. Even though gross energy value has little direct significance in ruminant livestock feeding systems, gross energy value is an important starting point for estimating useful energy indices used in ruminant nutrition studies (digestible energy, metabolisable energy and net energy). High digestibility value of the tuber gives an indication that its energy content could be used with high efficiency as the nutrients move along the digestive tract. The low fat levels reduces luxative effects when fed in compound diets.

The effects of *N. amboensis* on strongyloides may suggest the clean intestines that farmers observe after slaughtering cattle previously on *N. amboensis* diet. These findings confirm claims by local people that the tubers of *N. amboensis* contain chemical compounds that are effective in deworming ruminant livestock. Further work is required to identify the active compounds making *N. amboensis* a strong antihelmintic compound against Strongyloides, as well as how this active compound affects other types of helminths. *N. amboensis* could make an important contribution to the development or modification of broad spectrum antihelmintics in an industry that is faced with development of widespread resistance.

4.3 Distribution of *N. amboensis* in the study area

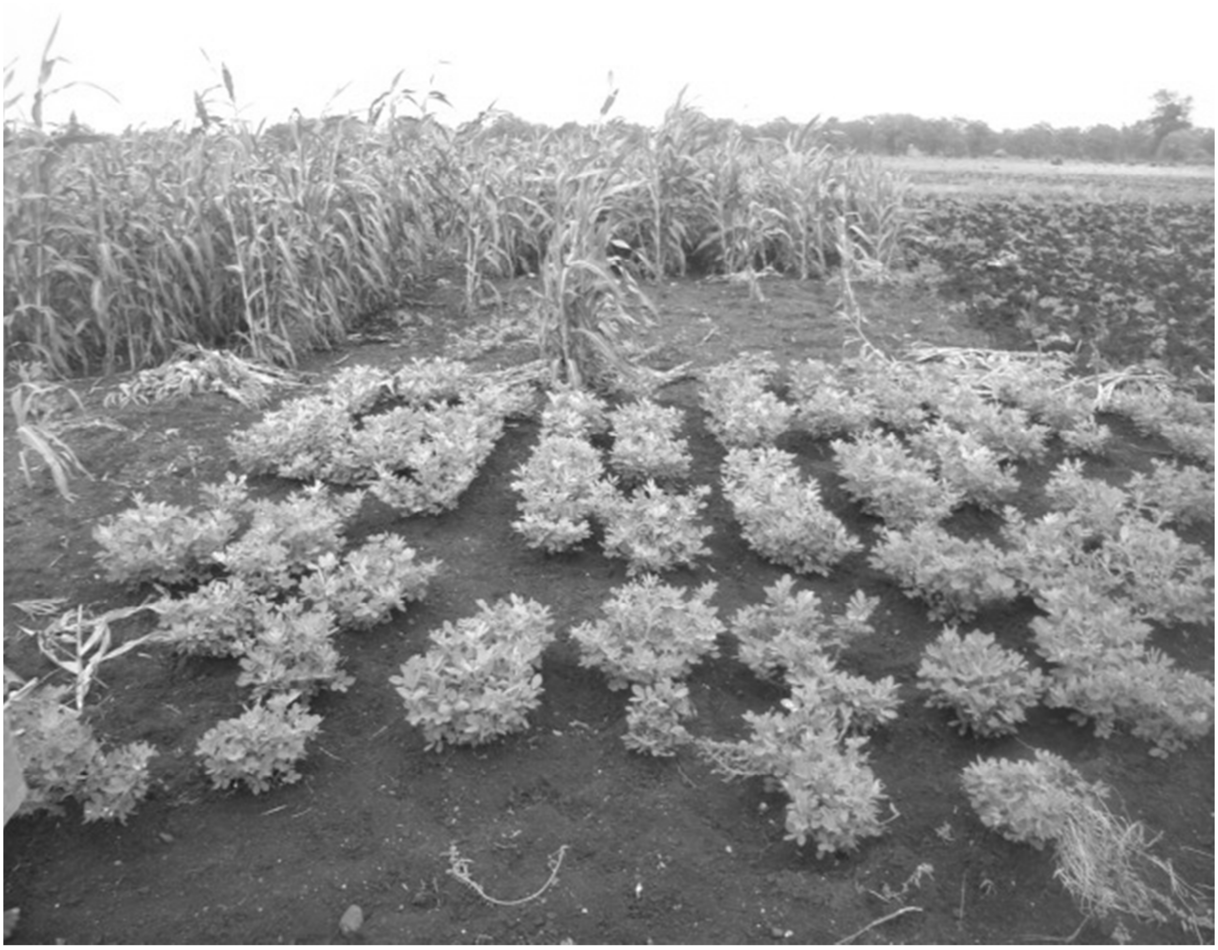
Information derived in this section is expected to add value to the biosystematics of *N. amboensis* as such knowledge is needed for exploring the commercial opportunities (Van Wyk, 1996). In principle, *N. amboensis* can grow in different soils but its abundance is affected by soil type and management. *N. amboensis* occurred more in Eutric vertisols and chromic luvisols maybe because these soils have weak structural properties that can facilitate expansion of tubers inside the soil during growth. Vertisols have unique properties of high clay content, volume changes with moisture, cracks that split and merge periodically, and evidence of soil movement in the form of slickensides (Özsoy and Aksoy, 2007). Chromic luvisols are characterised by dark-coloured A horizon of a sandy clay loam texture underlain by a deep homogenous dusky red B horizon of clayey texture and are moderately well drained (ISM, Unknown). Their macro structural development is mainly confined to the top soil and expressed as a weak medium sub-angular blocky structure with particle size distribution that indicates an increase in amount of clay with depth (Özsoy and Aksoy, 2007). Soils of loose structure and high nutrient content encourage growth of the tubers. It was also observed that N. amboensis correlates positively with open spaces. Open spaces are coincidentally areas with poor grazing and more cropping fields for example in Chikombedzi (11, Figure 4). In areas where grazing is a problem excessive use of *N. amboensis* is expected, but the recruitment process makes it recover in time for the following season. The recruitment process is not properly understood and requires further investigation. To avoid over exploitation, cattle farmers in the south-east lowveld of Zimbabwe arrange with nearby small scale commercial farms (average land size = 750 ha) and rent grazing. More work is needed on growth characteristics of *N. amboensis* in order to test for other factors like altitude, irrigation, day length, temperature and fertilization and to check if this tuber can be grown on a larger scale and this is work in progress. (Yineger *et al.*, 2007) indicated that knowledge concerning conservation and sustainable use of important medicinal plants require attention.

5. Conclusions

We identified *N. amboensis* to be an important medicinal feed that increases the resilience of household food systems to drought in semi-arid areas. It is an important plant saving cattle from death in the south-east lowveld of Zimbabwe. Positive effects of *N. amboensis* include keeping cattle alive despite lack of forage, high water content of the tuber and medicinal properties of the tuber making it possible for farmers to dose their cattle while feeding them to survive. Plant characteristics that make *N. amboensis* useful include the ability to grow in different soils under semi-arid conditions, forming an underground tuber which makes it usable only when necessary and its ability to propagate both vegetative and as seed. More work is required to understand the growth characteristics of the tuber plant. *N. amboensis* can be used most importantly as a survival feed during drought and to close the feed deficit gap during dry season.

Chapter 5

Enhancing crop production in semi-arid areas through increased knowledge of varieties, environment and management factors



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Abstract

A production system in the semi-arid south-east lowveld of Zimbabwe was studied. The growth and yield of four crops (maize, sorghum, millet and groundnut) was assessed during two contrasting seasons (2008/9 and 2009/10) in different landscape positions with or without manure. Daily rainfall, soil and manure nutrient levels, seed germination, crop establishment, grain yield and above-ground residue biomass were measured. Total rainfall in the two seasons was similar (491 and 476 mm) but highly variable across the seasons and the study area. Most important determining factors of crop yield were landscape position and the rainfall characteristics of the two seasons. Maize yielded more in the lower lowlands (1.30 t/ha) than in upper lowlands (0.46 t/ha) and uplands (0.20 t/ha). In a good season (2008/9) average maize yield across the treatments was 0.91 t/ha, whereas in the bad rainfall season 2009/2010 the average yield was 0.23 t/ha. In contrast to maize, the highest yields of sorghum were obtained in the uplands. Manure had a positive effect on crop production. With this experiment we quantified the mosaic of crop growth conditions, caused by the spatial variation in rainfall, different crop varieties, landscape positions and soil types. By making use of these differences in crop growth conditions the risk of production loss in such a semi-arid area can be reduced. This means that cropping areas in semi-arid areas have to be properly disaggregated in order to facilitate targeting of appropriate technologies to reduce the vulnerability of local households to rainfall variability.

Keywords: Semi-arid; erratic-rainfall; risk; landscape position; manure; crop; variety; yield.

1. Introduction

Some 260 million people live in the drought-prone semi-arid drylands of sub-Saharan Africa (UNDP/UNSO, 1997). The semi-arid areas are sandwiched between the Sahara desert and the moist Guinea savanna in the north and the Kalahari desert and the Miombo savannah in the south. Annual total rainfall ranges between 200 and 600 mm with potential evapotranspiration of 5 - 8 mm/day (Noy-Meir, 1973; Rockstrom, 2000). Pastoral and agro-pastoral millet/sorghum systems prevail (Dixon et al., 2001). Farming communities in semi-arid areas face periodic severe droughts, such as the 1991-1992 drought in southern Africa (Figure 1) when a massive loss of cattle occurred (Tobaiwa, 1993; Eldridge, 2002; Cumming, 2005). Semi-arid areas are characterised by poor rainfall with high spatial and temporal variability leading to risk of severe drought (Monteith, 1991; Han, 2007; Batisani and Yarnal, 2010). Farmers in these conditions give priority to manage their environment to reduce risks and buffer themselves from adverse weather conditions and droughts (Cooper et al., 2008).

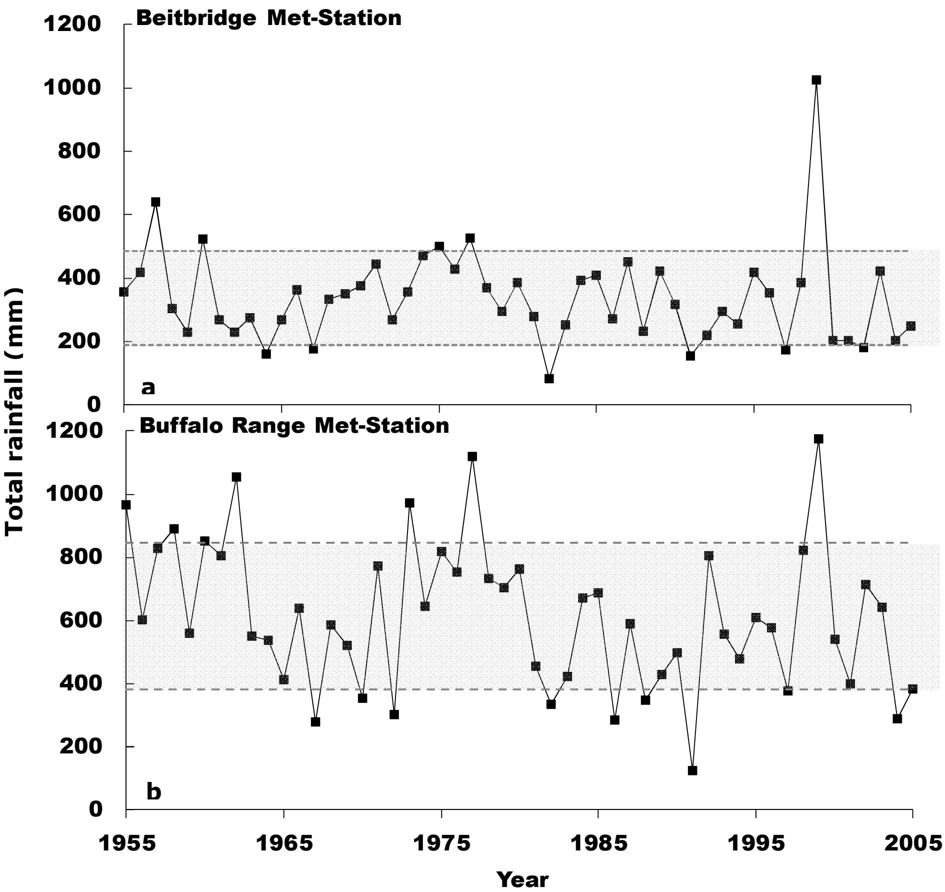

Figure 1: Long-term annual rainfall (mm) recorded at the two meteorological (Simelton *et al.*) stations closest to the study area: a) Beitbridge (30.0° E, 22.2° S) and b) Buffalo Range (31.6° E, 21.0° S). The shaded area on each graph indicates 1 standard deviation around the annual mean rainfall.

An example of a semi-arid region is the border zone of Mozambique, Zimbabwe and South Africa, and it exhibits a highly variable rainfall (Figure 1). The local people use fields in different landscape positions to take advantage of spatial-temporal differences in moisture as an important measure to cope with variability in rainfall. In this area, manure is not commonly used to fertilize crops despite the importance of livestock. The study area is part of regional plans targeted for developments geared to nature conservation, ecotourism, and wildlife habitat extension (Cumming *et al.*, 2007; Spenceley, 2008). For the farmers living in the study area, these initiatives are new hazards, additional to their coping with uncertain rainfall and floods (Dzingirai, 2003).

One option to improve food security in this area is to improve the productivity of cropping systems. This can be done by growing a variety of crops, by using more drought-tolerant varieties, and by better exploiting landscape variability. Collection and use of manure is a further option. Spatial variation in rainfall, different crop varieties, landscape positions and soil types combine to form a mosaic of crop growth conditions (Figures 1 and 2), as in many other semi-arid regions. The goal of this study is to analyse and quantify these different growing conditions to gain insight in how farmers currently cope with adverse conditions and to identify opportunities to improve crop production and reduce the risk of crop failure. The production potential of different crops and crop varieties (of short to long duration) across different landscape positions was investigated across two seasons. Sorghum (Sorghum bicolor [L.] Moench), pearl millet (Pennisetum glaucum [L.] R. Br.), maize (Zea mays L.) and groundnut (Arachis hypogaea L.) were the crops evaluated, with or without addition of manure. Combinations of crop, crop variety, manure and landscape position resulting in an increase in yield during a good year and least yield losses during drought were considered to be ‘best fit’ options (Giller *et al.*, 2011). The best fit options were used to evaluate implications of our crop experiments for household food self-sufficiency.

2. Materials and Methods

2.1 Site characteristics

The study area is located in the south-east lowveld of Zimbabwe (latitude 21^{o}55’S and longitude 31^{o}29’E). Annual mean minimum temperature ranges between 4.3^{o}C and 21.1^{o}C and annual mean maximum temperature between 27.8^{o}C and 37.3^{o}C. Soils in the area are distributed as 40 % Eutric vertisols, 29 % Leptosols, 17 % Chromic luvisols, 7 % Eutric fluvisols and 7 % Ferralic arenosols (FAO/UNESCO soil map of Zimbabwe).

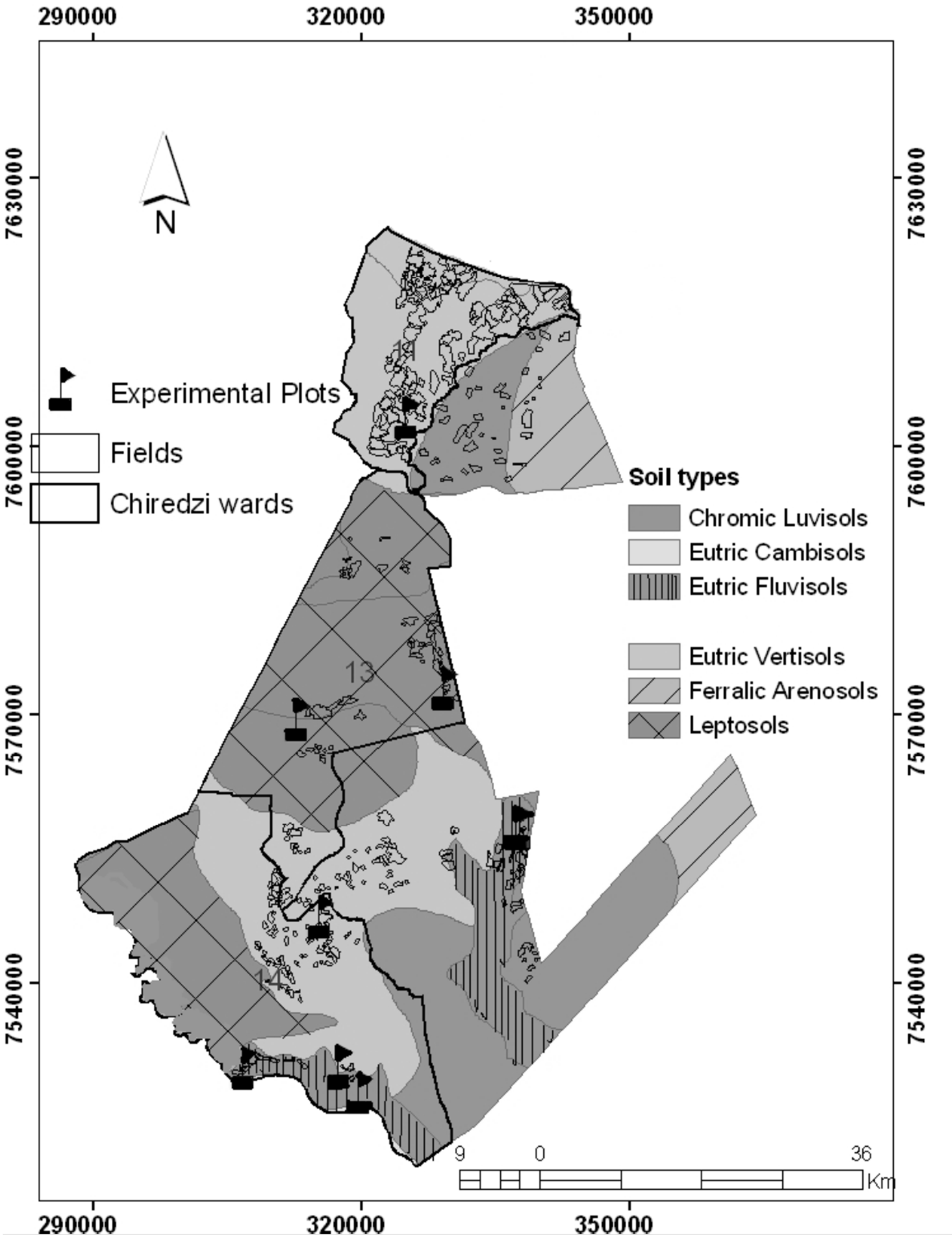

Figure 2: Distribution of all of the cropping fields in Wards 11 to 15 during the 2006/2007 season adjacent to Gonarezhou National Park, south-east lowveld, Zimbabwe. The flags mark the locations of the experimental plots and boxed numbers is the number of the experimental plot.

The boundaries of crop fields were walked and marked using a GPS (GPSmap 60CSx Garmin) and overlaid on a digitised image (2007) of all cropped fields using ArcView 3.1 (Figure 2). Total annual rainfall measured at the two closest meteorological stations, Buffalo Range located 100 km NE of the study area, and Beitbridge located on the Limpopo river 120 km to the west of the study area show a large inter-annual variability, with intermittent severe droughts (Figure 1). Farmers described the three important landscape positions used as the lower lowlands, upper lowlands and uplands (Figure 2). The lower lowlands lie within the floodplains and receive water from rainfall, run-on and flooding by rivers. The upper lowlands receive water from rain and run-on from adjacent uplands but are not flooded by the rivers. These upper lowland areas are also known in southern Africa as 'vleis', low-lying water retaining depressions that remain moist for longer into the dry season compared with the surrounding uplands. The upland areas are rain fed. Eleven sites were selected from the three identified landscape positions for the crop experiments.

In sub-Sharan Africa in general, maize production is expanding into areas that were typically considered only suitable for production of sorghum and millet (Dixon *et al.*, 2001). This is also the case in the study area. Open pollinated varieties are preferred because farmers can retain seed for next season from the current harvest. The Shangaan, the dominant people in the south east lowveld of Zimbabwe, are agriculturalists and to some extent, pastoralists who traditionally grew sorghum. Millet does not form an important part of the Shangaan diet, and is highly susceptible to bird damage. It is, however, a traditional staple food of the Ndebele who comprise a small proportion of the local population. Groundnut is commonly grown on small portions of land, usually not more than an acre, as it is among the first field crops that can be harvested for food.

2.2 Experimental design

The crops compared in the experiment are sorghum, maize, groundnut and millet. Five open pollinated varieties of maize were compared: ZM 309, ZM 401, local (also known as Gopane by some farmers and Chibhubhani by others in the same area), ZM 421 and ZM 521. The varieties ZM 309, ZM 401 and the local variety (Gopane) are short duration varieties whereas ZM 421 and ZM 521 are medium duration. Three sorghum varieties commonly grown in the area were evaluated: Gangara and Chibedlani (both medium season) and Chihumani (short season). Gangara is red grained variety that is rarely attacked by birds, and is said to be drought tolerant. Chibedlani is white grain sorghum with large grain which makes it less susceptible to bird damage. Chihumani is white, small grain variety that is very susceptible to bird damage but is the most preferred variety in the area due to its good taste and more appealing colour. The commonly-grown local varieties of millet, a medium-duration variety, and groundnut (Natal common) were included in the experiments.

Single replicate blocks comprised of five maize varieties, three sorghum varieties, one millet and one groundnut variety were planted with or without manure at 11 sites, giving a total of 220 sub-plots. Five sites were in upland, three in upper lowland and three in lower lowland positions. The cropping practices of local farmers were incorporated in the design. Maize is planted when enough rain has fallen to wet the soil to 20 cm depth. If germination is poor, maize is replanted with every good rain until March. Sorghum is dry planted and sorghum and millet are replanted if rain fails in the first part of the season, but only until the end of December to avoid crop ripening at the end of March when quelea birds (Quelea quelea) are particularly problematic. Before planting, germination of all seed was tested by the Department of Seed Services, Harare (accredited by the International Seed Testing Association).

Experimental plots were ploughed using an ox-drawn mouldboard plough to a depth of about 15 cm. Each plot measuring 20 m x 25 m was divided into two halves. Each half was sub-divided into ten plots of 5 m x 5 m. Row spacing of 90 cm was used for the cereals, with 45 cm spacing for groundnut and within-row spacing of 30 cm. Manure was applied at planting to the 10 sub-plots in one half (10.5 ton/ha on DM basis), banded along the six furrows in maize, sorghum and millet. An equivalent amount was spread and incorporated into the soil in plots to be planted with groundnut. The manure was applied alongside the furrows. Seed of groundnut was treated with Thiram 80WP (5 g per 400 seed). Maize, sorghum, millet and groundnut were hand planted. Replanting was done after a ‘good’ rainfall when emergence of crop was considered ‘hopeless’ by farmers.

At two weeks after emergence, establishment was estimated by counting surviving plants in each plot. Weeding was done twice, initially using a hoe and later by hand pulling. At harvesting, grain yield was estimated in both seasons and above-ground biomass measured in the 2009/2010 season. Grain samples were oven dried at 60 ^{o}C for 48 hours and all yields are reported at moisture contents of 15 % for maize, 11 % for sorghum and millet and 5 % for groundnut. Daily rainfall was recorded by farmers using rain gauges installed at each experimental field.

2.3 Soil and manure properties

Before preparing the plots for planting, soils were sampled using an auger to a depth of 15 cm from three points along the diagonal of each experimental field. Soil and manure samples were air-dried and passed through a 2 mm sieve prior to analysis. The pH was measured in 0.01 M $CaCl_2$, organic carbon determined using the Walkley-Black method (Nelson and Sommers, 1982), and total phosphorus was determined by the molybdenum-blue method after dry ashing. Exchangeable potassium was measured in an acidified ammonium acetate extract method using a flame photometer. Soil fractions were determined using the hydrometer method with sodium hexametaphosphate solution (calgon) as a dispersion agent as described by van Reeuwijk (2002).

2.4 Data analysis

Data were normalised using a arcsin(square-root(X)) transformation for crop establishment and $\log_{10}$ transformation for grain yield (McDonald, 2009). Analysis of variance was done in SAS 9.2 (SAS, 2008) using Tukey for post hoc separation of means. Crop growth and management combinations that resulted in better yields than using current practices and suffer less yield reduction during bad seasons (coined as ‘best fits’ in this paper), were used to analyse the consequences of certain cropping strategies for household food self-sufficiency. These ‘best fit’ options were compared to the current management strategies, which entail growing only one maize variety ‘local’ and three varieties of sorghum in all three landscape positions. Two key assumptions were implicitly made in this evaluation of strategies. The first assumption was that good years will be similar to 2008/9 season and bad years will be similar to 2009/10 season. The second assumption was that labour and cropping implements are not limiting in all households.

3. Results

3.1 Rainfall patterns

Total rainfall was highly variable between the 11 experimental fields – ranging from 376 mm to 646 mm in 2008/2009 and from 410 mm to 602 mm in the 2009/2010 season. Also, and in spite of average totals being close (491 vs. 476 mm), rainfall distribution in the 2008/9 and the 2009/10 seasons differed markedly, the latter showing more heavy downpours and longer dry spells (Figure 3). This caused major differences in establishment and yield of all crops. The effects of rainfall pattern are manifested in the number of times that farmers replant their crop (Figure 3). All crops were replanted once during 2008/2009 season. By contrast, long dry spells led to repeated crop failure during the 2009/2010 season (Figure 3). In the 2009/2010 season, sorghum, millet and groundnut were replanted once, but maize was replanted twice.

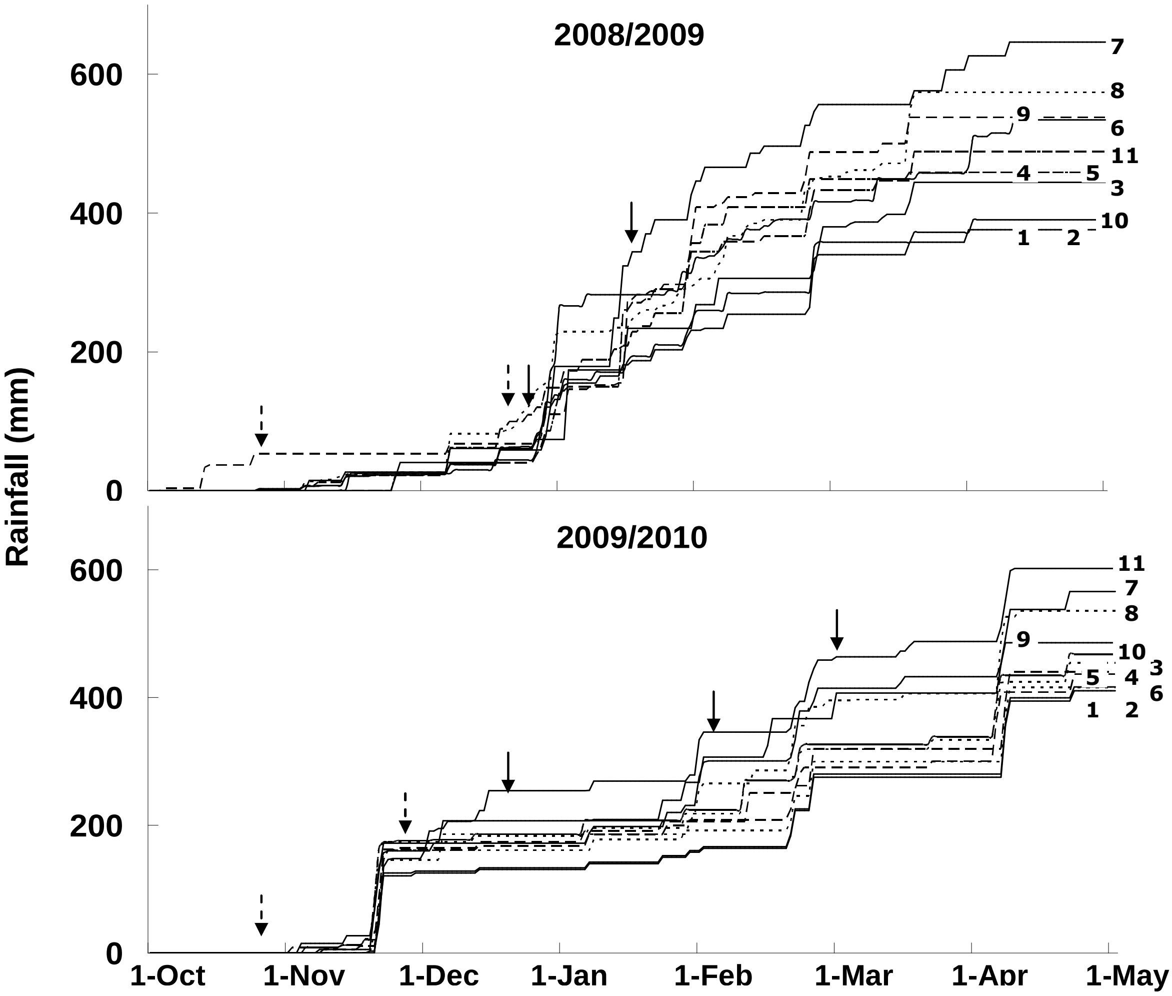

Figure 3: Rainfall (mm) during the 2008/2009 and 2009/2010 growing seasons at the eleven study sites in the south-east lowveld, Zimbabwe. Dashed arrows show (re)planting dates for sorghum, millet and groundnut and closed arrows for maize. Numbers on graphs correspond with the number of the experimental plot in Figure 2.

3.2 Soil and manure characteristics

The manure that was used in field experiments contained 520 g/kg DM ash (SD = 72.5). The 10.5 t/ha manure represents 2 730 kg/ha organic C (SD = 546), 147 kg/ha of N (SD = 10.5), 47 kg/ha of P (SD = 15.0) and 535 kg/ha of K (SD = 205). Upper lowland soils were finer textured than soils from the other landscape positions (Table

1). Also, bulk density for these soils was smaller and C and N content greater than those for the other landscape positions.

Table 1: Soil physical and chemical characteristics of the three land units (average values of 11 study sites) (standard errors in parentheses).

	Clay %	Silt %	Sand %	Bulk Density g/cm3
Uplands	20.4 (3.6)	19.0 (4.1)	60.6 (7.3)	1.51(0.05)
Upper lowlands	25.0 (4.7)	29.7 (5.3)	45.3 (9.4)	1.31(0.04)
Lower lowlands	12.7 (4.7)	18.3 (5.3)	69.0 (9.4)	1.41(0.05)

Component	pH	Organic Carbon (C) g/kg	Nitrogen (N) g/kg	C:N	Available Phosphorus (P) mg/kg	Extractable Potassium (K) cmol/kg
Uplands	7.1 (0.5)	9.0 (5)	0.6 (0.1)	15	555 (490)	1.24 (0.58)
Upper lowlands	6.9 (0.1)	18 (5)	0.8 (0.1)	22.5	556 (250)	1.98 (0.26)
Lower lowlands	6.7 (0.3)	10 (2)	0.6 (0.1)	16.7	311 (124)	1.22 (0.26)

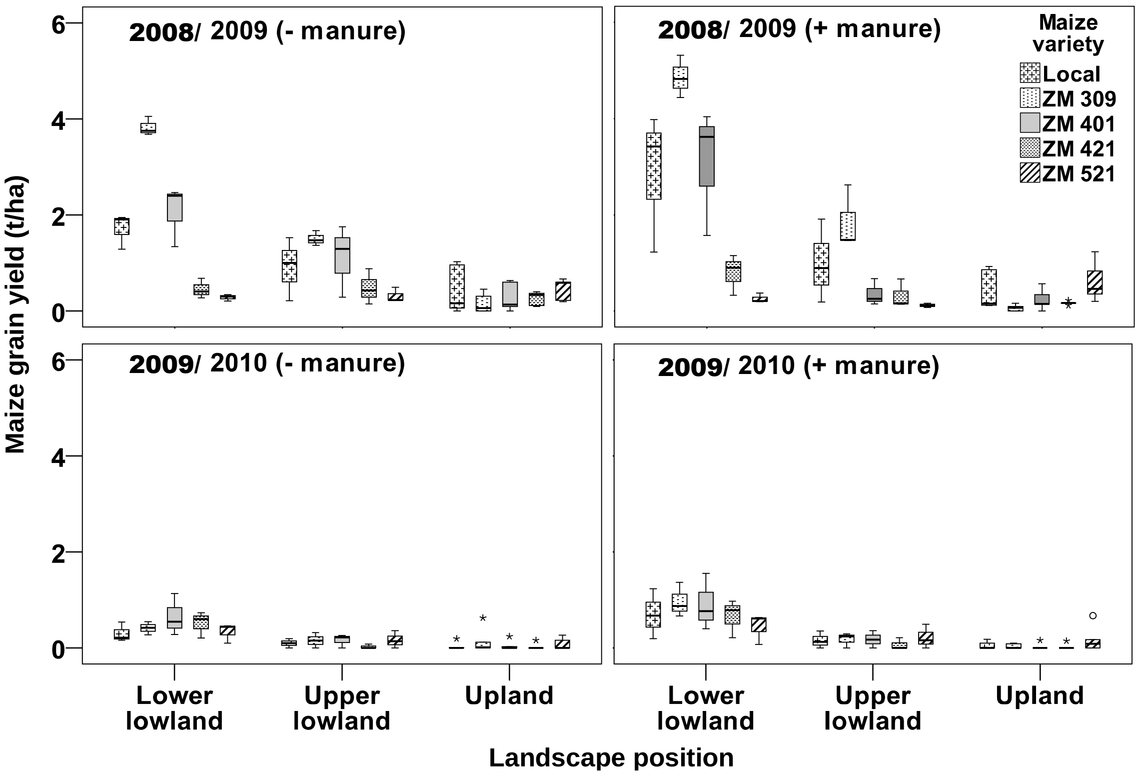

Figure 4: Grain yield (t/ha) of five maize varieties (local, ZM309, ZM401, ZM421, ZM521), at three landscape positions (lower lowland, upper lowland and upland), with or without application of manure at a rate of 10.5 t/ha, in the 2008/2009 and 2009/2010 growing seasons.

3.3 Maize production

Maize crop establishment was more successful in the 2009/2010 season than in 2008/2009 season (P < 0.05) but yielded substantially more in the 2008/2009 season (P < 0.05) than in 2009/2010 (Table 2). All four factors (season, variety, landscape position and manure) had significant effects on crop establishment and yield. However, there were significant interactions between season and variety, season and landscape position and variety and landscape position. Short season varieties (ZM 309, ZM 401 and the local variety) yielded more in the lower lowlands and upper lowlands than medium season varieties (ZM421 and ZM 521). All varieties yielded poorly in the uplands (Figure 4). Manure had no overall effect on crop establishment but it increased grain yield (P < 0.05) in the lower lowlands in both years. Maize grain yield was similar in the upper lowland and upland, even though establishment was more successful in the upper lowlands.

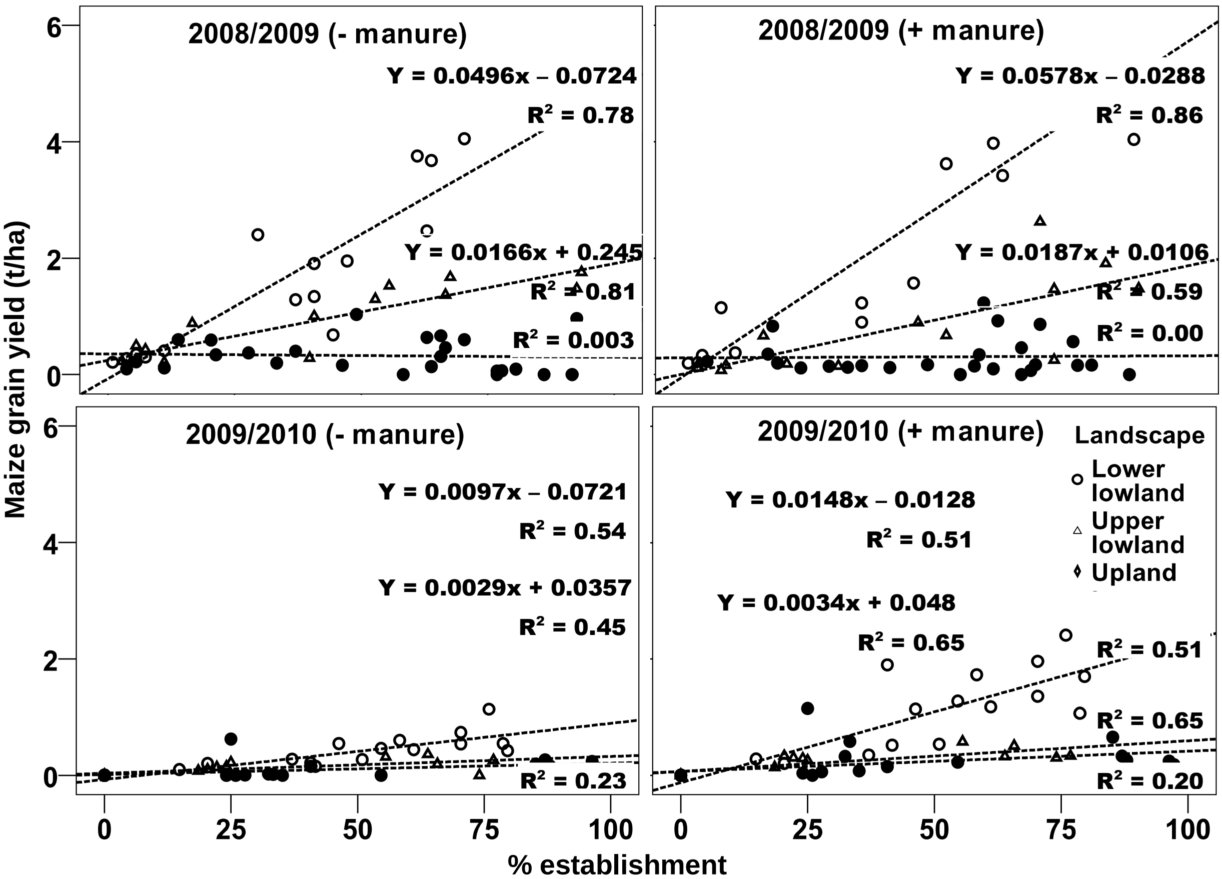

Figure 5: Grain yield (t/ha) of maize as a function of crop establishment rate at three landscape position (lower lowland, upper lowland and upland), with or without application of manure at a rate of 10.5 t/ha in the 2008/2009 and 2009/2010 growing seasons.

Crop establishment explained maize yield better in the lower lowlands and upper lowlands than in uplands (Figure 5).

In the 2009/2010 season, maize produced more above-ground biomass in the lower and upper lowlands ($P < 0.001$) than that in the uplands (Figure 6).

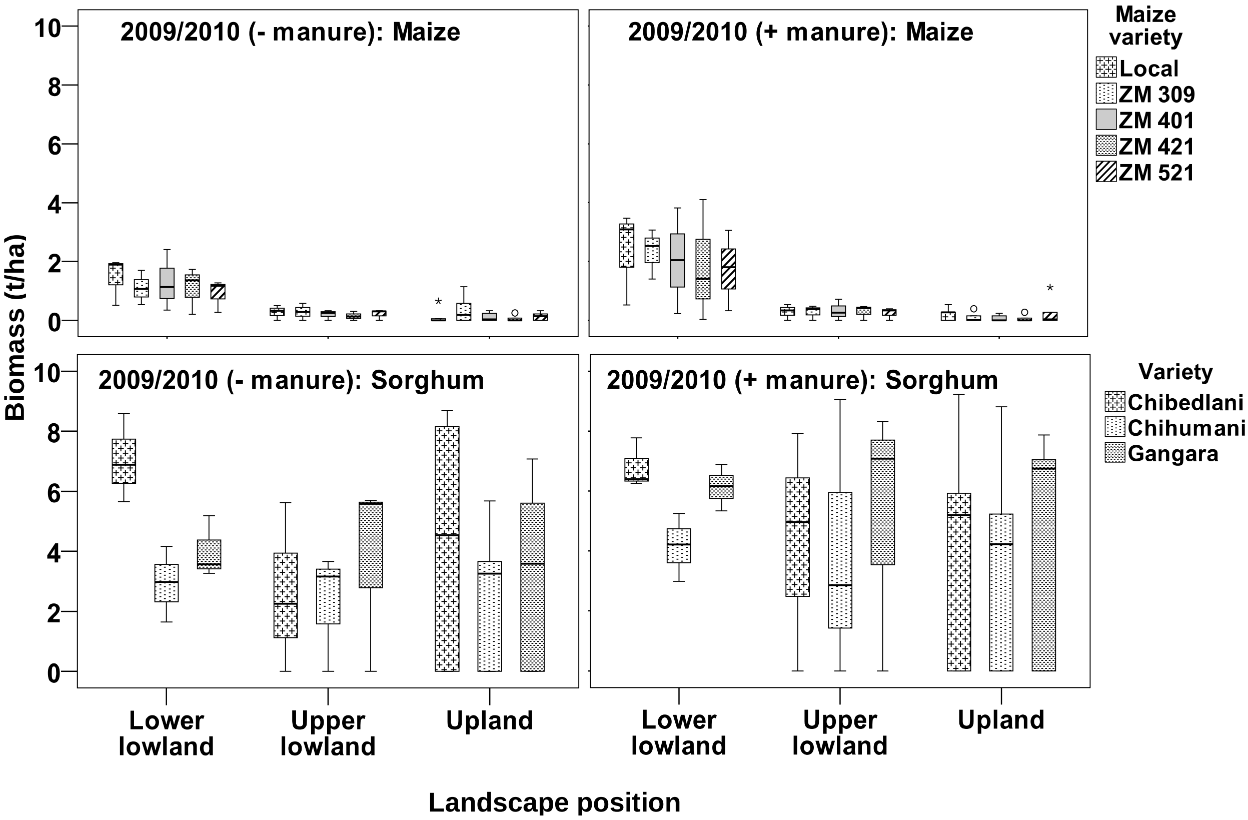

Figure 6. Above-ground residue biomass (t/ha) of five maize and three sorghum varieties, at three landscape positions (lower lowland, upper lowland and upland), with and without application of manure at a rate of 10.5 t/ha, in the 2009-2010 growing season.

3.4 Sorghum production

Sorghum established more successfully in the 2009/2010 season than in the 2008/2009 season, but yielded more in 2008/2009 than in 2009/2010 (Table 3). Only two factors (landscape position and manure) had a significant effect on crop establishment but all factors significantly affected yield (Table 3), and there were significant interactions between season and variety, season and landscape position and manure and season.

Table 2: Consequences of season, variety, manure and landscape position on grain yield of maize.

Factor	% Establishment	Grain Yield (t/ha)
Season		
2008/2009	44.4[a]	0.91[a]
2009/2010	35.6[b]	0.23[b]
Variety		
ZM309	55.8[a]	1.68[a]
ZM401	49.0[b]	1.13[b]
Local	41.4[b]	1.07[b]
ZM421	27.8[c]	0.28[c]
ZM521	26.0[c]	0.30[c]
Manure (at 10.5ton/ha)		
No manure applied	40.0[a]	0.51[a]
Manure applied	39.9[a]	0.63[b]
Landscape		
Lower lowlands	46.9[a]	1.30[a]
Upper lowlands	32.3[b]	0.46[b]
Uplands	40.5[a]	0.20[b]
P values		
Season	0.05	0.0001
Variety	0.0001	0.001
Manure	0.05	0.05
Landscape position	0.001	0.0001
Season x variety	0.0001	0.001
Season x landscape position	0.0001	0.05
Variety x landscape position	0.05	0.0001
R^2	0.76	0.73

Within column means under same factor, with different superscripts are different at $P < 0.05$. Non-significant interactions are not presented.

Manure had no effect on crop establishment but increased grain yield in the uplands ($P < 0.05$) (Table 3; Figure 7). The upland crop yielded the most although crop establishment was similar across all three landscape positions.

Table 3: Consequences of season, variety, manure and landscape position on grain yield of sorghum.

Factor	% Establishment	Grain Yield (t/ha)
Season		
2008/2009	64.3[b]	1.82[a]
2009/2010	76.5[a]	0.42[b]
Variety		
Gangara	71.3[a]	1.45[a]
Chibedlani	71.1[a]	0.92[b]
Chihumani	68.8[a]	0.98[b]
Manure (at 10.5 ton/ha)		
No manure applied	69.6[a]	0.92[b]
Manure applied	71.2[a]	1.31[a]
Landscape		
Lower lowlands	84.9[a]	1.15[b]
Upper lowlands	55.5[b]	0.63[b]
Uplands	72.0[a]	1.39[a]
P values		
Season	ns	0.0001
Variety	ns	0.0001
Manure	0.01	0.01
Landscape position	0.0001	0.0001
Season x Landscape position	0.01	0.001
Variety x Season	ns	0.05
Manure x Season	ns	0.01
Landscape x manure	0.01	ns
R^2	0.67	0.86

Within column means under same factor, with different superscripts are different at $P < 0.05$. Non-significant interactions are not presented.

Above-ground biomass of sorghum (Figure 6) was similar across the three landscape positions but between plots, variation was much smaller in lower lowlands than in the other two landscape positions.

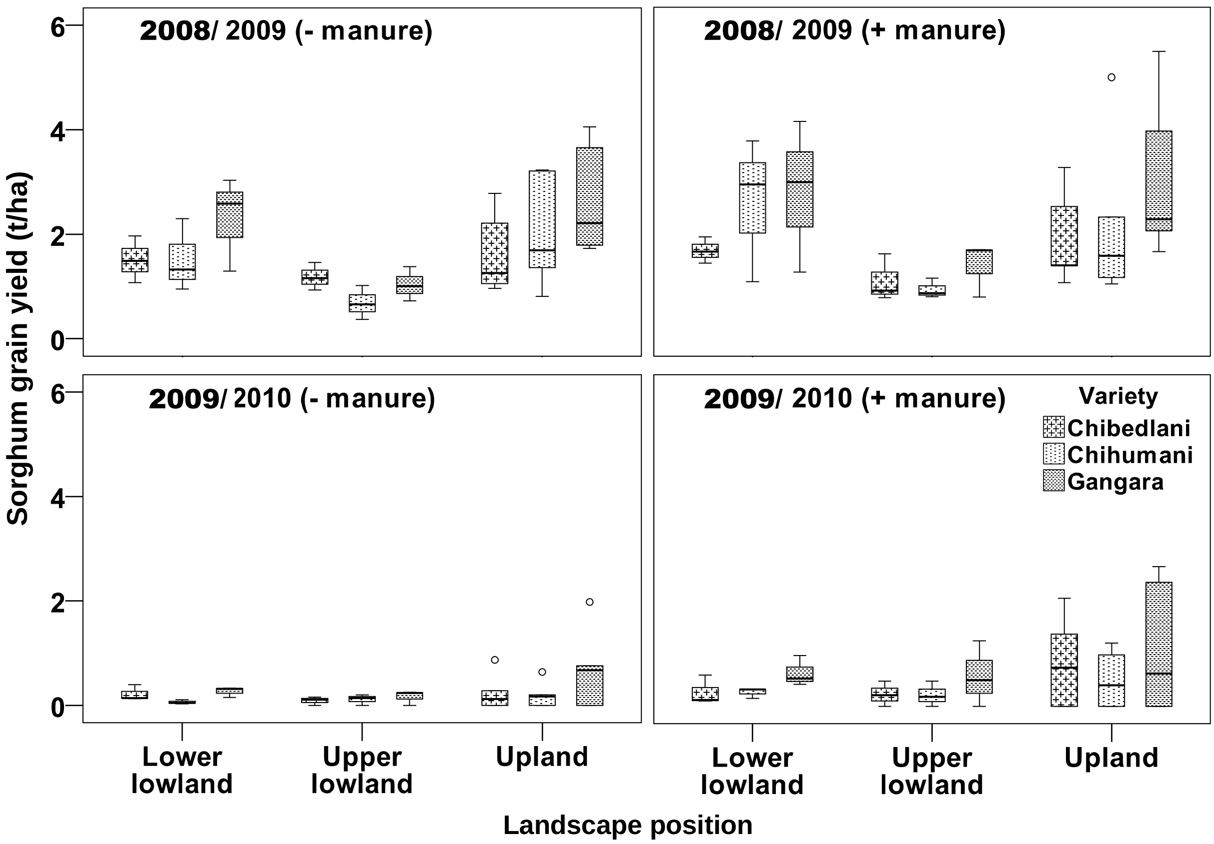

Figure 7: Grain yield (ton/ha) of three sorghum varieties, at three landscape positions (lower lowland, upper lowland and upland), with and without application of manure at a rate of 10.5 t/ha in the 2008/2009 and 2009/2010 growing seasons.

3.5 Millet production

Millet consistently yielded poorly in both seasons irrespective of landscape position or manure treatment. Establishment decreased significantly from 2008/2009 to 2009/2010 in upper lowlands (39.7 % to 17.7 %) and uplands (69.3 % to 33.2 %), but remained the same in the lower lowlands for the two seasons (66.7 % to 66.9 %). Manure did not make any difference for both establishment and yield. Millet yielded more ($P < 0.05$) in the 2008/2009 season (0.23 ton/ha) than in 2009/2010 (0.09 ton/ha). Poor grain harvests were obtained more frequently in the lower lowlands than in the other two landscape positions, particularly so in 2009/2010 (Figure 8). However, more above-ground biomass was produced in the lower lowlands (Figure 9).

3.6 Groundnut production

Groundnut established more successfully ($P < 0.05$) in 2008/2009 than in the 2009/2010 season but grain yields did not differ between the two seasons (Table 4). Application of manure seemed to reduce establishment, but no differences in grain yield were observed. Groundnut produced more above-ground biomass in the uplands than in the other two landscape positions (Figure 9).

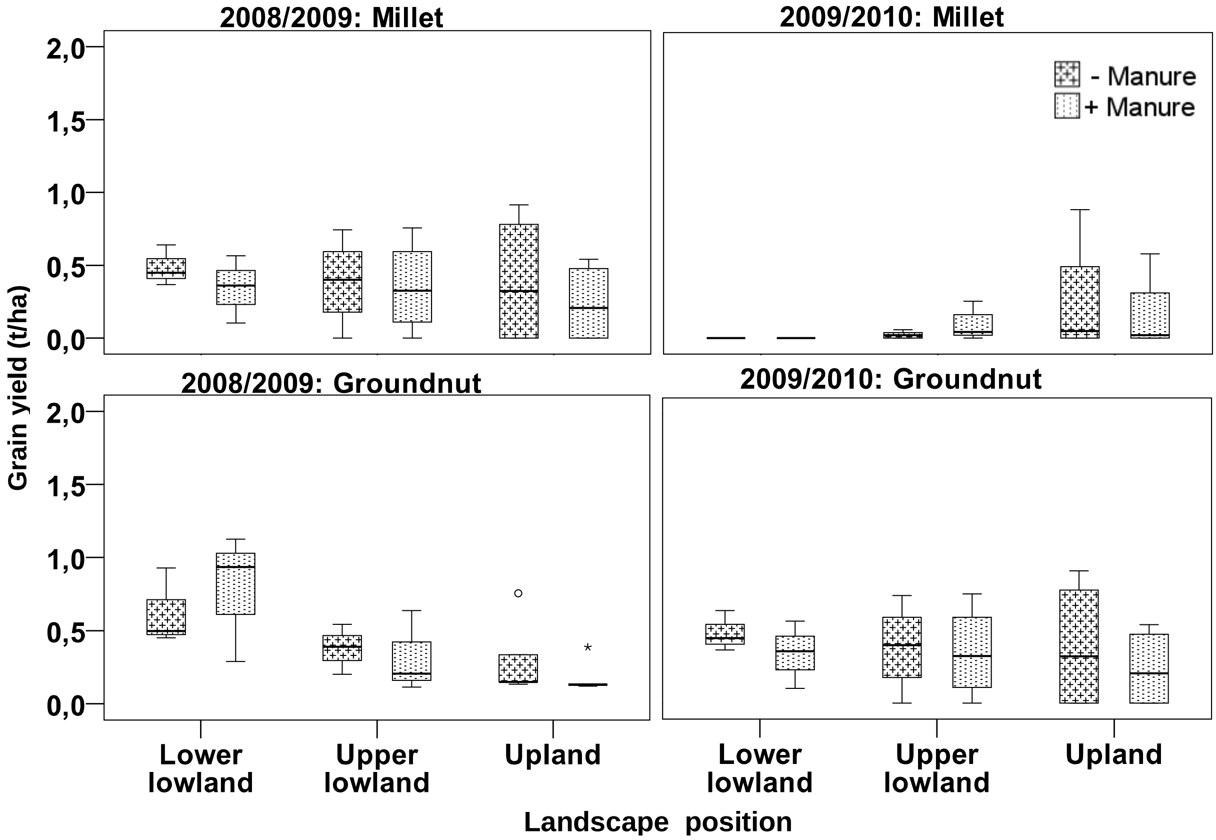

Figure 8 Grain yield (t/ha) of two millet and two groundnut varieties, at three landscape positions (lower lowland, upper lowland and upland), with or without application of manure at a rate of 10.5 t/ha in the 2008/2009 and 2009/2010 growing seasons.

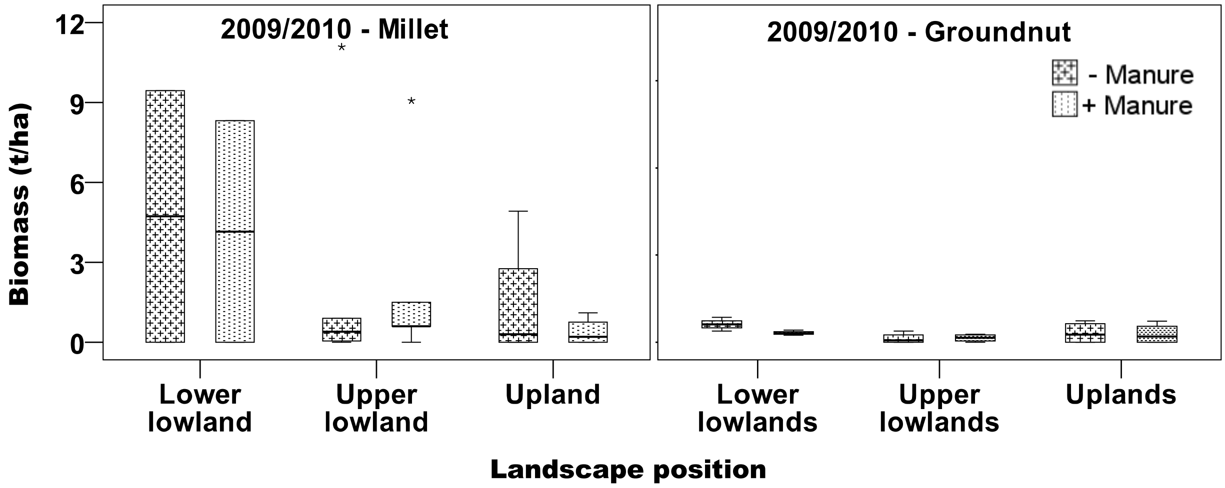

Figure 9: Above-ground residue biomass (t/ha) of millet and groundnut, at three landscape positions (lower lowland, upper lowland and upland), with or without application of manure at a rate of 10.5 t/ha in the 2009-2010 growing season.

Table 4 Consequences of season, variety, manure and landscape position of grain yield of groundnut in a semi-arid environment of Sengwe in south-east lowveld of Zimbabwe

Factor	% Establishment	Grain Yield (t/ha)
Season		
2008/2009	58.1[a]	0.69[a]
2009/2010	51.0[a]	0.40[b]
Manure (at 10.5 ton/ha)		
No manure applied	60.9[a]	0.58[a]
Manure applied	48.3[b]	0.51[a]
Landscape		
Lower lowlands	61.3[a]	0.85[a]
Upper lowlands	47.6[a]	0.44[b]
Uplands	54.7[a]	0.42[b]
P values		
Season	0.0005	0.0152
R^2	0.73	0.70

Within column means under same factor, with different superscripts are different at $P < 0.05$
Non-significant interactions are not presented.

3.7 Farm-level maximum expected grain production

Farm-level maximum expected grain production was estimated using a cropping system that resulted in highest yields for each landscape position. Sorghum did best with manure in uplands, cropping all three varieties to spread risk of loss by birds. Maize was best with manure in lower lowlands and without manure in upper lowlands, cropping short season varieties Local, ZM 401 and ZM 309. Millet has potential as observed from the biomass produced but grain yield losses to birds are substantial. Unless appropriate procedures are put into place either to control birds or to protect millet from birds, millet production will remain restricted. Sorghum and maize were chosen as 'best fit' crop options and assessed with and without manure at farm-level for their potential impacts on household food production (Table 5). Changing the farming systems from current practice to the practice that maximises production while reducing risk of crop failure, would result in an increased yield of 2.54 tons per farm in seasons similar to 2008/2009 and of 1.62 tons per farm in seasons similar to 2009/2010.

Table 5: Farm-level grain production potential of crop farmers in the south-east lowveld of Zimbabwe. Mean land size per household from survey data (Murungweni, 2011) were used in combination with yield data from field crop experiments carried out over two seasons (2008/2009 and 2009/2010).

Present strategy

Livelihood type	Landscape position	Crop	Manure	Area cropped (ha)	Yield (ton/ha)	Total harvest (ton)
	Upland	Sorghum/Maize	No	2.80	1.90	5.32
Good	Upper lowland	Maize/Sorghum	No	1.40	1.18	1.65
Year	Lower lowland	Maize	No	0.90	2.54	2.29
Total farm-level production 2008/2009						**9.26**
	Upland	Sorghum	No	2.80	0.38	1.06
Bad	Upper lowland	Maize	No	1.40	0.14	0.20
Year	Lower lowland	Maize	No	0.90	0.46	0.41
Total farm-level production 2009/2010						**1.67**

'Best bet' strategy

Livelihood type	Landscape position	Crop	Manure	Area cropped (ha)	Yield (ton/ha)	Total harvest (ton)
	Upland	Sorghum	Yes	2.80	2.46	6.89
Good	Upper lowland	Maize	No	1.40	1.18	1.65
Year	Lower lowland	Maize	Yes	0.90	3.60	3.24
Total farm-level production 2008/2009						**11.8**
	Upland	Sorghum	Yes	2.80	0.83	2.32
Bad	Upper lowland	Maize	No	1.40	0.14	0.20
Year	Lower lowland	Maize	Yes	0.90	0.86	0.77
Total farm-level production 2009/2010						**3.29**

4. Discussion

Semi-arid environments are prone to a series of hazards that affect agriculture adversely (Monteith, 1991; Rockstrom, 2000). Droughts, floods, and the presence of quelea birds are some, which affect the semi-arid south-eastern lowveld of Zimbabwe. Drought can manifest itself as an absolute lack of rainfall in a cropping year, but it can do similar damage to crop development when occurring as a series of dry spells with intermittent heavy downpours. This has been the case during the second year of our study, but is hidden from view when comparing the rainfall totals for both seasons, which are more or less similar. Next to this temporal aspect, spatial variation in rainfall over relatively short distance is also substantial, as Figure 2 shows.

Inhabitants of such areas are inherently vulnerable to such hazards, and in need of risk management strategies. The choices include: refrain from farming in the first place and instead rely on other sources of income including remittances; migrate to better-endowed areas or urban areas; or make use of genotypic, environmental and management variation in order to get the best out of relatively harsh and poorly predictable situations. After all, the ’best fits’ calculated in Section 3.7, show that quite substantial yield increases of 1.62 to 2.54 tons per farm were possible in case the land is used most cleverly.

Heterogeneity has been an asset in many African farming systems that face production challenges. Whereas large monocultures are often restricted to large-scale agriculture with a higher management intensity, ‘managed diversity’ is the key feature of many smallholder systems. As the case described in this study, (Gandah *et al.*, 2003) and (Stroosnijder and van Rheenen, 2001) provide several examples in the West African Sahel where physiographic differences at farm and village level are used for diverse agricultural production. More often, soil fertility differences are even amplified by farmers’ management, leading to preferred plots for the best crops (Wortmann and Kaizzi, 1998; Samake *et al.*, 2005; Tittonell *et al.*, 2006; Tittonell *et al.*, 2007). The use of manure is almost always beneficial for crops for obvious reasons (de Rouw, 2004; Zingore *et al.*, 2008). But the way it is stored and applied, and the relationship between its nutrient content, soil fertility and plant nutrient requirements determine its yield increasing potential. The results also suggest that short season maize varieties like ZM 309, ZM 401 and the locally grown Gopane grow best and their superiority is experienced in wetter areas. Longer maturing varieties like ZM 421 and ZM 521 were replanted many more times than the short season varieties because of poor establishment. However, multi-planting regimes are a common feature due to erratic rains associated with semi-arid areas.

For the ‘courageous’ farmer, the tool box in this study consisted of crop types, crop varieties, use of different physiographic positions in the landscape, and application of manure. By virtue of the experimental set-up, combinations of these four factors led to ‘best fit’ options, which would not have been possible when studied in isolation. To realize the potential, farmers have to be willing and able to invest labour, particularly when it comes to replanting, to store and reuse manure, to handle seed systems that cover a mix of crops and crop varieties and to deal with trade-offs. In terms of taste for example, farmers like maize better than sorghum, but in terms of drought tolerance, they prefer sorghum. Farmers make the same considerations when selecting crop varieties to plant e.g. Chihumani and Chibedlani varieties are liked more by farmers than Gangara, because they have good taste and more appealing grain flour colour (white). However, Gangara is more drought tolerant, has greater persistence and does not suffer from losses to birds the way Chihumani and Chibedlani do. To reduce losses by quelea birds, farmers hold a cultural event every year where some members of the community are tasked to check on the stage of growth of young birds in nests. About one week before young birds fly out of their nests, the whole community goes out to the rivers to harvest birds from their nests. Later on in the season farmers have to guard fields until the crop is harvested. Also, farmers would benefit from resource sharing, as the uplands and lowlands land units have different potential and hospitability towards the different crops and varieties which also respond to manure differently in these land units.

Although the dataset was not particularly large, the agronomic picture is rather clear. A hazardous environment offers opportunities to realize reasonable crop yields, but only if the diversity of plant, land and management skills is used. The knowledge provided in this study gives concrete clues and pathways for action in that respect. Whether farmers are willing and able to provide the labour and accept all the other prerequisites and trade-offs remains to be seen, as it has not been the focus of this study. Studies such as the one described in this paper would benefit from longer-term monitoring. Differences between years can be substantial, and a major flooding event in 2000 wiped out entire crops. Even integrated land, crop and nutrient management may not even help in such years. The years(s) following such events show the real resilience of the communities living in these areas, and depend much on food aid facilities for the disaster year, as well as skills and perseverance of the farming communities to move on from where they left. Against the backdrop of the proven increasing incidence of cropping years that are too wet, too dry, or average but with major dry spells (Rind *et al.*, 1989; Lean and Rind, 2009), it is of paramount importance to make clever use of the diversity offered by plants and land. Shared researcher-farmer knowledge and sense of coping strategies as worked out by Murungweni (2011) complete the set of tools needed to keep food production going in the south-eastern lowveld of Zimbabwe.

Chapter 6

General discussion

1. Introduction

Analysis of vulnerability as a social phenomenon has a long research tradition on critical questions of food security and famine (Watts and Bohle, 1993). One of the key lessons learnt is that society and economics may either counteract or amplify the climate signal (Simelton *et al.*, 2009), therefore, vulnerability assessments require holistic approaches that embrace the role played by society and institutions. As an example, the underlying socio-economic and political conditions in Ethiopia turned a minor climatic perturbation into a massive famine during the 1980s drought, (Comenetz and Caviedes, 2002). In southern Africa, a combination of local adaptability, pro-active governmental response, the holding of large national grain reserves and long-range forecasting reduced effects of the major drought of 1991-1992 resulting in an insignificant number of hunger stricken and famine-related deaths (Eldridge, 2002). In this thesis I have analysed the vulnerability and adaption possibilities of smallholder farmers to a range of different shocks and hazards (Chapter 2 and 3), but in Chapters 4 and 5 concentrated mainly on adaptation options to effects of drought. In this discussion chapter I revisit some of the findings of these chapters, and place them in a broader context by also looking at other hazards faced by smallholder farmers. The most important hazards and vulnerabilities faced by different people as listed by the smallholder farmers themselves, and the adaptive strategies currently employed and those possible to these hazards and vulnerabilities are assessed on their implications for household and regional food security in this chapter.

2. Hazards, vulnerability and resilience of semi-arid rural people of southern Africa

2.1 Drought as the major hazard

Sensitivity is an inherent property of a system; exposure makes the system express its sensitivity to a hazard. Gallopín (2006) analysed the vulnerability and resilience literature and concluded that the systems' coping capacity is same as capacity of response or adaptive capacity and all these are components of resilience. Drought is the main hazard affecting farming systems in Africa (Dixon *et al.*, 2001). Drought increases vulnerability of people to poverty. Drought can cause total loss in crop grain yield harvests as shown in Chapter 5, and severe or prolonged droughts cause loss of livestock. During drought, donor food becomes increasingly important (see Chapter 2, Figure 5). However, over reliance on donor food makes crop-based households more vulnerable to poverty because donor organisations are outside of the control the local people. In 2008, (a year following the 2007 drought in Zimbabwe), the greater proportion of donor organisations were asked by the Zimbabwean government to stop working because of political mistrust. Crop-based households were left exposed to hunger because donor food aid was their main source of food during drought. This is one demonstration that livelihood systems that rely on resources outside peoples' control make people vulnerable to poverty. As a result, strengthening systems of local food production makes more sense even though other activities (like ecotourism as proposed in the Great Limpopo Transfrontier Conservation Area) might help in strengthening existing livelihood systems.

2.2 Other hazards

Important hazards faced by people in semi-arid rural areas of southern Africa are shown and described in Table 1. Risk is an intrinsic property of the system and can be defined as the product of hazard, vulnerability and amount of loss experienced. Floods do not occur as frequently as droughts and are perceived differently by different households of the south-east lowveld of Zimbabwe. Only 16% of households (survey data 2008, n=156 Table not shown) perceive floods as a threat to their livelihood. Cattle and non-farm based households comprise the greater proportion (12%) of those affected by floods. Heavy-clayey soils of the south-east lowveld of Zimbabwe exacerbate the impact of floods on cattle-based households. People lose cattle because some of them get stuck in the clayey fields and die which is common during floods. Also during floods respondents report an increasing number of wildlife roaming outside of the park resulting in increased livestock/wildlife contacts and dangers for disease transfer. For non-farm households, their 'illegal' crossing points are closed by flooding rivers for a long time effectively cutting links between local people and their relatives across borders. Flow of remittances slows down making non-farm based face shortages in food supply. On the other hand, most crop farmers report a bumper harvest from upland fields during floods. Only those who crop in lower lowlands alone suffer because of water logging and direct damage from flooding in their fields.

Many livestock diseases like foot and mouth disease and lumpy skin disease are endemic to south-east lowveld of Zimbabwe. During drought, outbreaks of diseases of livestock, notably tick-borne, blackleg and foot and mouth diseases often occur. Diseases cause cattle death; some diseases like foot and mouth attract implementation of statutory instruments restricting movement of cattle out of disease zones. Fears for disease spread are already high in the region, threatening proper implementation of the Transfrontier conservation projects (Bengis, 2007).

Table 1 Hazards and vulnerabilities affecting people in semi-arid south-east lowveld of Zimbabwe and adaptive strategies that they employ in order to reduce impact on household food self sufficiency

Hazards *(probability of event)*	**Mechanisms triggering hazards**	**Vulnerability** *(degree of damage, function of magnitude of event and type of elements at risk)*	**Amount** *(Quantification of the elements at risk: e.g. number of people, etc.)*	**Field-level responses**	**Policy responses**
Drought	Low rainfall	Loss of grain yield	75% to 100% loss in grain yield (2yr crop experiment data)	**Managerial-based strategies** Application of organic manure (proposed), leaving legume trees in field, planting short season varieties, employing multiple planting regimes, changing diet,	Irrigation schemes Donor food
			84% population affected by drought (survey data, *n*=156)	**Community-based strategies** livestock redistribution, Group activities to ensure, timely cropping, migration	Government support schemes
		Low cow productivity, poor milk yields, reduced draught power and cattle deaths	up to 75% cattle deaths	**Managerial-based strategies** feed supplements (e.g. Zhombwe and Mopani leaves, targeted use of inputs **Community-based strategies** livestock redistribution, group buying of drugs,	Group fattening scheme and marketing (e.g. the abandoned Mpakati cattle feeding scheme)
	Long intra-seasonal dry spells	Negative effects on critical yield formation stages		Multi-planting regimes	Planting short-season varieties
		Increased lignification of grass and reduced biomass yield		Migration with cattle to areas with grazing (often mountains), renting grazing from commercial farms	

Hazards *(probability of event)*	**Mechanisms triggering hazards**	**Vulnerability** *(degree of damage, function of magnitude of event and type of elements at risk)*	**Amount** *(Quantification of the elements at risk: e.g. number of people, etc.)*	**Field-level responses**	**Policy responses**
Floods	Waterlogging	Loss of grain		Diversify crop/crop varieties and cropping on different landscape positions	Cropping across landscape positions
		Deaths of livestock		Kraaling cattle during heavy rains	
Damage causing animals	Grazing/trampling by elephants	loss of grain	65% population affected by wild animals (survey data 2008, *n*=156)	Guarding fields	Compensation strategy, fencing
	Predation	loss of livestock, draught power		Kraaling cattle at night	
	Damage by birds	loss of grain		High fences using wooden poles	
Theft	drought	Loss of grain		Herding cattle	Effective legal instruments
		Loss of livestock			controlling cattle movement
Livestock diseases	Drought followed by a flood	Loss of cattle		Group buying of medicines through dip tank committees	Quarantine, buffer zones.
		Loss of production		Use of traditional medicines	Proposing local beef processing
Non-conducive policies	Forced migration	Insecurity	23 families face forced resettlement from Chilothlela village in Ward 14	Increased poaching	Compensation
	Top-down policy development				Proper planning and consultation

Restricted movement leads to loss of markets making cattle-based households more vulnerable to poverty. In the south-east lowveld of Zimbabwe, people find an alternative 'illegal' route to Mozambique for trading their cattle. This route can as well be an outlet route for cattle-borne diseases and the resulting cattle movement exposes other regions to diseases that were not common in those areas. Therefore, illegal cattle trading can be a hidden hazard to the success of the Great Limpopo Transfrontier Conservation Area initiatives in southern Africa. However, control of outlet routes can exacerbate drought effects and make people more vulnerable to poverty if there are no alternative markets.

Theft is another hazard that the common people do not know how to cope with. Many local people claim the existence of complicated networks with some even blaming low enforcement agents as being involved. Some law enforcement agents blame members of the community for falsifying thefts as a way to account for cattle that they have illegally across the border into Mozambique. This reduces the vigilance of the law enforcement agents against theft and thus the growing mistrust between the two parties increases vulnerability of innocent people to more theft.

Damage causing animals like elephants, hyenas and lions from the park are considered to be hazards regardless of whether a homestead is located close to or away from the park. In the south-east lowveld of Zimbabwe, only households that are located close to the park according to community-based natural resource management program are expected to benefit from compensation from the park when there is destruction of their crops or killing of their livestock by predators from the park. People not benefiting are equally affected and they are not happy with the current compensation strategy. Even those living close to park are not content with the current compensation offered. Proceeds from the killing of problem animals, such as elephant in terms of meat, or lions and other animals through hunting fees benefits the whole community not specifically the individual affected. In addition to damage causing animals, quelea birds (*Quelea quelea*) are a menace to small grains especially during drought when grain production is reduced and many fields are bare. Presence of these birds strongly influences choice of crop and of crop varieties by farmers, reducing the use of the small grained cereals sorghum and millet that provide more resilience in the face of drought (Chapter 5).

2.3 Coping with drought

Adaptive strategies employed by different households at household scale are inadequate to ensure food security for all people. Higher level coping strategies also play an important role. Non-farm households extend their food net across borders. Networks between households facilitate food and resource distribution: for example, *kuronzera* - a process of cattle redistribution to the poor by the rich – assists both groups to cope with drought in the south-east lowveld of Zimbabwe. Intervention by government and donor agencies strengthens the whole system against hunger through provision of emergency relief. Cross-level interactions are important in reducing vulnerability of people to hazards (Adger, 2003).

Food production potential of the region can be assessed using estimates of household food production potential (Figure 1). Even though people spread risk by cropping across different landscape positions, survey data (n = 156) showed that in a good year 46% of households do not harvest enough grain to last the whole season, 40% harvest grain that can last one season only and 14% of households harvest sufficient grain to last between one and three seasons. Respondents said that during drought, upland fields are the worst affected and most food is derived from the lower lowland fields. None of the households harvest sufficient food to last the whole year in a bad year but those with access to lower lowlands will have some harvest. From survey data, a good year occurs only once in every three years.

Lower lowlands are important for reducing the vulnerability of crop farmers to drought in semi-arid areas. Access to lower lowland fields enhances the capacity of farmers to cope with erratic rain conditions experienced in the semi-arid areas (see Figure 1). In the south east lowveld of Zimbabwe, a large proportion of crop-based households (62%) own land in lower lowland positions averaging 1.1 ha (SD = 0.7). Lower lowlands are cropped a month or two later than upland fields. Farmers wait for a flood to occur and subside before lower lowlands are cropped. This delay helps farmers without cattle to work for wealthier households in return for draught power to prepare their lower lowlands fields later in the season. The delay also allows food deficient households to sell their labour to wealthy farmers and work for food to sustain them during the hunger period (the last 3 months before harvest). Access to lower lowlands also helps farmers reduce labour bottlenecks on their own farms. They can concentrate on the uplands and upper lowlands and later on come to lower lowlands. Also, lower lowlands have rich alluvial soils that are easy to work unlike the clayey upper lowland soils. Cattle-based households have more cattle spans, on average three spans (SD =2), crop-based households have less, only one on average (SD = 1) and non-farm households have none. Cattle-based households often hire labour during times of critical labour shortage for activities such as planting, weeding and harvesting. Cattle-based hire labour from households without adequate number of cattle spans in return for draught power when their work is done, or in exchange for food. The cropping season coincides with the time when most households are short on food especially if the previous season was not good, cattle-based households use their relatively strong asset base to employ others providing another form of local safety-net.

For cattle-based households, feed shortages can be complemented by feed supplementation but sourcing supplements is a major challenge. Neorautanenia amboensis (Schinz) - Zhombwe (Chapter 4) has potential to significantly reduce loss of cattle. Using Zhombwe as cattle feed is appropriate for cattle survival during drought but not for feed when sufficient grass or other fodder is available due to the labour needed to harvest it. The Zhombwe resource available in the south-east lowveld of Zimbabwe was quantified and results are presented in Table 2. At current quantity, the resource could assist all livestock in the study area to survive drought for two years. However, the amount used depends on severity of drought and the power of people to continue digging out the tubers. Also, most people only feed priority animals like the draught and the breeding stock. Therefore, the currently available resource can last many more years. Implications of over exploitation of the resource are not known, more work is needed on the recruitment process of new tubers and on how much time it takes the tubers to reach desirable size to start feeding livestock.

2.4 Coping with other hazards

2.4.1 livestock disease and poor markets

Livestock diseases are a threat to livelihoods in the south-east lowveld within the Great Limpopo Transfrontier Conservation Area (Cumming, 2005; Bengis, 2007). This problem can be reduced by increasing disease control and monitoring as being promoted by a French research organisation, CIRAD, in the south-east lowveld of Zimbabwe. This option can be an expensive adventure and if not coupled with empowerment of local communities may in turn make them more vulnerable post project. Instead, people and their stakeholders can become more enterprising and begin to initiate commodity-based formal markets run by themselves as being witnessed in the eastern cape (South Africa) through the Umzimvubu goat project or the proposed goat project for Sekhukhune district of South Africa (Anteneh *et al.*, 2004). In this case, communal farmers come together; open abattoirs where they agree to provide certain number of animals per year at certain specific time then slaughter and add value for export outside their region. Those way farmers control the marketing process and create local employment.

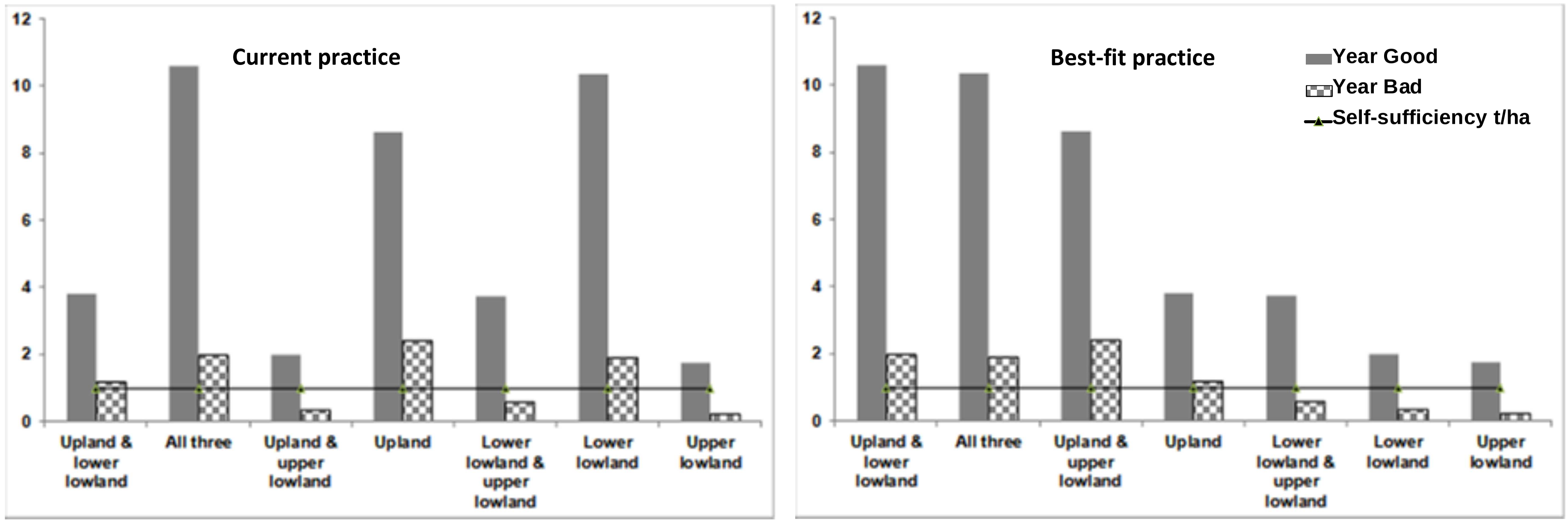

Figure 1: Potential food production (tonnes/household/year) in the semi-arid south east lowveld of Zimbabwe under a. Current system of management as being practiced by local people and b. Improved 'Best Fit' system of management as derived from experimental results. Assumption: Farmers make maximum use of the land currently available to them for grain crop only, labour is not limiting. 2% of the households do not have any farming land.

Table 2 Current relationship between available *N. amboensis* and total number of cattle in the south-east lowveld of Zimbabwe

	Chromic luvisols	Eutric vertisols	Ferrallic arenosols	Leptosols
Cropped or fallow land (Field)				
Mean counts (number/ha)	446	561	178	398
Field size (Ha)	1366	14042	572	1992
Total counts	609236	7877562	101816	792816
Natural veld				
Mean counts (number/ha)	62.2	126	24.5	58.3
Total field size (Ha)	57854	84188	23512	90521
Total counts (number/soil type)	3598518.8	10607688	576044	5277374.3
All counts (Field + Natural veld) per soil type	4207754.8	18485250	677860	6070190.3
Mean weight per soil type (kg)	14.8	15.8	10.8	18
Mean weight all soils (kg)	14.9			
Grand Total (all counts)	29441055			
Total Livestock in Area (2008 counts)	39175			
Feeding rate (tuber/animal/day)	1			
Total tubers for all cattle per day (number/day)	39175			
Number of days current Zhombwe would last	756			
Number of years current Zhombwe would last	2			

2.4.2 Theft

People reported an increase in theft during drought. Theft is largely reported on cattle. During drought, people seek for food sources from places far away from their own settlements. In the south-east lowveld of Zimbabwe, people sell livestock in Mozambique. Local markets also become more active because most people do not have food to sell. At their monthly local markets, many different people with different intentions also are present. From these markets cattle rustlers can already identify the pattern of cattle movements and capitalise on that. Even those legally driving their cattle for selling in Mozambique are said to include a few more cattle they find 'stray' along the way.

2.4.3 Damage-causing animals

Most people herd their livestock, kraal them at night and fence-off their fields and homestead to reduce incidence of predation by hyenas and lions. Some sleep in their fields and scare elephants away when they attempt to invade their fields. During crop harvesting time many stay in fields also to scare away birds. The Transfrontier conservation initiatives may constitute a major new threat to peoples' livelihoods. The proposed Sengwe-Tshipise corridor will cut across the major food production lower lowland zone (the Limpopo Banyeni), located in Ward 4. Respondents said that the Limpopo Banyeni is their main maize belt and their last hope for grain locally when there is drought. Current plans are that the Banyeni will be fenced off to create the corridor to create this migration corridor to encourage wildlife to cross between the three countries (Zimbabwe, South Africa and Mozambique). Local respondents said that the establishment of this corridor will make their livelihood insecure. This conclusion is strongly back up by the experimental results of Chapter 5 and the livelihood analyses reported in Chapters 2 and 3, which demonstrate the key role of the lower lowland fields in food provision. The risks associated with farming will increase because experience in the region shows that elephants cannot be kept inside by fences and compensation for crop damage is problematic as described above. People would have to sleep in their fields to get a harvest and face an increased frequency of encounters with wildlife making farming an increasingly risky and more labour intensive livelihood option in the south-east lowveld.

2.4.4 Importance of understanding adaptive strategies

Due to poverty in Africa, adaptive capacity of the African people to climate variability and change is regarded 'low' and it is exacerbated by a host of other factors. Boko et al. (2007) identified some of these factors as low GDP identified per capita, widespread endemic poverty (as portrayed in Chapter 1, Figure 4), weak institutions (see Chapter 2), low levels of education (47% household heads never attended school in south-east lowveld of Zimbabwe), little consideration of women and gender balance in policy planning (cultural differences are important), conflicts and limited access to capital, markets, infrastructure and technology. Some coping responses of people are short term, especially those currently employed by crop-based households. Short-term coping responses may lead to reduced adaptive capacity in the long run which implies loss of social–ecological resilience (Fabricius *et al.*, 2007). Poverty alleviation projects and new policies should take the issue of peoples' control and use of resource into consideration. Projects that are aimed at replacing or complementing existing livelihood activities (e.g. the GLTFCA initiatives) should ensure the involvement of local people from the beginning with full knowledge on how these people make a living. In the south-east lowveld of Zimbabwe, initiatives to introduce ecotourism as an alternative livelihood activity (Spenceley, 2008) should be implemented with caution (Katerere *et al.*, 2001; Dzingirai, 2003). Environmental considerations for wildlife protection and conservation should not be supported at the expense of the livestock-based livelihoods. Livestock development policies should not be ignored. We should be talking about integrating tourism with current farming systems rather than otherwise. This thesis provides useful information for planners in the GLTFCA to make more informed decisions.

3. Implications of adaptive strategies on regional food security

From the household survey data, 41% households in our study area belong to the crop-based livelihood type, 47 % belong to the non-farm based livelihood type and 12 % belong to the cattle-based livelihood type. Results on 'best fit' cropping strategies from Chapter 5 can be combined with the population census results to get insights on food security state in the south-east lowveld of Zimbabwe. The last census results shows that the total number of households in the study area (Wards 11, 13, 14 and 15) was then 6,400 then (CSO, 2002). Assuming that our survey was representative of these wards as a whole, it then follows that 2,624 (or 64%) were crop-based households, 62 % of these (or 1,626) have access to lower lowlands (average size 1.1 ha per household). Following the same arguments, 3 008 (or 73%) were non-farm households, 53 % of these (or 1,594) have access to lower lowlands (average size 1.3 ha per household) and 768 (or 12%) were cattle-based households, 42 % of these (or 322) have access to lower lowlands (average size 0.8 ha per household). According to Kinsey et al. (1998), each household requires 1.5 tonnes of grain per year. The total of 6,400 households needs 9,600 tonnes of grain per year. According to current practice, total food production will be 15,600 tonnes in a good year and 1,800 tonnes in a bad year. If people use all available land for grain (with labour not limiting), the region would produce a total of 37,300 tonnes of grain in a good year and 17,200 in a bad year. If best-fit practices are implemented then regional production will be 60,900 tonnes in a good year and 7,800 in a bad year. From this picture we see that even if all currently cleared agricultural land is made available for grain production, in a bad year food will always be in short supply in the south-east lowveld of Zimbabwe. If extra grain from a good year is to be saved for subsequent years to follow, then post harvest grain preservation methods have to be effective. Currently hard seed local variety Chibhubhani for maize and some red sorghum variety Gangara ensures long storage. Other varieties that are poorly resistant to weevils (e.g. Chihumani for sorghum and new ‘soft’ grain maize varieties that were improved for higher yields) can be consumed first.

4. Conclusion

In this thesis, the vulnerability analysis shows that policies relating to the permeability and/or enforcement of protected area boundaries or uninformed displacement of people can strongly aggravate the effects of other external influences, such as drought or climate change. *Neorautanenia amboensis* has a lot of potential for reducing vulnerability of cattle-based households to drought but more work is required to understand active factors in this tuber and their mechanism of action. In terms of food security, access to lower lowlands was found to be important for crop farmers to survive drought. The region has potential to be food secure but lacks capacity in terms of labour and other inputs. The best fit strategies identified in this thesis are improvements on current practices only if people have access to several landscape units; for farmers having access to a single unit the current practices seem always better. For ‘best fit’ strategies, a further analysis from ecological and economic gains and losses may be required.

5. Further work

Vulnerability analysis of livelihoods remains incompletely understood if we do not come-up with ways we can use to quantify feedbacks in real terms. Fuzzy cognitive Mapping shows us important changes in vulnerability in relative terms. This is important for understanding the effects of hazards on livelihoods but for planning action we need proper quantification in real terms. Dynamic simulation modelling can play an important role in quantifying the magnitude of change and map recovery path. From the newly discovered medicinal feed (Zhombwe), its growth characteristics and active compounds giving it the anthelmintic properties need further investigation in order to understand its proper function. Understanding the growth characteristics will open up opportunities for possible commercialisation of the tuber when it becomes necessary. From crop experiments, access to lower lowlands for people with upland fields was important to reduce vulnerability to drought and floods. Use of manure was encouraged, but the availability of manure and its long term use in fields was not quantified. Alternative use of organic material can be explored where manure is in short supply. Also, there are statutory instruments prohibiting use of flooded areas basing arguments on increase in river siltation resulting from increased soil erosion yet these areas are critical to local people. More work is needed to identify areas where capacity building is required to improve food security.

While the development of the Transfrontier conservation area may provide employment opportunities in eco-tourism for some, it raises a spectre of increased human-wildlife conflict. Low-lying riparian lands that are key to local and regional food security will be increasingly invaded by wildlife to the exclusion of local people. These conflicts demand urgent attention to ensure the future of both people and wildlife in the south-east lowveld of Zimbabwe.

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Summary

Vulnerability and resilience have emerged as powerful analytical concepts in the study of socio-ecological systems. In this research these concepts are used to enhance our understanding of heterogeneous rural livelihoods in a semi-arid area on the western border of protected wildlife areas in Zimbabwe's southeast lowveld. Characterized by high levels of poverty, households in this area are confronted with numerous hazards, such as livestock predation and crop destruction by wild animals and, most notably, recurrent drought conditions. Droughts may cause crop failure and immediate food insecurity, but may also cause livestock deaths because of limited fodder availability. Thus households' productive capacity is reduced and their vulnerability to future hazards increases. In semi-arid areas, livestock often play an important safeguarding role in adverse situations. In view of climate change studies, which predict an increase in drought conditions in sub-Saharan Africa, the understanding of rural households functioning and vulnerabilities is of particular relevance for development programmes that seek to alleviate poverty in semi-arid areas.

The goal of this thesis was to contribute to the knowledge base needed for developing sustainable solutions that increase food security and reduce poverty of people living in semi-arid rural Africa. The purpose was to develop a methodological approach that helps understanding both the vulnerability of rural livelihoods to change resulting from factors such as drought, damage causing animals, and protected area boundary enforcement, as well as the adaptive mechanisms households devises to cope with such vulnerability. Specific objectives were:

1. To identify, describe and explain key elements and relationships of the main livelihood systems in the semi-arid south east lowveld of Zimbabwe (Chapter 2)

2. To develop and apply a framework for analysing the functioning of different livelihoods and their vulnerability to external changes (Chapter 3)

3. To explore factors determining the resilience of land-based livelihoods to change in the face of hazards (Chapters 3, 4 and 5)

4. To explore local-level opportunities for enhancing household food self-sufficiency building on existing activities contributing to household food availability (Chapter 5)

5. To determine the implications of various strategies employed by people on poverty alleviation food insecurity (Chapters 3 and 6)

Using multiple methods, ranging from interviews, focus group discussions, and observations to a quantitative survey, field experiments and modelling techniques, this research identified three distinct livelihoods types – cattle-based, crop-based, and non-farm based – and explored the different ways in which these livelihood types (Eberhardt *et al.*) cope and recover from the hazards they face.

Although most households in the study area keep livestock, practice arable farming, and receive remittances, they differ in terms of their dependency on cattle, cropping, and non-farm and off-farm activities, especially in years of drought. Households most dependent on livestock – the cattle-based livelihood type – generally cope with hazards by selling cattle. Their main problem is an unreliable livestock marketing system. Households of the crop-based livelihood-type strive to spread the risk of crop failure by cropping across the landscape, ranging from flood plains to uplands on the interfluves. They cope with drought by relying on food aid distributions and, to a lesser degree, by increasing gardening and non-farm activities such as labouring for food, moulding bricks, beer brewing, and selling chickens and small stock. Households of the non-farm livelihoods type rely for their survival on paid employment outside the study area, mostly of households' members working in South Africa.

Fuzzy cognitive mapping (FCM) was used to assess the vulnerability of the three livelihood types to different hazards. Graphical representations of the major livelihoods activities, their interdependencies, and external factors influencing these, were made during participatory sessions with farmers and stakeholders. These 'maps' were then used as semi-quantitative models to analyse the vulnerability of livelihoods to (potential) external changes. Thus response to change could be analysed, albeit not in terms of the time period or pattern of recovery after external change, but in relative terms. Vulnerability analysis showed that policies relating to the permeability and/or enforcement of protected area boundaries can strongly aggravate the effects of other external influences, such as drought or climate change. FCM also appeared a useful participatory tool enabling farmers and researchers to communicate on, and better understand the complexity of livelihood systems in a way that is better appreciated by stakeholders.

As both cattle-based and crop livelihoods depend on cattle, reduced fodder availability during drought is a major problem of households of both livelihood types. To cope

with this drought induced fodder shortage, people have recently started to use *Neorautanenia amboensis* (Schinz). This tuber shrub, locally known as *Zhombwe*, is now saving many cattle from death in periods of drought, thus reducing livestock keeping households vulnerability to drought. An experiment confirmed local people's claim that *Zhombwe* is a medicinal feed, as it was found to possess strong anthelmintic properties. In addition, it was found that this tuber crop grows across different soil types, and occurs more in disturbed soils - e.g. crop fields - than in natural veld.

Crop experiments where used explore adaptive strategies deployed by or of potential use to households of the crop-based livelihood type. Faced with recurrent droughts farmers in the southeast lowveld cultivate across the landscape, growing different types of crops and varieties, and using manure (which is not often used in this area). Four crops (maize, sorghum, pearl millet and groundnut) were assessed during two contrasting rainfall seasons (2008/9 and 2009/10). Major yield determinants proved to be landscape position and within-season rainfall distribution. Maize yielded more in lower lowlands (1.30 t/ha) than in upper lowland areas (0.46 t/ha) and uplands (0.20 t/ha). In contrast to maize, the highest yields of sorghum were obtained in the uplands. Further, manure generally had a positive effect on crop production. The crop experiments quantified the mosaic of crop growth conditions, caused by the spatial variation in rainfall, and different crop varieties, landscape positions, and soil types. By making use of these differences in crop growth conditions the risk of production loss can be reduced. This means that cropping areas in semi-arid areas have to be properly disaggregated in order to target appropriate technologies that can reduce the vulnerability of local food production systems to rainfall variability. It was concluded that people living in semi-arid areas have the potential to grow enough food.

The outputs of this research include a tested tool that takes into account feedback mechanisms when analysing livelihood systems, hazards of importance to rural people living in semi-arid areas of southern Africa, vulnerability of main livelihoods to identified hazards as they are assessed in scenarios developed from knowledge of local people and stakeholders, adaptive mechanisms employed by different households to cope with change, role of manure in semi-arid cropping systems, performance of different crop varieties in different landscape position of interest to farmers and opportunities available for people to improve on their coping capacity while improving household food security.

Samenvatting

Kwetsbaarheid en veerkracht zijn krachtige analytische concepten in de studie van sociaal-ecologische systemen. In dit onderzoek zijn deze concepten gebruikt om ons begrip van het functioneren van heterogene rurale huishoudens in semi-aride natuurgebieden in het zuidoosten van Zimbabwe te verbeteren. Deze huishoudens, gekarakteriseerd door grote armoede, worden geconfronteerd met verschillende risico's voor hun bestaan, zoals predatie van hun vee en vernietiging van hun gewassen door wilde dieren, en, vooral, door terugkerende droogtes. Droogtes kunnen misoogsten veroorzaken, en daarmee onmiddellijke voedselonzekerheid, maar ook veesterfte door beperkte beschikbaarheid van voer. Hiermee wordt de productie capaciteit van huishoudens verlaagd, en wordt hun kwetsbaarheid voor komende schokken vergroot. In semi-aride gebieden speelt vee meestal een belangrijke rol in het omgaan met moeilijke omstandigheden. Met het oog op klimaatsveranderingstudies, die een toename in het voorkomen van droogtes voorspellen in Afrika ten zuiden van de Sahara, is kennis over het functioneren van rurale huishouden, en hun kwetsbaarheid, buitengewoon relevant voor ontwikkelingsstudies die trachten armoede te verminderen in semi-aride gebieden.

Het doel van deze thesis is om bij te dragen aan de kennisbasis die nodig is om duurzame oplossingen te ontwikkelen die de voedselzekerheid laten toenemen en die de armoede van mensen in de rurale gebieden van semi-aride Afrika verminderen. De manier om dit te bereiken was door een methodologie te ontwikkelen die bijdraagt aan het begrip van zowel de kwetsbaarheid van rurale huishoudens voor veranderingen (door factoren als droogte, schade veroorzakende dieren en natuurbeschermingsmaatregelen), als de adaptative mechanismen die huishoudens toepassen om met die kwetsbaarheid om te gaan. Specifieke doelen van het onderzoek waren:

1. Het identificeren, beschrijven en verklaren van kern elementen en relaties in de belangrijkste huishoud types in het semi-aride zuidoost 'lowveld' gebied in Zimbabwe (Hoofdstuk 3)

2. Het ontwikkelen en toepassen van een raamwerk om het functioneren en de kwetsbaarheid van verschillende huishoudens te analyseren (Hoofdstuk 3)

3. Het verkennen van factoren die de veerkracht van landgebaseerde huishoudens op veranderingen bepalen (Hoofdstukken 3, 4 en 5)

4. Het verkennen van lokale mogelijkheden om de voedsel zelfvoorzienigheid van huishoudens te verbeteren, voortbouwend op bestaande activiteiten die bijdragen aan de voedselbeschikbaarheid binnen het huishouden (Hoofdstuk 5)

5. Het bepalen van de implicaties van verschillende strategieen die door mensen worden gebruikt om de armoede te verlichten (Hoofdstukken 3 en 6)

Gebruikmakend van meerdere methoden, varierend van interviews en groepsdiscussies tot kwantatitieve vraaggesprekken, veldexperimenten en modelleertechnieken, identificeerde dit onderzoek 3 verschillende huishoud types – vee-gebaseerd, gewas-gebaseerd en niet-boerderij gebaseerd, en verkende de verschillende manieren waarmee deze huishoudens omgaan met de risico’s waarmee ze leven.

Alhoewel de meeste huishoudens in het studiegebied vee houden, akkerbouw bedrijven en geld ontvangen van andere familie leden in de stad, verschillen ze substantieel in de mate waarin ze afhankelijk zijn van vee, gewasproductie en niet boerderij gerelateerde activiteiten, vooral in jaren waarin het droog is. Huishoudens die het meest afhankelijk zijn van vee (het vee-gebaseerde type) gaan om met grote problemen d.m.v. het verkopen van vee. Hun grootste probleem is een onbetrouwbare veemarkt. Huishoudens van het gewas-gebaseerde type proberen het risico op mislukking van het gewas te verminderen door op verschillende lokaties in het landschap te verbouwen, varierend van overstromingsgebieden to hoger gelegen land. Ze gaan om met droogte door te vertrouwen op voedselhulp en in mindere mate door hun tuinier en niet-boerderij gerelateerde activiteiten (zoals arbeid voor voedsel, stenen maken, bierbrouwen en verkoop van kippen) te intensiveren. Huishoudens van het niet-boerderij gebaseerde type zijn afhankelijk voor hun overleven van betaald werk buiten het studiegebied, veelal in Zuid-Afrika.

Fuzzy Cognitive Mapping (FCM) werd gebruikt om de kwetsbaarheid van de drie huishoud types voor bepaalde gebeurtenissen in te schatten. Grafische representaties van de belangrijkste aktiviteiten in de huishoudens, hun onderlinge afhankelijkheden en de externe factoren die deze beinvloeden, werden gemaakt gedurende interactieve sessies met boeren en belanghebbenden. Deze ‘maps’ werden daarna gebruikt als semi-kwantatitieve modellen om de kwetsbaarheid van huishoudens voor externe veranderingen te analyseren. Op deze manier kon die kwetsbaarheid worden geanalyseerd, alhoewel niet in termen van tijd of herstelpatroon na een externe verandering, maar alleen in relatieve termen. Een gevoeligheidsanalyse liet zien dat beleid gericht op het strikt toepassen van grensbewaking de effecten van andere externe factoren als droogte of klimaatsverandering sterk kan verslechteren. FCM bleek een bruikbaar participatief gereedschap te zijn, die het boeren en onderzoekers mogelijk maakte om beter te communiceren, en om de complexiteit van huishoudens beter te begrijpen.

Aangezien zowel vee- als gewas-gebaseerde huishoudens afhankelijk zijn van vee, is de verminderde voerbeschikbaarheid tijdens droogtes een groot probleem voor beide huishoud types. Om hiermee om te gaan zijn de mensen recentelijk *Neorautanenia amboensis* (Schinz) gaan gebruiken. Deze knolstruik, lokaal bekend als *Zhombwe*, redt op dit moment veel vee van verhongering gedurende droogtes, daarmee de kwetsbaarheid van vee-houdende huishoudens verminderend. Een experiment bevestigde het beeld van lokale mensen dat *Zhombwe* medicinale eigenschappen heeft: het bleek namelijk sterke anthelmintische eigenschappen te hebben. Bovendien bleek het dat het knolgewas op verschillende bodemtypen groeit, en meer voorkomt in verstoorde bodems (i.e. akkerbouwgronden) dan in natuurlijke vegetatie.

Gewasexperimenten werden gebruikt om de adaptatie strategieen die nu of potentieel door huishoudens gebruikt kunnen worden te verkennen. Geconfronteerd met terugkerende droogtes cultiveren boeren uit de studie regio op verschillende plekken in het landschap, gebruiken verschillende gewassen en varieteiten en passen mest toe (dit laatste gebeurt niet vaak in zuidoost Zimbabwe). Vier gewassen (mais, sorghum, pearl millet and pinda) warden beoordeeld in twee contrasterende regenval seizoenen (2008/9 en 2009/10). Belangrijke oogstbepalende factoren bleken landschapspositie en de regenval distributie binnen het seizoen te zijn. Mais bracht meer op in laag gelegen velden (1.30 t/ha) dan in middelhoog (0.46 t/ha) en hooggelegen landen (0.20 t/ha). Contrasterend met met mais behaalde sorghum de hoogste opbrengsten in de hooggelegen landen. Daarnaast had mest over het algemeen een positief effect op de gewasproductie. De gewasexperimenten kwantificeerden de mozaiek aan gewasgroei condities, die veroorzaakt wordt ruimtelijke variabiliteit in regenval, en verschillende gewasvarieteiten, landschapsposities en bodemtypes. Door gebruik te maken van deze verschillen kan het risico op produktieverlies verminderd worden. Dit betekent dat gewasproduktie gebieden in semi-aride gebieden op de juiste manier gedisaggregeerd moeten worden om de juiste technologieen om de kwetsbaarheid voor droogte te verbeteren toe te passen onder de juiste condities. De conclusie kon getrokken worden dat mensen die in semi-aride gebieden leven de potentie hebben om genoeg voedsel te produceren.

De uitkomsten van dit onderzoek bestonden uit een getest gereedschap dat terugkoppelingen meeneemt in het analyseren van huishoudens, identificatie van de belangrijkste risico’s voor en kwetsbaarheid van mensen in de semi-aride gebieden in zuidelijk Afrika, analyses van adaptatie-mechanismen om om te gaan met veranderingen, van de rol van mest in gewasproductie in semi-aride gebieden, kwantificering van de prestaties van verschillende gewassen en gewasvarieteiten in verschillende landschapsposities en van de mogelijkheden van mensen om hun voedselzekerheid te verbeteren.

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Marondera, 31 July 2011

List of Publications

1. Journal papers

Murungweni. C, van Wijk, M.T., Andersson, J.A., Smaling, E.M.A., and Giller, K.E. 2011. Application of Fuzzy Cognitive Maps in livelihood vulnerability analysis. Ecology and Society. (Accepted).

Murungweni. C, Andersson, J.A., van Wijk, M.T., and Giller, K.E. 2011. Zhombwe (*Neorautanenia amboensis* Schinz) – A Recent Discovery for Mitigating Effects of Drought on Livestock in Semi-arid Areas of Southern Africa. Journal of Ethnobotany, Research and Application (submitted).

Murungweni. C, Smaling, E.M.A., van Wijk, M.T., and Giller, K.E. 2011. Enhancing crop production in semi-arid areas through increased knowledge of varieties, environment and management factors. Journal of Field Crops research. (submitted).

Murungweni. C, van Wijk, M.T., Andersson, J.A., Smaling, E.M.A., and Giller, K.E. 2011. Linking adaptive livelihood strategies to sustainable household food self-sufficiency in semi-arid rural Africa. Food Security. (submitted)

2. Proceedings and posters

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3. Technical papers

Anteneh, N.T., Mekala, D. G., Mnisi, P.E., Mukisira, C., Muthui, M., Murungweni. C, and Sebitloane, O. 2004. Goat Production and livelihood Systems in Sekhukhune District of the Limpopo Province, South Africa: Opportunities for commercialising goats and their by-products. Working Document Series 118, South Africa. http://www.icra-edu.org/objects/public_eng/RepFSSouthAfr2004.pdf

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4. Book Chapters

Giller, K.E., Baudron, F., Matema, S., Milgroom, J., Murungweni, C., and Twine, W., 2011. Population and livelihoods on the edge. In: de Garine-Wichatitsky, M., Cumming, D., Dzingirai, V., Giller, K.E. (Eds.), Transfrontier Conservation Areas: People living on the edge. (In press).

Dzingirai, V., Andersson, J.A., Baudron, F., Milgroom, J., Murungweni, C., and Poshiwa, X. 2011. On the edge of state, economy and society. In: de Garine-Wichatitsky, M., Cumming, D., Dzingirai, V., Giller, K.E. (Eds.), Transfrontier Conservation Areas: People living on the edge. (In press).

Murungweni, C., Ed. 2009. Using qualitative and quantitative methods. In: Collective Innovation, A Resource Book, Hawkins, R (Ed). Pretoria, NARDTT.

PE&RC PhD Education Certificate

With the educational activities listed below the PhD candidate has complied with the educational requirements set by the C.T. de Wit Graduate School for Production Ecology and Resource Conservation (PE&RC) which comprises of a minimum total of 32 ECTS (= 22 weeks of activities)

Review of literature (6 ECTS)
- Vulnerability and resilience of competing land-based livelihoods on South- Eastern Zimbabwe

Writing of project proposal (4.5 ECTS)
- Vulnerability and resilience of competing land-based livelihood in South-Eastern Zimbabwe (2007)

Post-graduate courses (7.7 ECTS)
- Land science: bringing concepts and theory into practice; PE&RC, WUR (2007)
- Complexity in and between social and ecosystems; CERES and PE&RC, WUR (2007)
- Introduction to GIS and RS; ITC, University of Twente (2007)
- Bayesian statistics; PE&RC, WUR (2010)
- Introduction to R; PE&RC, WUR (2010)

Deficiency, refresh, brush-up courses (6 ECTS)
- Systems analysis, simulation and systems management (2007)

Competence strengthening / skills courses (3.6 ECTS)
- Information literacy for PhD including EndNote introduction; WUR (2007)
- Competence assessment; PE&RC, WUR (2007)
- Basic statistics; PE&RC, WUR (2009)
- Techniques for writing and presenting scientific papers; EPS, PE&RC, WIAS, WIMEK, VLAG and Mansholt (2009)

PE&RC Annual meetings, seminars and the PE&RC weekend (1.5 ECTS)
- PE&RC Weekend (2007)
- PE&RC Day (2011)
- Global soil fertility seminar (2011)

Discussion groups / local seminars / other scientific meetings (10 ECTS)
- Competing Claims Start-up Workshop; Acornhoek (2006)
- Competing Claims Start-up Workshop; Wageningen (2007)
- Spatial Methods, Discussion Group; Wageningen (2007, 2010-2011)
- Maths and Stats Discussion Group; Wageningen (2007, 2010-2011)
- PhD and Post-Doc Resilience Dialog Discussion Group (2007-2009)
- Competing Claims Workshop; Masingir, Mozambique (2009)

International symposia, workshops and conferences (7.8 ECTS)
- Resilience, Adaptation and Transformation in Turbulent Times; Stockholm (2008)
- AHEAD Workshop – White River; South Africa (2008)
- 9th AHEAD-GLTFCA Working Group Meeting; Namaacha, Mozambique (2009)
- Agro2010 the Xth ESA Congress; Montpellier (2010)
- 10th AHEAD-GLTFCA Working Group Meeting; Hazyview, Mpumalanga, South Africa (2010)

Supervision of 1 MSc student; 6 months project (3 ECTS)
- Spatio-Temporal Dynamics of Land cover in the South-East Lowveld of Zimbabwe

Curriculum Vitae

Chrispen Murungweni was born on the 17th of July 1967 in Zvimba, Chinhoyi, Zimbabwe. He attended Primary School at Madzima (Zvimba), Kaponda (Mhondoro) and Kudakwashe (Harare), Secondary School (Form 1 to 4) at Glen-Norah no.1 High (Harare) and high school (A' Level) at Girls High School (Harare). He graduated from the University of Zimbabwe with a BSc. in Agriculture in 1993. He then worked as a High School Teacher of Physical Science, Mathematics and Chemistry between 1994 and 1998, and also acted as the Head of the Maths and Science Department. In 1999 he left teaching for further education at the University of Zimbabwe and obtained a MSc. Degree in Animal Science in 2000. During his MSc thesis work he focused his research on improving feeding value of legume tree based leaf-meal in ruminant livestock feeding systems. In 2001, he was employed at Grasslands Research Institute as researcher responsible for ruminant livestock production. In 2003 he was appointed Head of the Livestock Section, the position he still holds. His interests are on finding practical solutions to wicked forces that bind rural people to the poverty basin. Between 2001 and 2003 he worked with the Australian Centre for International Agricultural Research (ACIAR) in a project exploring the role of tropical legumes in sustainable farming systems in southern Africa and Australia. In this project, he successfully designed cost-effective diets involving *Mucuna pruriens*, *Lablab purpureus* and paprika (*Capsicum anuum* L) calyx. The diets doubled net returns for farmers and reduced inclusion rates of maize grain in cattle feeding systems by 25% when compared with conventional methods that the farmers were using before (ACIAR Proceedings No. 115, 2004). Because of his growing interests in research for development, he attended a 7-month professional training in Agriculture Research for Development (ARD) with the International Centre for development oriented Research in Agriculture (ICRA) in 2004. Together with six professionals from different countries, different disciplines and different institutions they produced a report with the title 'Goats production and livelihood systems in Sekhukhune district of the Limpopo Province, South Africa: Opportunities for commercialising goats and their by-products' (Working Document Series 118, Sekhukhune Province, South Africa). In 2007 he started his PhD research at Wageningen UR within the Competing Claims on Natural Resources Programme.

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