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SUSTAINABLE INTENSIFICATION & AGRICULTURAL INVOLUTION IN SOUTHERN AFRICA

Farming system analysis and bio-economic modelling of smallholder agriculture in the Okavango basin

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List of Abbreviations

BEM	Bio-economic model
CA	Conservation agriculture (based on planting basins and using 15 t of organic manure and 0.5 t of inorganic fertilizer)
DS	Dry Season
GAMS	General Algebraic Modeling System
GDP	Gross-domestic product
HH	Household
LORB	Lower Okavango River Basin (the Kalahari plains in Namibia & Botswana – includes study sites Mashare and Seronga)
NLP	Non-linear programming
ORB	Okavango River Basin
PC	Permanent rain-fed cultivation
RS	Rainy Season
SC	Shifting cultivation
SPC	Semi-permanent cultivation
SOM	Soil organic matter
SSA	Sub-Saharan Africa
TFO	“The Future Okavango” – research project (2011-2016)
TR Both	Traditional agricultural practices using both animal manure (5 t) and inorganic fertilizer (20 kg) as field inputs
TR None	Traditional agricultural practices using neither animal manure nor inorganic fertilizer as a field input
TR Manure	Traditional agricultural practices using only animal manure (5 t) as a field input
TR Fertilizer	Traditional agricultural practices using only inorganic fertilizer (20 kg) as a field input

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INTRODUCTION

A. Overview

In Sub-Saharan Africa (SSA), the number of the rural poor is projected to rise over the next decades. With the majority of the rural population depending on agriculture for its survival, the ongoing degradation of soils and the resulting decline in yield potential are serious threats for rural livelihoods. This study contributes to tackling this challenge by identifying optimal farming strategies for smallholders in the Okavango catchment, southern Africa. To do so field research is conducted to assess traditional farming strategies and an experimental conservation agriculture approach. Using the theoretical frameworks of Boserup (1965) for the analysis or agrarian societies and Ruthenberg (1971) for the analysis of tropical smallholder farming systems, this study identifies important bottlenecks for agricultural production and most likely future developments of the analysed farming systems. The insights generated here will be used to develop a bio-economic model of typical smallholder household categories in the *lower* Okavango River Basin, where land scarcity and adverse environmental conditions call for the sustainable intensification of smallholder farming. The model identifies optimal farming strategies for each household category i) by dynamically simulating the feedbacks between farm management and empirically assessed soil fertility, as well as the seasonal allocation of labour and ii) by assessing whether or not conservation agriculture can play a role in improved farming strategies.

B. Motivation

How will we feed 7, 9, or even 11 billion[1] humans in a world of limited and often declining resources? Finding an answer to this question has been described as potentially "*the greatest challenge of our era* (Hoff et al. 2013, 1)". A commonly stated but naive answer is to increase agricultural productivity (Garnett & Godfray 2012). However, at the global level we are already producing sufficient food to feed the world (ibid.). Instead, it seems that an equally pressing problem is that this food does not reach the poor and hungry – either because a lack of finances does not allow them to purchase food at the market or because imperfect distributional channels and markets do not allow them to even access it (Garnett & Godfray 2012). But how exactly should agricultural productivity be increased?

It has been suggested that a decentralized, smallholder-oriented development is not only a possible solution to overcome the distribution issue (Binswanger 1994, Babu 1999, Altieri et al. 2012) but that it is at the same time one of the best means to increase productivity in rural areas such as Sub-Saharan Africa (Holden & Otsuka 2014, Mellor 2014, Sitko & Jayne 2014). At the same time, it is equally important to achieve this goal while reducing the environmental footprint of agriculture, i.e. by making it ecologically sustainable (Foley et al. 2011). Over the last decades, efforts towards achieving this sustainable development have highlighted the close ties between human well-being and the state and functioning of natural ecosystems (MA 2003, WRI et al. 2005, Daily 1997). Therefore, any solution to the challenge presented above needs to preserve the services rendered by earth's ecosystems.

[1] Projected for 2050 (UN 2004).

On a global level the rural poor especially depend on these services and natural resources. Therefore, they are also seriously affected by any degradation of ecosystems and ecosystem services (Gowdy & Salman 2010, Srinivasan et al. 2008, EFTEC 2005, WRI et al. 2005 & 2008, Daly & Farley 2004). Nowadays, 70% of the 1.4 billion extreme poor[2] and almost half of the world's population (49.4% in 2010, UN 2008) live in rural areas – and this holds especially true for Sub-Saharan Africa (SSA) (IFAD 2011). For them, natural resources not only form the basis of daily survival, but may also present the only available means for improving their livelihoods (WRI et al. 2005). In this context, smallholder agriculture especially lies at the heart of most rural livelihoods (Hoff, Fielding & Davis 2013). Even in the medium run, this situation will not change because the ongoing urbanization and economic transformation of many developing countries is still limited. Therefore, the absolute number of people depending on agriculture will continue to increase over the next decades (Scherr & Hazell 1994, UN 2008).

At the same time, the world's rural population as a user of natural resources has to be regarded as having a major and direct impact upon local ecosystems. The growing integration of formerly isolated rural communities into national or international markets has been found to turn some local natural resources into more widely tradable commodities, thereby contributing to their commercialization and possibly their overexploitation[3]. In order to achieve the goals outlined above, i.e. the development of ecologically sustainable and more productive land uses for the rural poor, it is crucial to pay close attention to the feedbacks between rural livelihoods and the state of affected ecosystems (see Gordon & Enfors 2008).

In the context of agriculture, the production factor *soil* becomes highly important. It is a central natural resource, and both the state and development of it can be directly influenced by management decisions. By doing so, rural land users can either build or deplete natural capital (Reardon & Vosti 1995, Buresh et al. 1997). In order to secure livelihoods of the rural poor, an improved management of the soil is needed that combines sustainability with intensified production.

However in Sub-Saharan Africa (SSA), the opposite appears to occur. While the agricultural productivity of the tropics in general increased drastically during the second half of the 20th century (Scherr & Hazell 1994), the mean *per capita* production of food in SSA instead declined (Voortman 2013). The main cause of this trend was the ongoing degradation of this region's natural resources, especially its land and soils (Hoff et al. 2013). Land degradation can be understood as the decline or loss of the biological or economic production capacity of land, which in relation to soils describes the erosion or deterioration of their physical, chemical or biological properties (UNCCD 1994). The main causes of this degradation are the overuse of regions of high yield potential, caused by long-term, continuous cultivation (Hoff et al. 2013) as well as the gradual extension of agriculture into less productive and ecologically fragile marginal lands – especially in SSA (Scherr & Hazell 1994). Many of the latter regions have been used only rarely until quite recently, but nowadays they already need to carry a moderate to high population density (ibid.).

[2] Defined as humans with a disposable cash income of less than 1.25 USD/day (IFAD 2011, 47)
[3] Found e.g. for the Okavango catchment, southern Africa, by Pröpper et al. (2015).

This overexploitation of soils results in declining yield potential, especially in the already unproductive marginal lands. Therefore, in order to secure basic food needs, land users in these regions are often forced to employ more and more intensive means of production in regards to both the use of labour and/or field inputs. Ultimately, this often results in a further decline of the soil's yield potential. This vicious circle of soil degradation and food production has caused a poverty trap for large parts of SSA's rural population from which it is hard to escape without external assistance (see Barrett 2007, Voortman 2013, Hoff et al. 2013). Worldwide, about 1.5 billion humans already depend on degraded land for their survival (Bai et al. 2008, Hoff et al. 2013). For smallholders, a lack of assets, production means, capital, and knowledge, as well as the need to secure basic food needs with scarce resources on often marginal lands, make it impossible to invest in more sustainable or productive farming systems and thus escape the poverty trap (see Carter & Barrett 2006). This has been described as *agricultural involution* (Geertz 1974, first in 1963), a process where smallholders *modify* the existing farming system to feed a growing population (commonly via increasing labour input) but where they do not *switch* to a better adapted farming system. Hoff et al. (2013) summarized the resulting challenge as follows: "*…even though we urgently need to* increase *agricultural productivity, the way we use the land is often* reducing *productivity* (Hoff et al. 2013, 10)".

C. Problem statement: sustainable intensification of smallholder farming systems

The challenge described above can be countered in two ways. In the long term, macro level solutions aim at a better balance of humans and natural resources in marginal lands, e.g. via migration, economic diversification into the non-farm sector or by decreasing population growth by supplying means of contraception (Scherr & Hazell 1994, Jayne et al. 2014b). However, the growing number of humans depending on agriculture makes it necessary to find short and medium-term solutions, such as the diversification of rural livelihood sources and combating degradation / increasing productivity (Scherr & Hazell 1994). As degradation is (often) a reversible process and as the quality of the soil (e.g. its nutrient level) and other natural resources can be improved (see Scherr & Hazel 1994, Barbier & Carpentier 2000, Bai et al. 2008, Hoff et al. 2013), increasing agricultural production in marginal areas must be considered as theoretically possible.

A commonly used term that describes efforts towards this goal is Sustainable Intensification (The Royal Society 2009). Its origin lies in the 1990s and in the context of African agriculture, i.e. where yield potentials are often low and environmental degradation a serious concern (Garnett & Godfray 2012, Reardon et al. 1996, Pretty 1997). It therefore has a pro-poor, smallholder-oriented origin. Sustainable intensification has been defined as a form of agricultural production where "*yields are increased without adverse environmental impact and without the cultivation of more land* (The Royal Society 2009, ix)". Therefore, the term rather describes goals that are aspired but does not prescribe a certain method or mode of production such as conventional high-input farming, one of the various approaches to organic-farming or smallholder agriculture (Garnett & Godfray 2012).

Based on the considerations above, this study considers a smallholder-oriented approach for sustainable intensification as best suited for feeding the growing population of the rural poor in SSA (see also Barrett 2007, Sitko & Jayne 2014). As indicated before, adverse frame conditions that hinder intensification[4] may cause smallholders to fall into vicious cycles of soil degradation and gradual household impoverishment (Ruthenberg 1971) or get trapped in the process of agricultural involution (Geertz 1974). However, it was long ago proven that given the right frame conditions, smallholders are able and even likely to develop and adopt improved farming strategies on their own (Boserup 1965, Ruthenberg 1971) - a process called *Boserupian* (or endogenous) intensification. It specifically refers to smallholders increasing their land productivity (output per unit area) at the cost of labour productivity (output per unit labour input) in response to changing levels of land scarcity. In general, Boserup's (1965) findings indicate that smallholders adjust dynamically to degradation and changing scarcity of natural resources (see also Scherr & Hazell 1994). However, these adaptation processes take time and may begin only under relatively advanced stages of degradation, i.e. where livelihoods are already negatively affected (ibid.). This means that the adoption of new and innovative farming practices may not occur before a certain degradation (or at least awareness) threshold has come about.

Boserup's (1965) findings indicate that for promoting sustainably intensified farming strategies, a focus solely on technical solutions may easily lead to failure. Apart from understanding the conditions and bottlenecks of smallholder production, one needs to consider the impact of globalization[5] as well as availability of fossil-fuel based energy sources. The availability of the latter may easily overcome the trade-off between increasing land-productivity and rising labour-demand of agriculture that is the basic assumption behind *Boserupian* intensification (Fischer-Kowalski et al. 2011).

The question of whether *Boserupian* intensification is synonymous with Sustainable Intensification depends on the time frame considered. At first sight, it is not, and some of the typical stages described by Boserup (1965) represent unsustainable transitions between more stable stages, e.g. shifting cultivation under forest fallow and stages of permanent cultivation such as multi-cropping. However, from an economic point of view, both degradation and sustainability need to be defined in relation to optimal resource use levels and social considerations (Scherr & Hazell 1994). This means that even under sustainable production methods, it may be worthwhile to exploit a given resource for a limited time period and then to re-invest into its regeneration at a later point in time (Scherr & Hazel 1994, Barbier & Carpentier 2000) – such as in the case of soil fertility. Therefore over the long run, *Boserupian* intensification is one of the available options for achieving Sustainable Intensification. However, the speed with which these endogenous intensification processes occur may be too slow to cope with the rapidly rising population densities. In some cases, it

[4] These may include missing information on the long-term interactions between soil fertility and household resources or government intervention in the form of disaster relief, which reduces incentives to intensify. Other obstacles to intensification may arise from social pressure, e.g. fear of envy and/or witchcraft attacks, if a member of a rural society is overly successful or deviates from socially accepted behaviour (see e.g. Pröpper 2009 on the importance of witchcraft on decision-making of Namibian smallholders).

[5] The impact of globalization will be approximated in this study by the level of market integration and the proliferation of a consumption-driven lifestyle.

may be necessary to induce sustainable intensification by other means such as policy intervention and extension services.
It is important to keep the similarities and differences of both concepts in mind. Boserup's (1965) insights into agricultural development can aid in tackling the challenges presented above. In fact, recent research (Headey & Jayne 2014) revealed that even today, land scarcity (the central driver in Boserup's (1965) theory) is the main driver of land use change in SSA. Furthermore, *Boserupian* intensification remains the most successful means of smallholder adaptation to rising land scarcity. Therefore, this study argues that harnessing *Boserupian* intensification for designing improved farming strategies can make a valuable contribution to the sustainable intensification of smallholder agriculture in SSA. At the same time, this can contribute to tackling the challenge presented in the opening paragraphs: how to feed a growing number of rural poor in a world of often declining natural resources?

However, in the light of rapid urbanization and technological progress at a global scale, one might ask why it is worthwhile to focus any effort on the sustainable intensification of smallholder farming? Two main answers come to mind. First, nearly half of today's global population lives in rural areas and depends on the smallholder mode of production for its survival (UNDP 2007). The direction that the development of these societies takes will therefore have a tremendous impact upon global land and resource use in the future (Fischer-Kowalski et al. 2011). Second, understanding the peasant or household mode of production is of particular importance in the context of the developing world, where population growth, market expansion, and agricultural change create a highly dynamic environment (Netting 1993). Some authors see inherent and great potential in peasant societies and smallholder households to successfully cope with and adapt to these changes (Boserup 1965, Ruthenberg 1971, Netting 1993). In fact, they may present one of the best levers for raising agricultural productivity:

> "*Scarcity of rural resources and national demands for food production create just those circumstances in which agriculture intensifies and the household organization of production demonstrates its comparative advantage* (Netting 1993, 26)".

This study shares the optimism about the role that the peasant mode of production can play in securing and improving the future livelihoods of the rural population in Sub-Saharan Africa.

The Okavango River catchment in southern Africa is a region that may greatly benefit from sustainable intensification of its smallholder farming systems. The catchment is shared by the countries Angola, Namibia, and Botswana. It is a relatively pristine region that is currently undergoing dramatic socioeconomic and land use changes. Population growth and an ongoing transition to a cash-based economy can be observed. This results in increasing utilization rates of natural resources and arable land. Other important drivers of growing land scarcity are urbanization and the establishment of large-scale commercial irrigation projects (Pröpper et al. 2015). Taken together, these trends may contribute to rising levels of rural impoverishment and natural resource degradation. An appropriate option to counter this negative development may be the sustainable intensification of the catchment's smallholder farming systems.

One pathway towards this goal might be found in experimental farming methods based on conservation agriculture (CA). Such a method is already promoted in the region. However, as of yet no systematic analysis has been conducted on its potential role in optimal farming strategies of smallholders. It remains unclear to which degree it can be adopted by resource constrained smallholders. Furthermore, no systematic analysis assessing the potential and likelihood of Boserupian intensification in the dominant traditional farming systems in the catchment has been carried out.

D. Research aim and research questions

This study will fill a gap in knowledge on options for, and therefore make a contribution towards, the sustainable intensification of smallholder farming systems in Southern Africa. Its goal is to provide insights into the ecological sustainability of current farming systems and to identify pathways towards sustainable intensified smallholder farming systems. The analyses may serve as a reference framework for future extension work and facilitate an in-depth understanding of the constraints to crop production in the Okavango catchment. Although not explicitly testing any existing policy, the results can help improve the effectiveness of policies that aim to increase rural food security and alleviate poverty in the research area.

The results will be generated by first conducting farming system analyses of three rural communities in the Okavango catchment. These analyses are based on empirical observations that are interpreted using globally valid frameworks for the analysis of agrarian societies (Boserup 1965) and their respective smallholder farming systems (Ruthenberg 1971). Building on the system understanding gained from these analyses and using empirical data gathered in the three study sites, a bio-economic model of typical household categories will be created to identify optimal farming strategies of smallholders. Together, both approaches allow an assessment of the role CA may play in efforts towards sustainable intensification of farming systems in the catchment. The study utilizes a mixed method approach and combines the following empirical data-gathering methods: explorative and focused interviews of experts and smallholders with focus group discussions, quantitative household surveys, and a yield & soil-fertility assessment. As indicated above, the sample population will be drawn from smallholders of three rural communities in the Okavango catchment: study site *Cusseque* in the upper catchment in Angola, study site *Mashare* in the middle catchment in Namibia, and study site *Seronga* at the inland delta of the Okavango in Botswana.

The complexity of sustainable intensification requires the integration of various disciplines, e.g. from agricultural economics, anthropology, and soil sciences. This study benefits from the fact that it is embedded into a larger research effort on sustainable land use in the Okavango, i.e. “The Future Okavango” (TFO) research project. Between 2010 and 2016, this project brought together more than 100 international experts from various academic disciplines (ecology, economics, anthropology, remote sensing) to develop future sustainable land use strategies for the Okavango catchment. Data was collected by all disciplines in the same study sites, including the three rural communities analysed within this study. Therefore, the insights generated in the other disciplines as summarized in Pröpper et al. (2015) and Oldeland et al. (2013) and empirical data on soil fertility generated by TFO’s soil scientist (see Chapter 2.4.1.3) could be used for the design of this study.

The following research questions were formulated as starting points for the farming system analysis and the design of the bio-economic model:

1. How can the dominant smallholder farming systems in the study sites and the experimental conservation agriculture approach be characterized, and what are their main constraints to agricultural production?
2. Are the current dominant smallholder farming systems ecologically sustainable?
3. Is *Boserupian* intensification likely to occur and succeed in the study sites in the near future?
4. Under current socioeconomic conditions, what are optimal farming strategies for smallholder households in the ORB and which role does conservation agriculture play in these farming strategies?
5. Are these optimal farming strategies ecologically sustainable?

Questions 1-3 will be answered in part I of the study via a farming system analysis and questions 4-5 in part II via a bio-economic model of typical farm households.

E. Summary of chapters and main results

This study was carried out in the context of an economic transition of the Okavango catchment, i.e. from an ecologically pristine and relatively isolated subsistence-oriented region to a cash-based society, where the commodification of natural resources and the spread of a consumption-driven lifestyle have the potential to induce widespread land use changes.

The introduction will present the general research area, the Okavango River Basin (ORB), as well as important socioeconomic trends. It will be shown that population growth, urbanization, the commodification of natural resources, and the spread of a consumption-driven lifestyle are main drivers of land use change, the effects of which extend even to relatively isolated rural communities.

Part I of this study, the farming system analysis, starts with Chapters 1.1 - 1.5, which introduce the theoretical frameworks used for the analysis of the smallholder farming systems in the three study sites as well as the methods applied to empirical data gathering.

Chapters 1.6.1 – 1.6.3 present the study site-specific farming system analyses. Each analysis is preceded by a detailed description of both the biophysical and socioeconomic setting of the respective study site. They are followed by an in-depth analysis of the experimental conservation agriculture approach that is being promoted in study site Mashare, Namibia (Chapter 1.6.4). Chapter 1.6.5 summarizes and concludes part I of this study. It compares the findings of the individual farming system analyses and draws general conclusions on the most likely future developments of the different study sites. Furthermore, it identifies the aspects of the farming systems that are crucial for part II of this study, the bio-economic model.

Part II begins with Chapters 2.1 and 2.2, where the methodology used for farm household modelling, the valuation of leisure and time in farm household modelling, and bio-economic modelling is introduced. In Chapter 2.3 this is followed by a qualitative description of the bio-economic farm household model developed in this study. Based on the results of the farming system analysis and constraints in the database[6], this model will be formulated for typical household categories of the lower Okavango River Basin. This is achieved by combining the data from both study sites: Mashare, Namibia and Seronga, Botswana. Chapters 2.4.1 - 2.4.3 elaborate on the methods used for data gathering and the computation of model parameters (exogenous variables). The mathematical model formulation is presented in Chapter 2.4.4. This study concludes with the results of scenario analysis and their discussion in Chapter 2.5 and a general conclusion in Chapter 2.6

The main results can be summarized as follows:

1. The three study sites represent archetypical stages of tropical smallholder farming systems as described by Boserup (1965) and Ruthenberg (1971). These are shifting cultivation under forest fallow in Cusseque, Angola, semi-permanent cultivation under annual cropping for Seronga, Botswana, and a transition between semi-permanent and permanent rain-fed cultivation under annual cropping for Mashare, Namibia.
2. Under current farming systems, land scarcity and seasonal peaks in labour demand are important constraints to agricultural production in the study sites. If these constraints are binding, households can benefit from the adoption of conservation agriculture.
3. Land availability remains the main determinant of the ecological and economic sustainability of farming systems in the study sites.
4. Optimal farming systems depend on achievable levels of soil fertility and the degree to which land scarcity and seasonal peaks in labour demand constrain farming.
5. Traditional farming practices and conservation agriculture may complement, replace, or even pave the way for each other. There are big differences between these practices in terms of land, labour, and energy use efficiency as well as their relative cash needs.
6. The following generalization can be made: with increasing land constraints and rising seasonal peak in labour demand for traditional field preparation, conservation agriculture is more likely to play an important role in the stabilization and improvement of rural livelihoods in the study sites.
7. Soil fertility (approximated by the amount of macronutrients N, P, and K in a household’s field) may to some degree serve as a quasi-bank account for smallholders in the study sites. This is especially true for the poorer households that have limited ability to invest in livestock or for whom these investments may be too risky (e.g. due to increasing livestock mortality in Mashare and the effects of droughts in general).

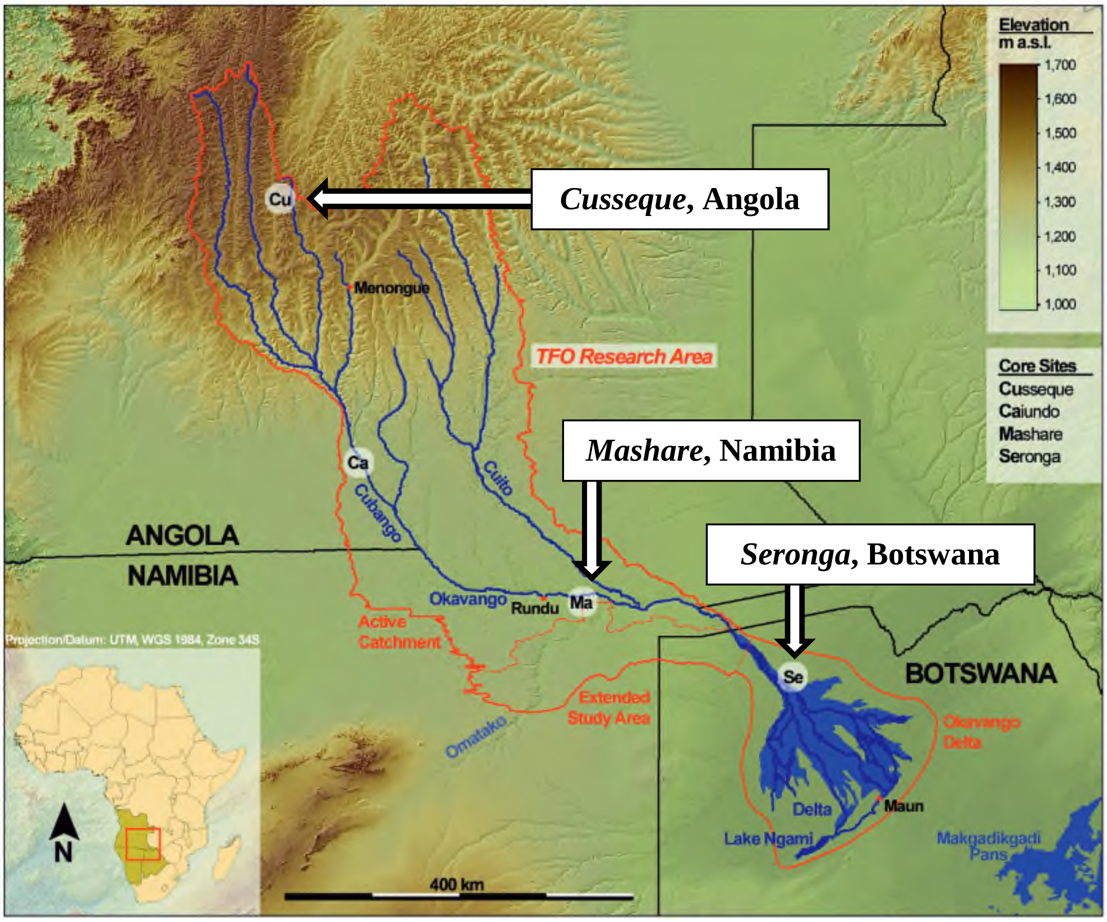
[6] The farming system analysis revealed that Cusseque in Angola can be assumed to follow a farming strategy that is optimally adapted for local production constraints. Furthermore, lacking variability in field management and lacking data on fallow growth were obstacles to creating a meaningful model.

THE ORB IN TRANSITION

This chapter provides an overview of the general research area chosen for this study, the Okavango River basin. After introducing the current biophysical and socioeconomic setting, the drivers of the basin's economic transition and its potential effects on local livelihoods will be presented. As a review it is then complemented by a short comparison of the economies of the three riparian states Angola, Namibia, and Botswana.

The chapter concludes by presenting the rationale behind the choice of the three study sites *Cusseque* in Angola, *Mashare* in Namibia, and *Seronga* in Botswana. The individual study sites where empirical data gathering took place will not be presented in detail here but rather in introduction to the site-specific analyses in Chapters 1.6.1 – 1.6.3.

Fig. 0.1: Map showing the location of the three study sites as well as the general research area



Source: Author's design based on Wehberg & Weinzierl (2013, 11). Note: The research area is delineated by the red line and includes the active Okavango catchment, the delta and an extended area in the Namibian hinterland.

F. Biophysical setting of the Okavango basin

The Okavango basin in southern Africa is one of the last nearly pristine ecosystems of Africa. In fact, due to its biodiversity and biological productivity, it is of international importance. Furthermore, its inland delta is a global hot spot of biodiversity and one of the largest RAMSAR sites in the world (OKACOM 2011). The Okavango basin (as considered in this study) comprises any active parts of the catchment that lie in south-eastern Angola, north-eastern Namibia and north-western Botswana (see Fig. 0.1).

Biophysically, the basin is characterized by a marked environmental gradient from the relatively humid Angolan highlands at about 1,850 m a.s.l. to the semi-arid reaches of the lower basin in Namibia and Angola (Revermann & Finckh 2013). While topography and geologic substrate create a diverse vegetation pattern (mainly *Miombo* woodland in the upper catchment), the soil in the flat lower basin is dominated by relatively infertile Kalahari sands. Therefore, vegetation patterns here are affected by low nutrient availability and a poor soil water regime (ibid.). This creates more favourable conditions for agricultural production in the Angolan highlands than in the Namibian and Botswanan parts of the basin.

G. Socioeconomic setting of the Okavango basin

The basin is dominated by rural communities that are mainly located along the roads and adjacent to the river(s), where access to water and a supply of natural resources are less scarce (OKACOM 2011). Throughout the basin, land is public and held either by the states or by so-called traditional authorities (ibid.). The basin's communities pursue traditional, subsistence-based livelihood strategies and depend largely on savanna and wetland ecosystems for their well-being. The main livelihood sources include the use of natural resources, livestock keeping, and rain-fed subsistence agriculture; in fact, the latter of these sources is the dominant land use in the basin (Pröpper et al. 2015).

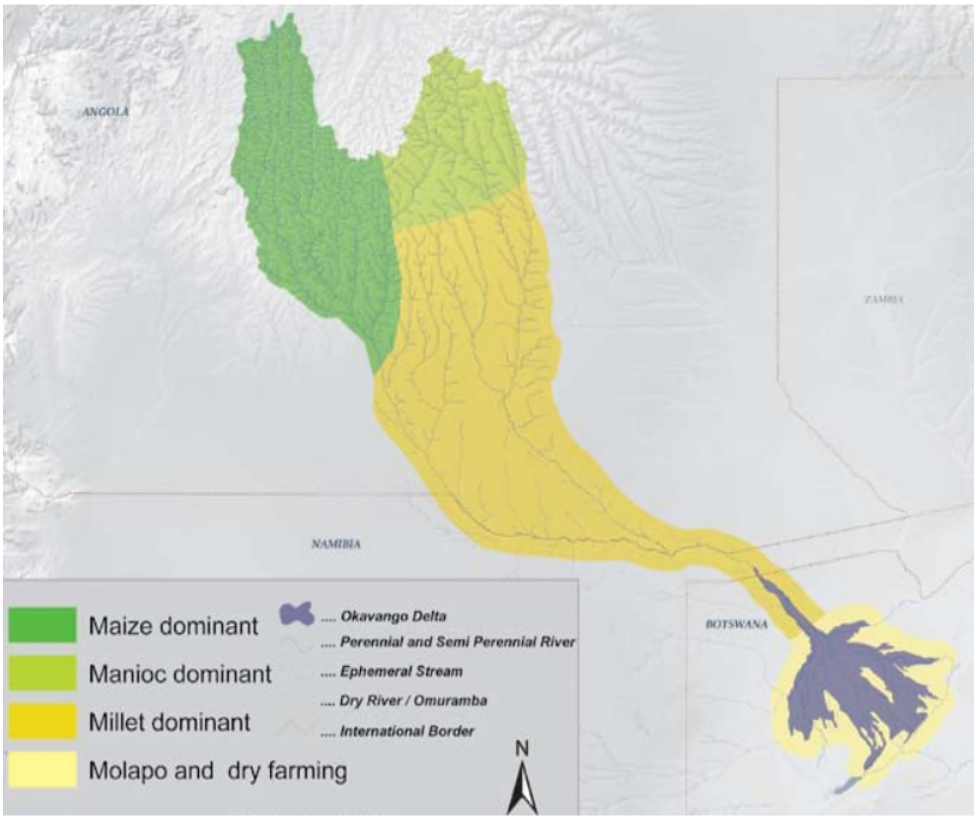
Any livelihood strategy encountered in the basin can be seen as adaptations to different biophysical settings. However, strategies are also shaped by the region's socioeconomic conditions. First, the basin populations in the three riparian countries must be considered remote in relation to their national economic centres and capitals, resulting in lower levels of social development indicators (OKACOM 2011). This means that "*the people of the basin are poorer, less healthy, and less well educated than other groups in their respective countries*" (OKACOM 2011, 18), especially in battle-scarred Angola. Second, important differences between the livelihood strategies arise from differences in local population density. Around the few urban centres in Angola and along the river in the Namibian part of the basin, population density is very high and human pressure on ecosystems pronounced (OKACOM 2011).

H. The main rural livelihood sources in the Okavango Basin

From a land-use perspective, the basin is dominated by small-scale subsistence agriculture conducted on a few hectares, combined with the keeping of small herds of cattle and goat (OKACOM 2011). Both the biophysical and socioeconomic settings result in three principal cropping areas (Fig. 0.2). Except for the sub-humid to humid Angolan highlands, crop productivity is very low. While in Angola, up to 80% or rural income is provided by cropping, it is less important in Namibia and Botswana (due to low yields and significant crop losses caused by drought and wildlife: OKACOM 2011). Instead, the importance of livestock is markedly higher in these regions.

Arable agriculture in the basin is characterized by pronounced seasonality, with intense demand for labour just before the onset of the rainy season. The use of organic manure or compost as field inputs is practiced to a low degree, only, and the application of chemical field inputs is even rarer (Mendelsohn 2009). Cultivation is carried out mainly by hand or using draught animal power, as tractor availability is very limited (OKACOM 2011). Complementary to rain-fed dryland agriculture, there exist traditional farming systems of recessional agriculture, i.e. on the floodplains along the rivers. These are *molapo*-farming around the Okavango Delta in Botswana and the *olonaka*-system in Angola. The regular flooding of these areas maintains higher levels of soil moisture and fertility, which results in a higher land-productivity than in dryland agriculture (OKACOM 2011). However, for this study these types of agriculture do not play a role, as they do not occur within the chosen study sites.

Fig. 0.2: The three principal cropping areas of the Okavango Basin.



Source: OKACOM (2011, 83).

Animal husbandry is a central livelihood source in the lower basin, where it provides important goods & services, such as meat, milk, draught power and, via investments in new animals, the function of a quasi-bank account (OKACOM 2011). Many households own cattle and goats and larger herds are usually kept at designated cattle posts or ranches. As the civil war depleted most livestock herds in Angola, animal husbandry in the upper basin is of lesser importance and smaller in scale. This can be seen in the low number of cattle-owning households in the Angolan highlands (less than 5%) versus the large group of cattle-owners in the Namibian and Botswanan sub-catchments (about 50%) (OKACOM 2011).

For the livelihoods of all rural communities in the Okavango basin, natural resources play an important complementary role. However, their role is slightly more important in the lower catchment than in Angola. Relevant uses include the collection of firewood, construction material such as reeds and timber, as well as wild foods and medicinal plants. In some regions, especially in the densely populated regions of Namibia, overutilization has already significantly reduced natural resource availability (OKACOM 2011).

I. The Okavango Basin in Transition

Currently, the Okavango Basin is "*turning into a global hot-spot of accelerating commercialization, land use-change and potential land-use conflicts* (Pröpper et al. 2015, 7)". A main reason behind this trend is a steady and ongoing population growth in all three sub-catchments. At the end of the first decade of the new millennium, the basin's population was at about 882,000. By 2025, it is expected to have reached at least 1.28 million, the majority of which will be living in Angola (62% vs. 16% in Botswana and 22% in Namibia) (OKACOM 2011). Even if actual growth remained below projected growth, demand for goods and services would still increase due to a growing demand for a higher standard of living in the region. This rise in demand may be especially pronounced in Angola, which experienced a twenty-seven year civil war which began in 1975 and ended a little over a decade ago (in 2002). During that time, the country suffered physical, social, and political strife which hindered its development for decades. Nowadays, the situation is changing and Angola undergoes a rapid development. Taken together, both population growth and the increasing demand for goods and services can the main drivers of change in the basin (ibid.).

In future, additional competition for scarce resources such as arable land will come from new land use options. One prominent example are large-scale irrigation projects which the governments of Namibia and Angola are planning to establish adjacent to the basin's rivers. In Namibia, these are already quite advanced but both countries plan a significant increase in the number of these projects (OKACOM 2011). Another important trend is the increasing urbanization of the Okavango basin which contributes to an increasing demand for goods and services and natural resource depletion around towns (OKACOM 2011). While the basin is still characterized by mainly rural livelihoods, 40% of the Angolan sub-catchments population, 20% of the Namibian- and about 30% of the Botswanan sub-catchment population is urban. And as can be seen for the urban center Rundu in Namibia, the urban areas have a higher growth rate than the surrounding rural areas (2.5%/year vs. 1.5%/year) (ibid.)

Thus, the Okavango basin is under increasing environmental pressure from a growing human population and human infrastructure (Mbaiwa 2004, OKACOM 2011). As traditional livelihoods in the basin are natural resource based, this trend has the potential to alter ecosystems through the overutilization and commodification of natural resources and may have unforeseen consequences for rural communities (Pröpper et al. 2015). Representative of the three riparian countries agree that these challenges should be overcome by developing sustainable management approaches for the basins resources (OKACOM 2011).

However, to be able to do so it is worthwhile to also consider the wider economic situation within which such an effort would take place. The next section will therefore introduce central characteristics of the countries involved.

J. Economic overview of the three riparian countries

Angola has the largest and fastest growing economy among the Okavango basin's three riparian countries. In 2007, it was eight times larger than that of Botswana or Namibia, with a growth rate of 20% as opposed to 5% in the two other countries (OKACOM 2011). Of course, this largely reflects the rapid economic recovery of Angola after decades of civil war, which occurred in the second half of the 20th century and rendered any chance of economic development during this time impossible. Recently, Angola has also benefited from the increasing price of oil during the first decade of this millennium and is now one of the leading oil-exporting countries in Africa. In contrast to this, both the Namibian and Botswanan economies benefited from decades of steady and significant growth (OKACOM 2011).

Another important difference between the three countries lies in their degree of sectoral diversification. While both Angola's and Botswana's economies are relying strongly on the extractive sector, Namibia has a more diversified economy. In numbers, more than a half of Angola's GDP stems from oil & gas mining, about 40% of Botswana's GDP comes from diamond mining, whereas each of the trade, transport, manufacturing and mining sectors contribute around 10% to Namibia's GDP (OKACOM 2011). Apart from mining, Botswana has a relatively strong service sector (OKACOM 2011).

In Angola, the combined resources sector, i.e. agriculture, hunting, forestry and fisheries, accounted for less than 7.8 percent of GDP in 2006, but employed up to 85% of the country's workers. However, the majority of these activities are carried out on a subsistence basis and, only about 10 percent of the country's agricultural land is being used on a commercial basis (OKACOM 2011). Contrary to this, and due to adverse climatic and soil conditions, the importance of arable farming for both rural livelihoods and the national economy is markedly lower in Botswana and Namibia than in Angola. At the same time, livestock and game ranching are of considerable importance in both countries, especially in Namibia.

The World Bank classified all three countries as upper-middle-income countries, although Angola was only recently added to this group, having risen from the lower-middle-income countries (World Bank 2012). None of these countries is thus eligible for funds from the World Bank's International Development Association (World Bank 2016). All three countries have strong export-led economies, although Botswana and Namibia are generally regarded as having more open economies than Angola (OKACOM 2011). Also, intra-country trade barriers restrict the movement of goods and services within the basin and may form important barriers for the creation of a strong basin-economy (ibid.).

What these findings illustrate is that within each of the three riparian countries, there is a stark contrast between the national scale on the hand, where one can find relatively well-developed economies and a medium standard-of-living, and the sub-catchment scale on other hand, where one finds isolated rural economies which are dominated by economic poverty and subsistence-oriented livelihoods. Obviously, one should avoid or at least be very careful when using information that was gathered at the national level for the analysis of the local level, i.e. the Okavango basin. This study will therefore be based mainly on empirical data gathered directly within the three study sites.

K. The three study sites

The three study sites were briefly mentioned in the introduction, and all further research and empirical data gathering will concentrate on them. They comprise various rural communities of the basin, specifically: *Cusseque* in Angola, *Mashare* in Namibia and *Seronga* in Botswana (see Fig. 0.1). Their characteristics, i.e. both the biophysical as well as the socioeconomic setting, will be presented as the introduction to their site-specific analyses in chapter 1.6.1 – 1.6.3. However, before introducing the methodology that is used to analyze these rural communities and their respective farming systems (next chapter), the following paragraphs explain the rationale behind the choice of these study sites.

To a large extend, the idea behind these three sites was to capture i) a variety of the Okavango Basin’s ecosystems, ii) all dominant land-use types and land-use intensities as well as iii) the diversity of all “modern” economic impacts, such as different degrees of market access (Pröpper et al. 2015). Together, all three study sites furthermore represent a climatic gradient of increasing annual temperature, decreasing precipitation and a gradual change from the undulating Angolan highlands to the flat Kalahari basin in Namibia and Botswana. Thus:

- Study site Cusseque in Angola represents *Miombo*-woodland areas with a low- to medium population density,
- Study site Mashare in Namibia represents woodlands on Kalahari sands with a high population density, and
- Study site Seronga in Botswana a transitional region between the Kalahari dune area and wetlands of the Okavango Delta.

L. Outlook

This concludes the introduction of the dissertation, which introduced the research aim of this study (chapter C - D) and the chosen research area (chapters F – K).

The following study is split into two parts, namely the farming system analysis of part I and the bio-economic model of part II.

The farming system analysis generates an in-depth understanding of the system that is to be modelled. Also, it which allows for drawing first conclusions on the sustainability of current smallholder farming systems in the study sites as well as their most likely future development trajectories.

The bio-economic model will be used for identifying optimal farming strategies and assessing the potential role of conservation agriculture as a means of sustainable intensification of smallholder agriculture in the Okavango basin.

The next chapters represent the beginning of part I of this study and will introduce the methodology used for analyzing both the agrarian societies within the study site on a macro-demographic level as well as their farming systems on a micro-economic level.

PART 1: FARMING SYSTEM ANALYSIS OF THE OKAVANGO RIVER BASIN (ORB)

1.1 Overview and summary of part I: farming system analysis

In the following chapters, I will present the first part of this dissertation – the farming system analysis. This analysis constitutes a first, descriptive step that sets the stage for the quantitative modelling exercise. It lies at the heart of this dissertation. By identifying the processes that shaped and are still shaping the evolution of the farming systems in the individual study sites, the analysis goes beyond presenting a snapshot of the current state. The conclusions generated offer an in-depth understanding of the constraints to farming in the research area and about likely trajectories of future development. The farming system analysis is based on empirical observations from the study sites which are evaluated via an analytical framework and literature review. The results of this analysis will determine the structure and validity of the bio-economic model (presented in the part II of this dissertation) and provide insights on the most likely future development in the study sites.

The farming system analysis will be carried out for each of the three study sites, i.e. *Cusseque* in Angola, *Mashare* in Namibia and *Seronga* in Botswana. The main goals are i) to classify the respective farming systems in light of a globally valid reference frame, ii) to identify central mechanisms and drivers of change that determine the functioning of these farming systems and iii) to then deduct their most likely future development pathways.

To be able to do so, the dissertation applies the Boserup (1965)-Ruthenberg (1971) framework, which is a theoretical framework for the analysis of smallholder farming systems that is valid for all of Earth's tropical and subtropical areas. By following this framework, this dissertation applies both a methodology for capturing the society-level (presented in chapter 1.2) as well as for capturing the farm-household level (including typical challenges to farming at the various societal stages, presented in chapter 1.3).
Chapter 1.4 will complement this theoretical framework with a review of drivers of land use change that currently affect smallholder farming in Sub-Saharan Africa. This will on the one hand improve the predictions on the likely development trajectories of the three study sites and on the other hand be used to proof the historical validity of the framework's underlying assumptions.

Together, both the theoretical framework and the analysis of dominant trends of land use change in Sub-Saharan Africa will form the basis for interpreting the field-observations made in the study sites (data gathering and analysis are presented in chapter 1.5). The results of the three farming system analyses will be presented in chapters 1.6.1 – 1.6.3. They are followed by the analysis of the experimental conservation agriculture approach in study site Mashare (chapter 1.6.4). Chapter 1.6.5 discusses the findings and draws conclusions for the bio-economic model presented in part II of this dissertation, which aims at the optimization of farming strategies of typical household categories from the mid- and downriver areas of the ORB (i.e. study sites Mashare and Seronga).

Important results of this dissertation are summarized below:

- The theoretical framework is well suited to explain observations made at both the societal level as well as at the farm-household level. The study sites represent archetypical farming systems that can in similar forms be encountered worldwide in all tropical and sub-tropical agrarian societies.
- All study sites are or will be affected by two main drivers of land use change, i.e. decreasing land availability and increasing market access. Each study site is furthermore affected by site-specific drivers of change and constraints.
- It is unlikely that the rural communities living in the study sites will on their own and in time adapt to the changes caused by these drivers of change. Instead, it is more likely that smallholders in all study sites will be increasingly affected by processes of household impoverishment and natural resource degradation – although the pace of these processes and intervention possibilities differ strongly between the sites.
- In the lower part of the basin, the main constraints to farming are i) seasonality of labour-demand as well as ii) soil fertility and its management. Both will be central mechanisms in the bio-economic model described in part II of this dissertation.
- Modelling results indicate that conservation agriculture can play an important role for the sustainable intensification of smallholder agriculture in the lower part of the basin (study sites Mashare and Seronga in the Kalahari part of the basin). The likelihood of its adoption rises when the above-mentioned constraints to farming become more binding. Access to cash to purchase inputs is a main constraint for the adoption of conservation agriculture by poorer households.
- Policy intervention is needed to promote improved farming practices; one possible approach towards sustainable intensification in Mashare and Seronga lies in the combination of input-based traditional farming practices with conservation agriculture.

There are various reasons for why this dissertation places importance on understanding the dynamics of smallholder farming systems and related societal change: First, the analysis will reveal that smallholder agriculture will remain the backbone of rural livelihoods in the study sites for at least the next years or decades. It is therefore a valid assumption that challenges of smallholder agriculture will continue to affect a majority of households in the research area. Second, smallholder agriculture is not something static, but undergoing a constant adaptation process to changing frame conditions (Ruthenberg 1971). Therefore, going beyond an analysis of a system's current state greatly increases the likelihood of capturing all relevant trends and drivers of change of the respective farming systems. And lastly, despite official pledges for the support of rural communities, all three national governments of the Okavango's riparian countries appear to favour projects that either aim at large-scale industrial agriculture or at conservation (Tello 2015). Instead of actually supporting smallholders, they thus tend to impose restrictions on traditional subsistence activities (ibid.). The following analysis will illustrate that smallholder agriculture in the research area will not remain in its current state, but is likely to be affected by degradation dynamics. Therefore, there are dangers inherent in neglecting the smallholder sector in land use policy planning and it is unwise to postpone pro-smallholder policies to a later point in time.

1.2 Theoretical foundations for the analysis of agrarian societies

An understanding of smallholder farming strategies cannot be achieved without considering the wider socioeconomic context in which these smallholders operate, i.e. without assessing which trade-offs and constraints shape their choice of livelihood strategies[7].

In general, rural livelihoods in SSA are based on a wide variety of different activities, including the use of natural resources, animal husbandry or formal and informal employment. Yet at the same time, the livelihoods of the rural poor are still dominated by small-scale arable agriculture for the purposes of both subsistence production and cash income generation (IFPRI 2012). These activities are carried out under diverse biophysical situations, institutional settings and cultural backgrounds. This leads to the important question of how to adequately conceptualize and analyze these livelihood strategies and their related farming systems?

A considerable amount of literature is dealing with this issue and various frameworks have been proposed that help with analyzing these rural communities. In this dissertation, the entry point into the economic analysis of smallholder livelihoods is the field of *Peasant Economics* (Ellis 1988)[8], which will be introduced in the next chapter (1.2.1).

However, this study compares three very different study sites and attempts to place them in a global and logical context. This makes it necessary to clearly present the theoretical assumptions behind the applied framework. Therefore, the following chapters will cover theory in a more extensive way than would be necessary for an analysis of just one or a few very similar study sites. It may appear as if the methodology part is quite extensively dealing with a broad topic – this is misleading, because in fact it is strictly narrowed down to present only those factors that are important for farm-management in the study sites. Although this includes important aspects such as institutional- or socio-cultural factors, these will be dealt with rather shortly.

It has to be kept in mind that it is nearly impossible to give a concise summary of all contributions made to the debate on agricultural development, even if it was restricted only to those dealing with subsistence smallholders. The theories presented here represent some of the most dominant or widely-accepted theories on the topic. Where appropriate, they were complemented with less known theories or theoretical frameworks that helped to illuminate specific aspects of the smallholder societies under scrutiny.

As this dissertation is building on interdisciplinary cooperation, the following literature review also aims at allowing scholars from other disciplines to understand the foundations of the following analyses. Readers with an in-depth knowledge of the theory on agricultural development and the theoretical frameworks of Boserup (1965) and Ruthenberg (1971) may skip the respective chapters and continue directly with chapter 1.4.5.

[7] Livelihood strategies are understood here as a specific combination and relative importance of various livelihood sources, such as arable farming, livestock keeping, hunter-gatherer activities or cash-based livelihood sources (pensions, salaries etc.).

[8] This study will use the terms *peasant* and *smallholder* synonymous.

1.2.1 Peasant Economics

For Ellis (1988), the term *peasant* incorporates all those farm-households and agrarian societies which can be defined as occupying "*the margins of the modern world economy. With one foot in the market and the other in subsistence they are neither fully integrated into that economy nor wholly insulated from its pressures* (Ellis 1988, 1)". The term is thus characterized by two aspects: i) only partial integration of peasants into markets and ii) a certain degree of market imperfections which they have to deal with. These defining aspects separate peasants also from similar modes of production, such as the commercial family farm, which is fully integrated into perfectly working markets (Ellis 1988). He provides an even more exact definition of what constitutes a *peasant* by approaching the term from two different directions – from the peasant society as a whole and from the unit of the peasant farm-household. When looking at the peasant society as a whole, four distinct characteristics of peasants can be identified (Ellis 1988):

1) Peasant societies are in a dynamic state of *transition* and stand halfway between a tribal and an industrial society. They developed out of relatively small and isolated but self-sufficient communities but are not yet fully integrated into market economies.
2) A peasant society is always connected to a larger economic system and therefore at least to some degree subject to market forces. They face a trade-off between producing for the market to generate cash income and producing for subsistence purposes.
3) A recurrent phenomenon is subordination, i.e. unequal social or cultural status of peasants and coercion of one social group by another.
4) Peasant societies are heterogeneous[9].

The second approach towards a definition of peasants is via the peasant farm-household. For Ellis (1988), a peasant is always a farmer. The farm-household is therefore the unit of production which is both an enterprise and a family, and as such both a producer and a consumer. Peasants can be furthermore characterized as i) having access to land as the basis of their livelihood and as ii) relying on family labour as a central economic characteristic. Due to the fact that peasants may use capital both for purchasing factors of production and goods for consumption, it is not possible to use the concept of *profit* to describe the peasant households' rate of return on capital. Above all, and due to various market imperfections, peasants can be characterized by their varying rather than total commitment to the market; the ability to survive even when withdrawing from the market distinguishes peasants from all other family farmers (Ellis 1988).

Building on these thoughts, Ellis (1988, 12) summarized his definition of *peasants* and the *peasantry* as follows:

> "*Peasants are farm households, with access to their means of livelihood in land, utilizing mainly family labour in farm production, always located in a larger economic system, but fundamentally characterized by partial engagement in markets which tend to function with a high degree of imperfection* (Ellis 1988, 12)"

[9] Although the degree of heterogeneity may differ strongly between typical stages of peasant societies, as will be shown when presenting Boserup's (1965) and Ruthenberg's (1971) theories in the following chapters.

Obviously, the farm-household is a central concept in this definition. In peasant economics, the farm-household forms the basic social unit of analysis. It can be defined as containing all persons which share the same abode or hearth (ibid.). Generally, it is assumed that a household pools its resources, shares its income and that decisions are made jointly by all adult household members. For economic analysis, it is therefore appropriate to associate the household with the farm as the production enterprise (ibid.).

Netting (1993) reinforced this view on smallholder households in agrarian societies and found that "*in the farming community, no other social unit is as salient and significant as the household* (Netting 1993, 62)." Households form the fundamental social unit in all agrarian societies and (despite a big variety in form and structure) they can be characterized as performing the same basic tasks to ensure the survival of their members over time: food production, processing and storage; construction and maintenance of the homestead; animal husbandry; preparation of meals and provision/maintenance of clothes and last not least facilitate biological reproduction (Netting 1993). This study will use the peasant or smallholder farm-household as the basic level of analysis and for its analysis take into account all the activities mentioned above.

However, Netting (1993) also criticized *Peasant Economics* for its focus on social relations based on unequal access to wealth and power. He argued for the inclusion of ecological relationships between population, agricultural technology, household organization, as well as land tenure in the economic analysis to be able to fully capture peasants' distinctive adaptions to their local environment. This study overcomes this criticism by analyzing smallholder households of the research area in light of the theoretical framework of Boserup (1965) and Ruthenberg (1971), which is presented in the next chapters. This framework specifically takes into account the economic-ecological relationships of a specific agrarian society as well as the role of technology within it.

The following chapters (1.2.2 – 1.2.6) will introduce important macro-demographic theories explaining the long-term evolution of peasant societies. The goal is to identify the dynamics and the main drivers of change that shape the way that agriculture is carried out within societies. The need to include this level of analyses into the study was given in the current chapter and is based on Ellis' (1988) thoughts on peasant economics: As peasant societies are undergoing a constant adaptation process to changing socio-ecological environments, understanding the key driving factors that cause these adaptations can greatly facilitate the analysis of these societies. Also it may help in formulating relevant policy interventions.

1.2.2 The evolution of peasant societies

One of the earliest theories on the organization of agricultural production within peasant societies (albeit in a European context) was put forth by Thünen (1826). He developed a hypothesis concerning the spatial differentiation in the production of agricultural commodities across a landscape. According to his hypothesis it was mainly the distance to markets which affected both intensity of agricultural production and choice of produced commodities. Distance to markets included aspects such as transportation costs, perishability of produced commodities and competition for scarce land around the markets. Thünen's (1826) central message was that a growing proximity to markets induces a switch to higher value commodities in order to increase the value of agricultural production per hectare. According to Headey & Jayne (2014), this switch can be regarded as a form of agricultural intensification and as such it represents a direct link between Thünen and contemporary theories on peasant societies (which will be introduced below).

A few years earlier, Malthus (1789) had proposed a macro-demographic theory which would establish the relationship between demography and agricultural development as a focal point of scientific debate in a number of literatures (Headey & Jayne 2014). Written during a time when all nations were still largely agrarian and characterized by low incomes (Stevens & Jabara 1988), Malthus postulated that a human population equilibrates with resources at a certain level which was determined by available technology and a specific level of material welfare (Lee 1986). He claimed that biophysical parameters such as soil fertility limited human land use, but that limitations in carrying capacities could be overcome or raised by technological innovations (Netting 1993). If human population would rise beyond the carrying capacity (i.e. without any accompanying innovations that permitted higher food production), population would be pushed back below this carrying capacity by so-called positive checks – such as an increased death rate caused by food scarcity. This process is known as the Malthusian Trap, in which population growth would lead to disaster and social disorder by causing natural resource depletion, poverty and starvation - eventually leading to a population decline back below its carrying capacity (Decker & Reuveny 2005). Malthus therefore opted to apply so-called preventive checks that aimed at keeping population levels below this critical value.

Malthus couldn’t foresee the rapid advances in technology and science that would soon accelerate industrial and agricultural production and therefore render his theory irrelevant for industrialized societies. However, as Malthus’ analysis was generally valid for the agrarian world he observed (Stevens & Jabara 1988), his theory still contributes to explaining today’s peasant societies. In this regard, his most important contribution to macro-demographic theory may be introduction of the assumption that population growth rates are endogenous to agrarian societies. Nevertheless, there is little consensus in scientific debate on how exactly technology limits population growth and under which conditions Malthus theory may hold.

One of the most recognized opponents of Malthus’ theory was Danish economist Ester Boserup, who rejected his pessimistic view on the dangers of population growth and turned his rationale around. Contrary to Malthus, she regarded population growth not as constrained by the level of (agricultural) technology, but as the main driver of technological progress in agrarian societies. According to Boserup (1965), technological development in agriculture is driven by population pressure and induces an intensification of land use to provide nourishment for the increasing number of people on a limited amount of land. In other words: If land became a limiting factor (due to population growth AND a restricted ability to migrate to other areas), people had to increase quantity and reliability of food production within their limited area (Netting 1993). Her approach is therefore based on the assumption that population density or land scarcity are independent variables that may trigger a process of agricultural intensification (ibid.) and thus even lift people out of a Malthusian trap.

Boserup was the first to propose the idea that, as population density in agrarian societies increases and land becomes scarce, farming households gradually switch from extensive farming systems (which are characterized by regular or infrequent expansions or the shifting/relocation of cultivated land) to more intensive systems, where diminishing land availability is substituted by other inputs (Headey & Jayne 2014). These dynamics lead to a sequence of typical stages in the development of agrarian societies that range from various forms of shifting cultivation to stages of annual cultivation and finally to other, intensified forms of permanent cultivation.

Although Boserup and Malthus differ strongly in their perception of the origins of technology, they share various assumptions about the relationships among population, technology, and resource use (Turner & Shajaat 1996). First of all, both authors shared the assumption of diminishing returns to labour for a fixed technological level (Lee 1986). Also, both authors assumed that a rise in population will increase demand for food. Malthus' contribution to this common ground was that population growth rates are endogenous to agrarian communities while Boserup's contribution consisted in also regarding technological change as endogenously determined by demographic factors (Lee 1986).

For this study, the assumptions and predictions of Thünen, Malthus and Boserup are very relevant. The research area, i.e. the Okavango River Basin (ORB), is affected by developments that are included and interpreted in all three theories. For instance, ongoing population growth and reports on degrading natural resources indicate that smallholders of the ORB could soon either be affected by positive *Malthusian* checks or will need to respond to these drivers via endogenous, *Boserupian* intensification. At the same time, smallholders of the ORB are affected by urbanization and increasing access to regional and international markets. Possibly, this has important consequences for production decisions.
However, all three theories have been developed before the rise of fossil fuels and assume that smallholders live isolated agrarian communities, where manual or animal labour represents the main source of energy. This assumption appears very problematic (see Fischer-Kowalski et al. 2011). However, chapter 1.4 will proof that these theories still provide valuable insights for many contemporary rural communities in Sub-Saharan Africa. At the same time, criticism on these assumptions has also led to a number of reformulations and qualifications of these theories. As Boserup's (1965) theory has proved as a valuable tool for the analysis of the three study sites, the following chapters will focus on her approach as well as important qualifications of her approach.

1.2.3 Endogenous Intensification (Boserup 1965)

Boserup (1965) provided a general theory of agricultural development which allows for the dynamic analysis of peasant agriculture. One of her central messages is that peasant agriculture cannot be regarded as immutable because great changes are occurring in response to changing population densities. Thus, she also considers farming systems not as adaptations to certain biophysical conditions, but as the result of adaptation processes to changing population densities.

The mainstream economists of her time considered two main responses to changing population densities: the creation of new fields (expansion) and/or increasing the yield of existing fields (intensification). Boserup extended this view by integrating apparently unused, non-cultivated land of a specific region into her analyses. She achieved this by focusing on the frequency of cropping and by abandoning the differentiation between cultivated and uncultivated land. This allowed her to reconsider forests and other marginal lands as integrated parts of a farming (or socioeconomic) system, which serve as a source of natural resources, as fallow areas or as pastures. Thus, she was able to include all types of shifting cultivation into the analysis of agricultural development.
Her approach also allowed for better understanding the changes in agricultural technology that can stem from changing population densities. As an example, according to Boserup (1965), an increase in population density in a shifting cultivation society may lead to the establishment of new fields. As total arable land is limited, this necessitates a reduction in fallow period length and thus an increase in the frequency of cropping, which she considered as intensification – and as this intensification is induced endogenously to the society, she labelled it *endogenous intensification* (today also referred to as *Boserupian intensification*, e.g. by Headey & Jayne 2014).

In order to facilitate the analysis of this intensification process, she defined five main historical stages of peasant farming systems: Forest-fallow, bush-fallow, short-fallow, annual cropping and multi-cropping cultivation. The first two stages, forest- and bush-fallow, are sometimes grouped into the larger category of shifting cultivation. Their basic characteristics are presented in Tab. 1.1.

Under low population density within a given area, i.e. in land abundant stages of agrarian societies, food production is possible with low levels of labour input and basically no capital investments are needed. The reason is that very long fallow periods allow for the preservation of soil fertility. However, with increasing population densities gradually exhausting the available land, fallow (as the main means of managing soil fertility) needs to be complemented and later substituted by other means, i.e. non-land inputs (Headey & Jayne 2014). Therefore, the frequency of cropping as well as intensity of non-land input-application (especially of manual labour) is increasing from stage to stage.
Inputs for intensification initially include organic fertilizers and animal traction, which in later stages are replaced or complemented by inorganic fertilizers, pesticides/herbicides and use of machinery. At a late stage, farmers begin to transform the landscape via the construction of structures such as terraces, irrigation schemes and increased cropping intensity (ibid.).

The issue of soil fertility management illustrates an important assumption of Boserup's (1965) theory: along with introducing the concept of frequency of cropping, she abandoned the idea of naturally fertile vs. less fertile land. Instead, she treated soil fertility as an endogenous variable within a farming system. It becomes strongly linked to population density and dominant cultivation methods. She thus argued against treating (in-)fertility land as a driver of agricultural land use change, such as Malthus did when he defined a non-variable carrying capacity of agricultural land.

Tab. 1.1: Boserup's (1965) main cultivation stages of agrarian societies

	Forest-fallow	Bush-fallow	Short-fallow	Annual cropping	Multi-cropping
Relative pop. density	Very low	Low	Medium	High	Very high
Land use intensity	Very extensive cultivation	Extensive cultivation	Increasing cultivation intensity	Majority of fertile land cultivated; marginal land as pasture	Intensive cultivation; livestock kept in stables
Fallow period (in a)	20 +	6 to 10	1 - (a few years)	Seasonal (i.e. less than 6 months)	Negligible (0 - 3 months)
Cultivation period (in a)	1 - 2	variable (1 - 2 up to 6 - 8)	1 - 2	continuous; 1 harvest per year	continuous; 2 + harvests per year
Vegetation on fallow	Forest (virgin & secondary)	Bushland and small trees	Natural grassland	Farmland	Farmland
Non-fallow soil fertility management	Ash as fertilizer	Ash as fertilizer	Animal manure as fertilizer	Animal - & green manure; crop rotation;	Animal - & green manure; various other adaptations
Tools & techniques	Fire for clearing; digging stick, later: hoe cultivation; no weeding needed	Fire & hand tools for clearing; hoe cultivation; little weeding needed	hoe cultivation, later: Advent of plough cultivation & animal traction; weeding important; no fodder cropping;	Plough & animal traction; fodder cropping appears	Plough & animal traction; (irrigation possible)
Production/Labour ratio	High	High	Decreasing	Decreasing	Low
Leisure/Labour ratio	High	High	Decreasing	Decreasing	Low
Land rights	General cultivation rights within tribal area	Household specific cultivation rights to specific plots appear	Landlords may appear		Private land rights appear
Characteristics of two main farming systems	**Manual cultivation of relatively small areas with mixed root crops and cereals by means of fire; additional food provided by hunting and foraging**		**Cultivation of a relatively large area with cereals; use of fire abandoned due to its ineffectiveness against grass roots, rising important of animal based ploughing to cope with rising seasonal labour peaks; casual labour a common income source in short-fallow stage**		

Source: Author's design based on Boserup (1965).

By creating a continuum of stages, Boserup (1965) aimed not at a mere classification of various types of agriculture, but to describe the main stages in the actual evolution of peasant agriculture. However, it remains impossible to accurately determine the population density threshold that signifies the divide between extensive and intensive agrarian societies (see Netting 1993). Also, it is possible that societies skip certain stages or that different farming systems or idealized stages of agrarian societies can coexist within a certain area – e.g. in the form of regularly cultivated lands near settlements on fertile land and less frequently cultivated marginal lands in some distance to settlements, where forest-fallow dominates.
Each transition from one stage to another normally entails a change in the way a society organizes itself and in its attitude to labour. Therefore, Boserup (1965) focusses on the role of institutions and a society's attitude towards labour in order to assess its chances for economic development, understood as a transition from one stage to another

1.2.3.1 Boserup's (1965) view on labour

Boserup's (1965) analytical focus lies on the relationship between (manual) labour and land use. Her assumptions have important implications for the objective function in the bio-economic model (part II of this study). Also, they form the basis of this study's discussion whether or not households will adopt sustainably intensified production methods (synthesis chapter 1.6.5 of part I of this study).

Manual labour represents the main non-land production factor in agrarian societies and can be provided either by humans or by animals (Boserup 1965). Interestingly, Boserup's conception of peasant attitude towards labor is similar to that of Chayanov's *Theory of peasant behavior* (Turner & Shajaat 1996). According to Chayanov (1966, in Turner & Shajaat 1996, 14984), the *drudgery of labor* in peasant production is of such a level that farm households do not produce the maximum amount possible, which may be expected if profit maximization is the goal. Instead, they produce just enough to cover a certain standard of living (Ellis 1988). Boserup argues in a similar line and strongly rejects the idea that profit or income maximization is a farm household's main goal in agrarian societies.

Furthermore, the intensification process described by Boserup typically entails a change in the working habits of peasants: In the early stage of long-term fallow systems, foraging is complemented by some agriculture. Here, a few irregular labour hours are sufficient to feed a household and no daily regular work is needed. Starting with the change to bush-fallow and later stages where fallow is gradually shortened, peasants have to carry out hard in one or two peak periods while still preserving a relatively long season with none or little agricultural work (commonly during the dry season). The peak seasons include tasks such as land preparation or weeding, because an increasing frequency of cropping usually implies a rising stationarity of fields. With stationarity, weed infestation is a growing problem (which was more suppressed by the regular field rotation in shifting cultivation systems).

It has to be noted that in many cases, a peasant could produce more food by working harder without transitioning to another (higher) stage. Boserup (1965) argues that (due to her perception of labour) a peasant is unlikely to do so. Only population pressure or compulsion of social hierarchy could induce a change to higher working hours. Boserup relies upon anthropological insights for the reasoning behind this assumption, as well as for her claim that agrarian societies see "*hunting, fishing and food collection as pleasurable activities while food production is resorted to only to the extent that other and more agreeable activities fail to provide sufficient food*" (Boserup 1965, 45). This observation helps to explain her following finding:

> "*The effort devoted to food production is often seen to be limited to the bare minimum of hours necessary to avoid starvation. This attitude may help to explain why, in communities with a system of long fallow and with abundant land and little input of agricultural labour, the cultivated area is often barely sufficient to give a crop which can last until the following harvest*" (Boserup 1965, 45).

In some case, however, the peak seasons especially in the stage of intensive bush fallow may demand so much labour that even when working full-time, peasant households may be not be able to cultivate an area sufficiently large to cover their subsistence needs (Boserup 1965). In these cases, the advent of plough cultivation may be a means to cope with this high labour demand. Typically, the plough is introduced in the stage of short-fallow where it allows for preserving "*the long periods of freedom from agricultural toil even with relatively high densities of population* (Boserup 1965, 45)"[10].

A change in working habits away from relatively long periods of this seasonal freedom towards regular, daily working hours is often only acquired at stages of high intensification, e.g. where peasants are forced to feed their stabled animals year-round via produced fodder or where they apply labour-intensive irrigation (ibid.). Some authors put a more negative spin to the process of labour intensification demanded from the transitions between these stages:

> "*This sets in motion a vicious cycle of labour intensification & demographic growth that increases the workload on the people and the exploitation of the environment without allowing for a substantially improved standard of living for the peasant family* (Fischer-Kowalski et al. 2011, 10)."

Yet apart from the negative consequences for peasants' leisure time, it may also be argued that intensification can also induce longer, harder and more diligent working habits and thus lay the foundations for true economic growth.

1.2.3.2 Boserup's (1965) view on institutions

According to Boserup (1965), the ongoing intensification process from stages of lower frequency of cropping to stages of higher frequency[11] entails the gradual development of private property rights to formerly communal lands. Before the rise of private property rights, all systems of land tenure analyzed by Boserup (1965) share the fact that some households were recognized as having cultivation rights to specific areas while other households were excluded from these cultivation rights. Also, so-called "free land" virtually disappears even before the agricultural stage is reached (Boserup 1965, 69). In these communal, or tribal,

[10] Although now, draught animals need to be able to feed on sufficient organic matter.

[11] As Boserup (1965) illustrated on the example of European settlers in northern America, this trend may be reverted if peasants or farmers encounter a situation of declining or lower population density.

lands, often a so-called *general cultivation* right coexists with *specific* or *exclusive use rights* of a household, commonly to a certain plot it has cleared. These exclusive rights do normally last throughout the entire long-term fallow period, and as there is normally sufficient suitable land available to create new fields, households show a low interest in returning to the same plots. In this case, i.e. especially in forest fallow, it are generally the members of the dominant tribe that have a general right to cultivate within a certain territory while non-members can obtain it only via explicit recognition of the dominant tribe (Boserup 1965)[12]. A rise of rural population densities will gradually turn the more fertile plots[13] into a scarce good, households start to be more possessive about the plots they cultivate. With a further increase in the scarcity of suitable plots, more formalized land right systems and private property rights are likely to occur (Boserup 1965). This study will consider the land tenure system as one classification criteria for the farming system analysis.

1.2.3.3 Boserup's (1965) view on intensification

Now, a clearer definition of what intensification means for Boserup and on how it will be conceptualized for this study can be given: Intensification can on the one hand be defined as an increase in the frequency of cropping within a certain area. But it is also characterized by certain aspects of labour productivity – i.e. in agrarian societies (where manual labour and not fossil fuels is the main energy source) it requires a rising input of human labour in agricultural production. This results in an increase in land productivity (i.e. yield/ha) from stage to stage, albeit at the expense of a decreasing labour productivity (i.e. yield derived per unit of labour invested in agricultural production).

Intensification according to Boserup basically describes a process of increasing land productivity by increasing labor-input into agricultural production with the goal of feeding more people at the same nutritional level as before (Fischer-Kowalski 2011). Examples for the rising labour needs with the reduction of fallow periods are i) the increasing use of ash as fertilizer (very early stages), ii) the increasing need to weed the more permanent fields or to change to plough cultivation to get rid of the relatively fire resistant grass roots (early stages), iii) the use of animal manure to balance the reduced soil fertility levels caused by more frequent cropping (medium stages) to iv) systems where the annual crop production needs to be complemented with annual fodder production to sustain the livestock needed for cultivation and manure provision (late stages).

1.2.3.4 Conditions of agricultural change and endogenous intensification

Boserup did not imply that an increasing population density would automatically trigger technological progress – instead, it would merely increase the probability of technological advances (Lee 1986). Via lowering agricultural output per labour-hour in the short-run, population growth would create both new problems as well as opportunities for invention, e.g. in the areas of organization and food transport. Therefore, short-run disadvantages of

[12] As is the case for the village of Cusseque in study site Cusseque; see chapter 1.6.1.

[13] Although this study follows Boserup (1965) by recognizing soil fertility to be an endogenous variable and not determined solely by natural site conditions, it is still used here to describe the relative suitability of one plot versus another one.

population growth may or may not be off-set long-run advantages of greater population density for technological innovation (ibid.).
Boserup also found that in the long-term evolution of agrarian societies, there would likely be a transitory but critical stage during which labour productivity in agriculture would decline while that of other activities would increase. "*This period is likely to be one of considerable political and social tension, because people in rural areas, instead of voluntarily accepting the harder toil of a more intensive agriculture, will seek to obtain more remunerative and less arduous work in nonagricultural occupations* (Boserup 1965, 106)". In the study sites, migration of household members to urban centers (with the goal of finding formal employment) seems to be an important trend. This study will therefore include this trend in its analysis as a possible obstacle to the intensification of rural farming systems.

1.2.3.5 Qualifications and limitations of Boserup's Theory

Boserups (1965) contribution towards the scientific debate on agricultural development is widely acknowledged and various studies confirmed its' aptitude for the analysis of contemporary agrarian societies (see Jayne et al. 2014b; Fischer-Kowalski 2010 & 2011; Turner & Shajaat 1996). She identified the central role that the marginal return of labour plays in agrarian subsistence societies and the role of decreasing land availability as an incentive to substitute leisure with agricultural labour. She thus provided a theory that was able to explain why peasants in land-abundant areas adopted certain agricultural technologies, while ignoring others which might have yielded higher harvests per area.

Over the decades, Boserup's theory has been extended by various authors and these qualifications offered even deeper insights into peasant societies. Headey & Jayne (2014) identified three main phases in the scientific debate about agricultural intensification and Boserup's theory. In the first phase (1980s and early 1990s), research sought to test whether rising population densities actually spark intensification. In the second phase (1990s), the implications of population growth on degradation of natural resources moved into the focus of analysis. And in the last phase (2000s), since the Green Revolution successes in Asia, a broader literature emerged that focused on intensification and technology adoption, where population pressure was regarded as a main driver. Recent literature did rarely revisit or extend the findings of these earlier decades (Headey & Jayne 2014). While the pre-ceding chapter focused on the basic rationale behind Boserup's framework, some of the more recent contributions and clarifications of her theory will be presented on the next pages. The chapter closes with an overview of the main drivers of change in agrarian societies acknowledged by literature and integrated into this study.

The entry point into the discussion on Boserup's theory starts with the findings of Bonneuil (1994), who identified *non-adaptation to rising population pressure* as the actual problem in agrarian societies (and not population density itself). According to him, population density does not drive technological change in smallholder agriculture in a mechanistic manner. Instead, it modifies the set of opportunities that these rural households are able to achieve in their efforts to adapt to growing population densities. Therefore, Bonneuil (1994) regarded the

shrinking set of opportunities or achievable options (while time is passing and population growing) as the real incentive for technological progress and thus also intensification.
His reasoning is in line with Pingali & Binswanger (1988), who found that the decisive factor for preventing a decline in human welfare from population pressure is the speed with which this pressure is countered. This view can be complemented by Netting's (1993) conclusion that (although smallholder intensification is not environmentally determined) efforts towards intensification may either be constrained or aided by biophysical parameters, such as climate, soils and topography (Netting 1993). This leads to the following conclusion: Although smallholders may face incentives to change their behaviour and thus avoid Malthusian population control (i.e. a breakdown of the population due to population growth to levels beyond the carrying capacity), they may still chose not to do anything. However, should these smallholders at a later point in time decide to change their behaviour, their set of achievable options may have reduced to such a level that endogenous intensification is not possible anymore. In these cases, households may be on a pathway towards a Malthusian trap. This finding will be used in the farming system analysis to determine the success likelihood of endogenous intensification in the study sites. Study sites with characteristics of advanced land degradation will be judged to have a lower likelihood of success than those in pristine environments.

A second contribution to Boserup's theory comes from Netting (1993) and focuses on population growth, which already Malthus (1789) identified as an endogenous factor in agrarian societies. Netting (1993) found that a variety of factors can lead to population growth and that at the same time a variety of other factors can lead to population control. Apart from increasing their agricultural output via *Boserupian* intensification, he found that smallholder societies also manage to adapt to rising population pressure by controlling population itself, e.g. via birthrates. This issue may be relevant for the future of the study sites and will therefore be re-visited in some more detail below, when the framework of Jayne, Chamberlin and Headey (2014) will be presented.

Apart from these various contributions to Boserup's (1965) theory, there was a continuing debate whether her or Malthus' (1789) theory describe the effects of population pressure on agrarian societies more adequately. For instance, Demont et al. (2007) analyzed the effect that growing population densities have on agrarian societies in northern Cote d'Ivoire which are not completely isolated, but where peasants had the option to migrate. Their results indicated that the theories of Malthus and Boserup coexist rather than contrast. They found that the key factor allowing peasants to escape a Malthusian trap and to successfully adopt technological innovations was access to labour[14]. However, as long as the option to migrate is kept open, this means of Malthusian population control appears to dominate over Boserupian mechanisms of endogenous innovation. In the case of northern Cote d'Ivoire, the process of Boserupian agrarian transition appeared to occur only above a certain population density or land use intensity (in the case of Cote d'Ivoire: 30 persons/km² or land use intensity of 30 %). Below these values, the Malthusian mechanism of out-migration appears to dominate. This is

[14] It is possible that the authors encountered a situation where households wished to intensify but in which their *set of opportunities* (Bonneuil 2009) to do so was severely limited. Access to labour may have increased this set of opportunities and allowed some households to intensify their production.

an important finding, because under current global population growth rates (see e.g. UN 2013) and considering the concurrent levels of land use expansion into marginal lands (see e.g. Barbier 2011), migration might soon become less and less of an option. Together with an ongoing urbanization and rising demand for food, feed and fiber, Demont et al. (2007) expect that the saturation of marginal land will increasingly induce Boserupian intensification.

The co-existence of both theories was also found by Turner & Shajaat (1996), who conclude that the critical stages of agricultural development described above (where a Malthusian-like responses of involution and stagnation become likely) may actually be wide-spread and facilitate the needed intensification towards a new agricultural stage. Contemporary scientific discourse has therefore moved beyond a simple Malthus–Boserup debate and demonstrated that actually both theories may be supported by empirical evidence, depending on where in the intensification process an analysis is undertaken or depending on the time period analyzed (Turner & Shajaat 1996). However, the authors do point out that those process that actually divert intensification into involution and stagnation pathways are actually less well understood than those that cause Boserupian intensification (ibid.).

This study will rely on these findings and pay special attention to whether or not a study site is close to one of these critical stages – here the need and will for endogenous intensification may be high, but the likelihood of successful intensification depends on the state of environmental and household resource degradation.

1.2.4 The role of market access for agricultural development

Another common criticism of Boserup (1965) concerns her apparent (earlier) neglect of market access as an incentive for intensification (Netting 1993). However, this criticism fails to understand that Boserup considered the development of market access and the formation of markets also as being induced by population growth, namely via an ongoing urbanization, the evolution of specialized production and exchange as well as via the development of infrastructure (ibid.).

Market access of smallholders can be understood as "*access to either spot markets or a supply chain that delivers the required market services* (Tilburg & Schalkwyk 2012, 38)". The term *market access* is used here in a broad way, i.e. as a farmer's ability to reliably sell his harvest, either for cash or in kind. The term thus includes local and regional markets as well international markets. It was already described by Thünen (1826) as a central driver of agricultural development.

According to Barrett (2007), the degree of smallholder market integration is affected by two main entry barriers: At the micro-scale, by insufficient access to assets, financing and improved technologies which allow for producing a marketable surplus. At the meso-scale, by transaction costs, which limit market access at household-level and spatial price transmission and trader competition at the market-level. This can result in thin and volatile markets and decrease households' incentive to generate a marketable surplus (Barrett 2007). These barriers may lead to a situation where smallholders lack the will, knowledge and/or ability to produce surplus, and where traders have therefore little incentive to invest effort into reaching these households. This reinforcing feedback may continuously bar rural households from accessing the wider market and thus keep them in a situation where they have to continue to rely on subsistence (ibd.).

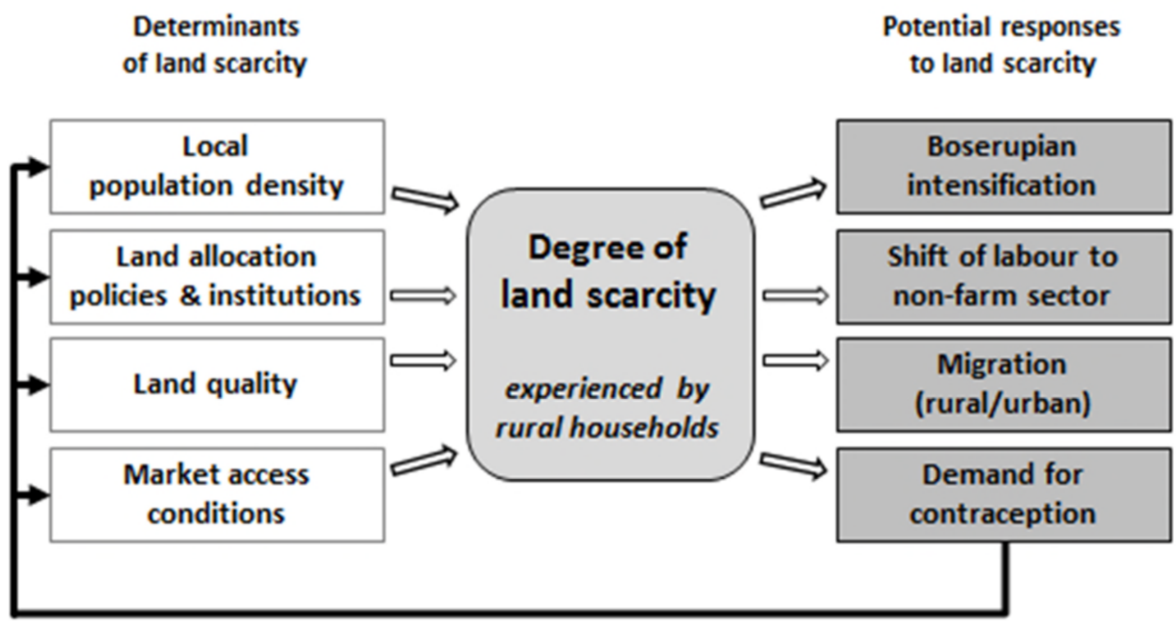
This implies, that in the Okavango basin, it cannot be expected that the ongoing growth of urban centers and the rising integration of these centers into international cash markets will allow for the widespread commercialization of smallholder production (see e.g. Sitko & Jayne's (2014) analysis on commercialization in Zambia). This study will include the degree of *market access* into its analysis by following the theoretical framework of Jayne et al. (2014b), which is presented below and which considers the degree of market integration as an important determinant of land scarcity (and thus as a co-driver of population density).

1.2.5 Contemporary frameworks for the analysis of rural communities

Jayne et al. (2014b) provide the most recent review of Boserup's theory. In general, their findings confirm the applicability of Boserup's theory for most isolated farming communities in Sub-Saharan Africa (see also Headey & Jayne 2014). Furthermore, Jayne et al. (2014b) aim to analyze the effect that rapid rural population growth has on peasant households in contemporary Sub-Saharan Africa under increasingly binding land constraints. To be able to do so, the authors developed a theoretical framework (Fig. 1.1) that complements Boserup's theory of endogenous intensification with three additional means of smallholder adaptation: 1) reduction of household fertility rates, 2) migration to more land abundant regions as well as 3) diversification into the non-farm sector.

Jayne et al. (2014b) follow Boserup (1965) in regarding the *degree of land scarcity* as a main driver of change in agriculture and related socioeconomic systems. However, they complement Boserup's main driver of land scarcity, which is population density, with three additional drivers: i) land quality, ii) market access conditions and iii) land allocation policies & institutions.

Fig.1.1: Conceptual framework for examining the determinants and smallholder responses to land scarcity



Source: Author's design, based on Jayne et al. (2014b)

An important reason for Jayne et al. (2014b) to create this extension of Boserup's theory is her focus on autarkic subsistence economies, where the non-farm sector is non-existent and migration highly constrained (Headey & Jayne 2014). These strong assumptions appear unlikely to hold in today's globalized world and the alternative means of adaptation cannot be ignored. However, in chapter 1.4 it will be proven that apart from Boserupian intensification, these other means of adaptation do largely fail in the context of Sub-Saharan Africa.

Another important contribution to the analysis of rural communities was made by Fischer-Kowalski et al. (2010 & 2011). These authors stress that many contemporary rural communities cannot be regarded as isolated anymore. Instead, they must be considered as affected by globalization and so-called interventions from higher social levels, which can be grouped into four main categories: (a) provision of services, (b) regulatory mechanisms, (c) supply of (often subsidized) fossil-fuel based technologies and (d) supply of specific aid and subsidies. These interventions may hinder endogenous intensification.
Furthermore, the authors find that Boserup's theory fails to describe the dynamics within farming systems which are increasingly dependent on fossil fuels and industrial fertilizers. In these systems, the Boserupian link between intensification, increasing working time and decreasing labour productivity is dissolved. It is replaced by an industrial link between increasing use of fossil fuels & industrial technology on the one hand, and increasing labour productivity on the other hand (Fischer-Kowalski et al. 2011). They argue that the wide-spread application of fossil fuels changes the Boserupian dynamics and allows for an escape from the "*trap of labour intensification* (Fischer-Kowalski et al. 2011, 34)", albeit at the cost of an increasing pressure on the environment (ibid.).
However, the authors acknowledge the importance of Boserup's theory for the analysis of agricultural change in isolated farming systems, i.e. those which still rely mainly upon manual labour or animal traction. This study will prove that in the research area, the use of industrial inputs and fossil fuels is still very limited and manual labour remains the dominant energy source (chapters 1.6.1 – 1.6.3). Thus, it is a valid assumption that Boserup's theory can be applied to the research area. At the same time, the analyses will show that there are increasing interventions from higher social levels. Thus, there may be a reduced likelihood of Boserupian intensification in the three study sites in future.

1.2.6 Relevance of macro-demographic theories on agricultural change for this study

This study will apply Boserupian theory for the analysis of the study sites yet remain aware of the potential shortcomings that have been presented above. It shares Boserup's positive view that smallholders are able to overcome the negative effects of population pressure. It considers the "degree of land scarcity as experienced by smallholders" as a main driver of agricultural change in the Okavango basin. By following Jayne et al. (2014b), another potentially important trend can be included in the analysis: It can be assumed that urbanization in the research area leads to an increasing availability of industrial goods – such as cell phones, coca-cola etc. This may induce the basin's rural population to strive towards a cash-based, consumption driven lifestyle which is perceived as modern. As this would rely on increased cash income, one pathway towards this lifestyle may lie in increasing sales of natural resources & agricultural goods (thus an intensification of land use). Within Jayne et al.’s (2014b) framework, this is conceptualized as *market access*, which serves as one determinant of land scarcity. By following this approach, this study will analyze the effect of changing lifestyles and increasing commercialization from a viewpoint of land scarcity.

The next chapter presents Ruthenberg’s (1971) theory on smallholder agriculture in the tropics. This theory is the micro-economic complement to Boserup’s macro-demographic theory. Together, the Boserup-Ruthenberg framework allows for conducting a analysis of the current situation in the three study sites and for identifying their likely development trajectories.

1.3 The Boserup-Ruthenberg framework for the analysis of tropical smallholder farming systems

Ruthenberg (1971) classified and described seven major cultivation systems of tropical smallholder agriculture. These are similar to Boserup’s stages of agrarian societies and characterized by different degrees of land use intensity. However, contrary to Boserup, his focus lies on the agro-economic setting of these systems, i.e. their specific management problems & economic characteristics as well as possible development pathways. Due to the complementarity of both approaches, they are sometimes called the Boserup-Ruthenberg framework and have been applied over many decades to aid in explaining the determinants of agricultural growth, intensification and technology adoption (Binswanger-Mkhize & Savastano 2014).

The central idea behind the Boserup-Ruthenberg framework is as follows: decreasing land availability necessitates a gradual shift from farming systems that rely on fallowing for the soil fertility regeneration (shifting systems) towards systems that abandon fallowing and instead combine various pro-active measures of soil fertility management (permanent cultivation systems).

Ruthenberg (1971) introduced an important quantitative measure of land use intensity into this framework, namely the *rotation intensity*, or *R-value.* This value indicates the percentage of land that is cultivated in a given year compared to the total land that available in a given year, i.e. the cultivation- as well as the fallow areas. It is defined at the level of the individual farm-household. For instance, a value of 30 would indicate that 30 % of the available land is cultivated in a given year and a value of 200 would indicate that all available land is cultivated twice per year, thus yielding two harvests. This important indicator will be used later to distinguish the main tropical farming systems and help in classifying the three study sites.

As mentioned previously, this study will apply the Boserup-Ruthenberg framework to analyze the three study sites Cusseque, Mashare and Seronga in the Okavango basin. The main goals of part I are to identify i) important bottlenecks in the peasant economy of the Okavango basin and ii) likely development trajectories of these systems. The chosen framework allows for integrating these analyses into a global reference frame and thus for achieving these goals. The following literature review will focus on issues related to these goals.

1.3.1 Tropical farming and its main challenges

Farming systems of the tropics have to deal with specific challenges that set them apart from most systems in more temperate regions. These challenges are caused by the tropics' characteristic biophysical features, which need to be understood to be able to compare and evaluate any tropical smallholder farming system. The following overview is based solely on MacArthur's (1971) contribution to Ruthenberg's (1971) work.

In regards to climatic influences, tropics are characterized by a seasonal character of rainfall, which results in alternating rainy and dry seasons. Due to great variations in timing and spatial distribution, floods and droughts are recurrent phenomena. Furthermore, high levels of sun radiation can cause physiological problems to animals and humans and reduce productivity. In regards to soil conditions, only few generalizations can be made: First, strong rainfalls result in widespread nutrient leaching and erosion from run-off. Second, the change between rainy and dry seasons leads to short periods of warm and humid conditions during which a rapid breakdown of organic material occurs. This results in low levels of soil organic matter and short-term mass releases of nutrients (which are in danger of leaching). Therefore, natural soil fertility can typically be considered as low. Lastly, under humid enough conditions, the biological environment provides good habitat to pests such as weeds, fungi and parasites and thus lead to crop damages and storage losses.

In agrarian societies of the tropics, farmers deal with these problems either by adaptation or avoidance. Translated into managerial thinking, there are four main challenges to tropical farming. The first challenge is to maintain and protect soil fertility. The second challenge is to deal with risk and uncertainty due to variable climatic conditions, pest occurrence and storage losses; this often induces farmers to invest more resources into subsistence farming than what seems necessary. The third and fourth challenges lies in coping with the fact that labour (availability) is often the most limiting factor in production and that smallholders have to operate under pronounced climatic seasonality. In areas where rainfalls occur only during a short time window, most agricultural tasks need to be carried out at a rapid pace, beginning from the moment that rainfall has sufficiently moistened the soil for ploughing, then continuing with cultivation as long as crop growth is possible. In contrast, the dry season is often characterized by low labour-demand aside from maintenance tasks.

The challenges to tropical agriculture presented by MacArthur (1971) indicate that the management of seasonal labour use as well as soil fertility is of central important in tropical smallholder agriculture. Furthermore, *seasonality of labour demand* is often a main constraint; in these instances, the issue of labour rationalization becomes an important consideration for smallholders (i.e. many favour crops and farming practices which offer increased returns to labour and reduced risk).

The following overview of typical tropical smallholder farming systems will elaborate on the solutions commonly found for these challenges in the respective system. This will later serve as important indicators for the classification of the study sites.

1.3.2 Archetypical stages of tropical smallholder agriculture (Ruthenberg 1971)

> "*In describing farming systems and their characteristics, we start therefore with the assumption that they did not come about by chance and that there is always a reason why farming in a specific case is carried out in one way rather than another* (Ruthenberg 1971, 7)"

Ruthenberg defines typical farming systems for the various stages of agrarian societies that were introduced by Boserup. Within each stage of these stages, peasants' developed typical strategies that allowed for dealing with the challenges to tropical farming presented above. The following overview will introduce Ruthenberg's (1971) view on important stages of tropical smallholder agriculture, i.e. the two shifting systems of *shifting cultivation* & *semi-permanent cultivation* as well as the permanent cultivation systems *permanent rain-fed cultivation*. As the following chapter is based solely on Ruthenberg's (1971) works, no further citations will be given. The information presented here helps to understand the meaning behind the classification of the farming systems in the study sites. A reader with sufficient knowledge on the three above-mentioned farming systems may skip this chapter and continue at chapter 1.4.5.

According to Ruthenberg (1971, 62), peasants' main goals of agricultural production are to 1) ensure a reliable food supply, 2) to produce tasty food. Therefore millet or maize are often preferred over crops such as manioc. A third goal is 3) to produce cash with one dominating cash crop, such as groundnuts or tobacco. These three goals drive the organization of crop production both in shifting systems and permanent systems, yet both systems differ strongly in regard to their main cropping principles. These will be presented below:

a) Shifting systems

The overview of tropical farming systems starts with **shifting cultivation**, which may be considered as the world's pioneering farming system which initiates the conversion of forested land to cultivated land. In shifting cultivation, a few years of cultivation alternate with a lengthy fallow period – therefore, fields (and often also homesteads) have to be periodically relocated - they slowly 'shift' through a landscape of mostly natural vegetation.
This system works almost without capital and is based on the balanced exploitation of soil nutrients during cultivation periods and soil nutrient regeneration during fallow periods (Ruthenberg 1971). Under sufficient land availability, i.e. where fallow periods are long enough to allow for the complete regeneration of soil fertility, this system allows for covering the basic food needs of peasants in a sustainable and labour-efficient way.
However, the system changes as soon as rising food needs of a growing population or increasing cash-cropping necessitate a gradual expansion of arable agriculture. This spatial expansion reduces the area of uncultivated land and ultimately forces households to replace long-term fallow by shorter fallow periods.

A cultivation system that typically follows on shifting cultivation under long-term fallow is **semi-permanent cultivation**. In this system, a cultivation period of a few years is usually followed by a fallow period of similar length. Homesteads are quasi-stationary, because the

shifting aspect of farming is reduced and most re-locations occur over longer time periods and short distances only. Still, it can still be considered as a shifting system.
The reduced fallow period is often insufficient for the regeneration of denser woody biomass. Therefore, the fallow vegetation in semi-permanent cultivation consists mostly of grasses and smaller bushes. It also results in a gradual soil nutrient exploitation and thus in lower yields/ha than in shifting cultivation systems (at least unless inorganic or organic fertilizer is applied, which is rare in semi-permanent systems). Stable semi-permanent cultivation is therefore found mainly in dry or humid savannas or in higher altitudes, where soil fertility is generally high and nutrient leaching a lesser problem. Only here do soils and climate allow for relatively stable yields under the short crop-fallow cycles of semi-permanent cultivation. In most other cases, ongoing soil degradation is a typical attribute of semi-permanent systems. They can therefore be seen as a rather *transitional* phase between shifting and permanent forms of cultivation, but not as a stable system (Ruthenberg 1971, 79). Many of the challenges that semi-permanent cultivators encounter are caused by their use of working routines that have been developed within shifting systems. Yet at the same time, these challenges also dramatically increase the likelihood of adoption of innovative technologies into farming with fallow periods. Semi-permanent cultivation may therefore be seen as a promising or even necessary step in the development of peasant societies.

An important difference between *shifting cultivation* and *semi-permanent cultivation* is that (with decreasing fallow periods) the similarity between peasant's livelihood strategies slowly reduces. In shifting cultivation, households tend to apply very similar farming practices and cultivate just enough land to meet their basic food needs and generate some cash income. In semi-permanent cultivation, farm sizes vary considerably and there is a clearer social stratification into wealthier and poorer households. This situation becomes even more pronounced with rising land scarcity and under higher degrees of commercialization. Among others, it is farm-managerial abilities which determine how well a household deals with these changes. Differences in these abilities can be a main reason for social stratification and explain the wide variation in choice of crops, farming methods, field sizes and technology adoption.

Peasants whose farming systems have a pronounced *shifting* character try to adapt to the biophysical conditions of their specific environment. Ruthenberg (1971) identified three main approaches in peasant's adaptation to natural site conditions: The first approach lies in the choice of land that is cultivated, and this trade-off decision goes beyond considerations of soil fertility. It includes aspects of labour needs for clearing, but also weed growth, pest occurrence or a plots distance to roads and water sources. Farmers may therefore choose to cultivate various less fertile but easily accessible plots near their homestead rather than a large tract of highly fertile but hard-to-clear land deep in the forests.
The second approach lies in the skillful combination of medium- and long-term fallow. While short-term fallows of 1-2 years are usually the result of unexpected labour-scarcity, longer fallow-periods of 2-5 (medium-term fallow) or 5-20 (long-term fallow) years represent answers to the problems of growing weed infestation and decreasing soil fertility that occur over the course of successive cultivation periods.

The third approach to adaptation lies in three interlinked principles of cultivation: *Mixed cropping, Phased Planting, Crop Rotations*. These three principles can be encountered in all forms of peasant cultivation, shifting as well as permanent. However, in shifting systems they are of highest variability. *Mixed cropping* refers to the simultaneous cultivation of two or more crops on same plot. In shifting systems, the choice of these crops is usually based on their adaptation to soil and surface conditions and rarely organized by a formalized principle. Usually, row cultivation is adopted only in later agricultural stages of higher permanence, i.e. when tree stumps and termite mounds have been removed from the fields and when plough-cultivation has been adopted (see next section on stationary farming). Advantages of mixed cropping lie in the reduction of yield risk from pests, the possibility to adapt cropping both to the soil conditions as well as the light and shade requirements of the planted crops, but also in the lengthening of the period of fresh food supply as well as more continuous soil cover due to different growth cycles of individual crops. *Phased planting* of different crop species results in a continuous sequence of growth and harvesting. It allows for the distribution of agricultural labour over a longer time period, a reduction of risk of crop failure due to weather or predation and the advantages listed under mixed cropping. *Crop rotations*, i.e. the replacement of one crop species with another in subsequent growing periods, does rarely occur in long-term fallow. Instead, one crop or a specific mixture is commonly cultivated for a few consecutive years. Only when cultivation periods last several years do peasants develop crop rotations (in order to deal with increasing weed & pest infestation and reduced soil fertility). In this case, important features of crop rotations are i) a division of fields into several smaller plots with different crops rather than a general rotation for the entire field and ii) a temporal sequence of crops, with crops requiring higher soil fertility (such as maize) being replaced over time with crops that are either not nutrient-demanding or that compete better against weeds and bushes (such as manioc).

Soil fertility management in Shifting Systems

The comparative advantage of *shifting cultivation* over any other peasant system lies in the "*cost-free, effortless regeneration of soil productivity during the fallow period, especially when the fallow consists of forest or bush vegetation*" (Ruthenberg 1971, 31-32). As long as fallow periods are of sufficient length to allow for the regeneration of soil fertility, shifting cultivation allows for the ecologically sustainable production of relatively high and stable yields even under the adverse climatic and soil conditions of the tropics.

Long-term fallow as the main means of managing soil fertility is commonly supplemented by one or many of the following practices: i) using domestic waste to fertilize plots near the homestead, ii) establishment of garden plots on old animal *kraals* or homestead sites, iii) mixing of green vegetation with soil, iv) using ash of burned vegetation as fertilizer or, very rarely, v) the application of inorganic fertilizer.

The transition from shifting towards *semi-permanent cultivation* presents a major challenge to farm management. Fallow periods are now of insufficient length to restore soil fertility completely. However, no adequate alternative fertilization techniques have been developed yet. Therefore, "*semi-permanent land-use systems often represent nothing more than degraded forms of previously balanced systems of shifting cultivation* (Ruthenberg 1971, 67)". The most common forms of evolving alternative fertilization methods include: i) shifting of the holding to a nearby, fertile plot, ii) fertilization of fields with animal manure by livestock-rearing peasants. To minimize the labour-needs of this task, peasants tend to avoid the manual spreading of manure on their fields but rather shift their *kraal's* location, thus creating a sequence of fertilized plots within an otherwise un-manured field, iii) green manuring, i.e. the incorporation of cut fallow vegetation and weeds into soil by manual labour and, where cash and markets are more easily and reliably accessible, iv) via inorganic fertilization. In general, this system's ability to provide food in the long-run depends on either i) highly fertile soils that even over long time periods manage to compensate for reduced fallow periods or ii) the ability to restore soil fertility even under grassy fallow. A more common phenomenon, however, is the iii) stabilization of yields at low average levels.

Labour use and seasonality of labour-demand in Shifting Systems
Labour requirements, both total and seasonal, differ strongly between shifting cultivation and semi-permanent cultivation. In shifting cultivation, time spent on farming typically accounts for less than half of a household's working time. The most labour-demanding tasks are field clearing, harvesting and food processing. Due to long distances between fields and homesteads, crop transport can also be a time-consuming task, especially in case of root crop cultivation such as manioc. Weeding becomes a bigger task only under longer cultivation periods, because grass growth is suppressed by both fallow vegetation and clearing by fire. Land preparation and planting are less arduous tasks than in other systems, because hoe-based soil cultivation usually becomes the rule only in semi-permanent cultivation. The exception to this is shifting cultivation in the dry savannas. Here, longer cropping periods of up to ten years (which are sometimes interrupted by short-fallow periods of one to two year) necessitate the use of intensive hoe-cultivation practices. This will for example be the case in study site Cusseque, Angola.

A typical characteristic of shifting cultivation is labour division, which exists in three distinct forms: i) division by gender, ii) division by plots (e.g. men taking care of heavier work while women focus on grassy plots) and iii) division by crops, with men usually focussing on cash crops and women on subsistence crops.

Shifting cultivation usually relies upon hand-tools as major implements and avoids the use of domestic animals for cultivation. Reasons for this include limited grazing possibilities in dense forests, the high labour needs of animal husbandry and the fact that the tree-stumps left in shifting cultivation fields are an obstacle for effective plough-cultivation. Removing tree-stumps from fields whose location is regularly shifting would be very labour-consuming and also reduce the growth of the desired fallow vegetation. Another important reason for the low importance of draught animals is the low seasonality of labour-demand: clearing, harvesting and processing, the three central tasks of shifting cultivation, can be done in a relatively leisurely manner and over a longer time period. The speed and strength of oxen-drawn ploughs are not yet needed to cope with growing seasonal labour-needs (such as occur in semi-permanent cultivation).

Contrary to shifting cultivation, the most time-demanding tasks of semi-permanent cultivators are hoe cultivation and weeding. They are more fatiguing than the main tasks of shifting cultivation and need to be carried out in a timely manner within the growing season. In

general, peasants in semi-permanent cultivation spend more time on their fields than in shifting cultivation, because of rising labour-needs per unit of output produced as well as because of the additional labour required by cash cropping.
For these reasons, the relatively rigid division of labour common to shifting cultivation is replaced by a more flexible system, where for example men are becoming increasingly involved in field work (such as weeding or harvesting). Furthermore, the subdivision of the fields into individual plots for each family member is abandoned in favour of a more centrally organized use of land and labour.
Seasonality of labour-demand becomes very pronounced in semi-permanent cultivation, especially as long as no draught animals are introduced to the system for helping with ploughing and weeding. This seasonality typically contributes to the rising importance of cattle husbandry in semi-permanent cultivation. It also begins to serve as insurance for crop losses or sickness, which become more common in semi-permanent cultivation due to reduced and more erratic yield levels. Ultimately this development may result in a rising social function of cattle, e.g. as a bride price or a status symbol. Cattle also becomes an important provider of meat and milk. Due to these reasons, large cattle herds are characteristic for later stages of semi-permanent systems, while in shifting cultivation livestock plays only a little or no role at all.

Evolution towards permanent farming systems

A typical evolutionary pathway of (rain-fed) tropical peasant farming systems leads from shifting and semi-permanent cultivation to permanent farming (Ruthenberg 1971, 98). This trend signifies an intensification of labour use, which aims at increasing land productivity.

Ruthenberg identifies two main reasons which induce intensification: The first is *necessity*, a push-factor, and it is typical for those areas where population pressure forces smallholders to abandon fallowing and find alternative soil fertility management practices. While traditional systems become increasingly unable to provide for the basic food needs of smallholders, they become more likely to try out and develop new, more labour-intensive production methods. The second reason is the existence of pull-factor for intensification. As peasants seem to prefer living close to markets, water sources and neighbours, they tend to move into already relatively densely populated areas. Here, they are again forced to adopt systems of shorter fallows or even permanent cultivation systems. In fact, the benefits of living here seem to outweigh the additional labour needs that arise when adopting more intensified systems.

Another advantage of adopting a more sedentary lifestyle lies in the easier dissemination and adoption of technological innovations. It can also cause increasing investments into infrastructure, such as fences, anti-soil erosion terraces or the replacement of grass or clay huts with solid houses and tin roofs. Rising permanency may thus present the foundation for an intensification process that would not be possible under fallowing systems.

b) Permanent cultivation systems

Systems of permanent cultivation are characterized by cultivation periods which are either not at all or only for a short time interrupted by a fallow period. The most common permanent cultivation systems of the tropics are *irrigation farming* and *perennial cropping*, which represent rather late stages in the intensification process. In this dissertation, the focus lies on the stage of *permanent rain-fed cultivation*, which is rarely a stable farming system, but rather represents a possibly negative end-point of the intensification process. As will be shown in chapter 1.6.2-1.6.3, study site Mashare and possibly also Seronga are in danger of following this development.

Generally, systems with *permanent rain-fed arable farming* develop out of shifting systems via the continual expansion of arable farming at the expense of fallow. They are typically characterized by i) a permanent division of arable land and grassland within the same holding, ii) a clear demarcation of fields and iii) a dominance of annual and biannual crops. Although trends towards these characteristics may already be discovered in shifting systems, they dominate only under permanent systems.

The following overview will focus on permanent rain-fed cultivation in the African savannas, i.e. areas matching the biophysical environment of the Okavango catchment. Here, permanent cultivation has usually developed due to two different goals of peasants. First, it is used to cover the basic food needs of a slowly increasing population. This is often achieved by developing sophisticated methods of manuring. Due to the high labour needs of these methods, holdings are usually small and yield per invested labour hour low. Second, it is employed to generate additional income by increasing the share of cash cropping. In this case, the adoption of sophisticated manuring techniques is less common and soil mining widespread (at least until all available land had been put into production).
However, there is a third way of how rain-fed permanent cultivation has developed. In India, this happened especially in areas where soils are naturally poor and where no irrigation is adopted, so that after centuries of cropping the yields stabilized at very low levels. This describes a Malthusian trap and areas characterized by these farming systems this are known as *famine areas*. Most traditional types of permanent rain-fed agriculture in the tropics can therefore be characterized as relatively poor farming systems.

The main cropping principles of permanent rain-fed cultivation
Contrarily to shifting systems, peasants who follow permanent cultivation systems tend to adapt their environment to the needs of agriculture - and not the other way around. This includes the construction of irrigation systems or dykes against soil erosion.
The main cropping principles are *crop rotations*, *mixed cropping* and *relay-planting* (the joint planting of crops and crop varieties that mature early with those that mature late in the season. This prolongs the time during which fresh food is available). Crop rotations in permanent cultivation become highly variable and formalized. Only with increasing intensification and commercialization are these principles abandoned in favor of mono-cropping and row cultivation.
There are three dominant ways of how crops are organized in space:

- According to the soils found in the field. Permanent cultivators cannot anymore choose the plot most suited for a desired crop. Instead, they have to choose the crop which is best adapted for the available plots.
- Second, in concentric belts around the homestead (due to rising efforts for manure transport, the more intensively fertilized plots lie near the homestead and the less fertilized ones at a greater distance).
- Third, according to micro-climate, such as topography, rainfalls or danger of flooding.

All of these types of organization may already be found in shifting systems, but only under permanent farming they become pronounced (this will help later for the classification of Mashare as a stage between semi-permanent and permanent cultivation).

Soil fertility management in permanent rain-fed cultivation

In permanent rain-fed agriculture, fertilization methods are as varied as crop rotations and normally, at least some methods are practiced. In general, they are better adapted to their specific environment if natural soil fertility was low and/or if the transition to permanency occurred long ago. In many cases, however, smallholders still rely on the main fertilization methods of shifting systems, none of which can be successfully applied in permanent cropping: fallowing is impossible due to a lack of land; and organic fertilizer is usually scarce, because permanent cropping is often accompanied by a decline in cattle numbers (which is caused by overgrazing on communal pastures - see paragraph on labour below). Therefore, fertilization in rain-fed permanent agriculture is often insufficient and the resulting soil mining may lead to a stagnation of yields at a low level in late stages of permanency.

The usual evolution of fertilization (in early stages of permanent rain-fed farming) begins with the application of household refuse and animal manure as field inputs. In more advanced fertilizer economies, this is complemented by planting green manure crops and composting. In situations of long-term land scarcity, use of night soil may be adopted, too.
Furthermore, permanent farming usually requires that smallholders start to import nutrients into their holding. This is either done by grazing the livestock herds outside the holding during day and keeping them in kraals overnight for collecting their manure. Nutrients may also be important as fuel materials and be applied as ash or part of compost on the fields. They may even be collected as green biomass which is directly incorporated into the soil. If draught animals are scarce, the labour-needs for this form of fertilization may become very high and result in the concentric belts of cropping described above.
In more advanced stages of land scarcity, a new challenge may arise for fertilization: a lack of fallow vegetation can cause fuel shortages, so that peasants are forced to burn manure and crop residues (which are then not anymore available for fertilization).

Labour and Seasonality of labour-demand in permanent rain-fed cultivation

Permanent rain-fed agriculture is characterized by efforts towards a better coordinated use of labour. This is usually achieved via the centralization of farm management and the merging of the individual subplots of the family members into one coherent field.

The reason for this centralization is that smallholders have to cope with an increased seasonality of labour-demand. This phenomenon is more strongly pronounced in permanent rain-fed farming than in any other peasant cultivation system. It manifests itself in a high degree of underemployment in the dry season and insufficient labour-availability at the beginning of the rainy season. At the same time, the rising permanency of cropping requires that a bigger amount of labour is invested in weeding (which results in a decrease in labour-productivity - Boserup 1965).

Labor-saving technologies (such as plough cultivation) would be of great help for farm management, at least in early stages of permanent cultivation. However, Ruthenberg (1971) found that it is *hoe* and not *plough cultivation* that over time comes to dominate permanent rain-fed farming (which is the optimal tool in shifting systems where tree stumps and termite mounds are obstacles to plough cultivation). The reason for this lies in the relatively small size of holdings as well as limited availability of grazing, which leaves little resources for animal husbandry.

This reveals a major bottleneck of permanent rain-fed agriculture: Households need to cope with high labour-demands for ploughing at the beginning of the rainy season. Draught animals present a means for coping with seasonality and allow for quicker land preparation than manual labour. However, lack of grazing opportunities and the inability to grow fodder on the limited household land lead to a decline in the average livestock herd size of most households over time. At the same time, this trend goes hand in hand with a growing concentration of livestock ownerships within a few wealthier and successful households. Therefore, total cattle densities in these community's areas remain constant and high. Only in early stages of permanency, where there is still grazing available in some distance to the households (or in areas where shifting and permanent systems still coexist) may the majority of households be able to feed and maintain livestock herds. Therefore, the role of cattle in permanent rain-fed farming changes from that in semi-permanent cultivation and later also within permanent farming; in early stages of permanency, cattle is kept for providing draught-animal-power and manure and less for the production of milk or meat. In later stages, the accumulation of large cattle herds becomes less important. On the one hand, this is caused by the declining availability of grazing and on the other hand by the fact that the acquisition of land becomes a new and alternative way to gain social status and security. This trend is facilitated by the rise of private land rights that is often coupled to the rising permanency of cropping.

Evolution pathways of permanent farming systems

Stable permanent rain-fed systems can be found either i) where fertilization is practiced to such an extent that the degradation process that began under semi-permanent cultivation is stopped or ii) on fertile soils that allow for ongoing cultivation without a strong decline in yields. Yet stable permanent rain-fed systems are rare. Where possible, permanent arable cultivation systems often develop into perennial systems or irrigated systems. Longer-lasting permanent cultivation systems are found most commonly in areas of high population density where irrigation farming cannot or has not yet been adopted. Here, a Malthusian impoverishment process may prevent intensification and cause a vicious cycle of soil degradation and poverty, which represents a variant of the so-called *poverty trap* (Barrett 2008; Voortman 2013; Hoff et al. 2013). This has also been designated as "*low-level equilibrium trap* (Ruthenberg 1971, 125)", which describes a situation where traditional means of adaptation to growing food needs and increasing land scarcity, i.e. intensification or a change of cropping patterns, increasingly fail to ensure that production growth rates remain above population growth rates. In this case, households reduce their area of cash-cropping in order to meet increasing subsistence demands and they increasingly replace high-quality but low-yielding crops such as maize and millet with high-yielding but low-quality crops such as manioc and sweet potatoes. The last stage of this process represents a situation of very small holdings that cultivate mainly root crops and that do not have sufficient land for cash crop cultivation. This can result in poor nourishment of households and widespread occurrence of diseases. A similar process affects the livestock economy, where lack of animal fodder has led to poorly fed cattle herds or the replacement of cattle with goats and sheep (see above). Peasants in these late stages of rain-fed permanent production therefore rely mainly on subsistence production. Their only escape from this low-level equilibrium trap, except for migration, is the adoption of yield-increasing innovations (Ruthenberg 1971). Ruthenberg (1971) thus claims that this stage does not only have a stronger need for technological innovation than any other agricultural stage, but also the highest likelihood of voluntary adoption of these new technologies. However, being caught in low-level equilibrium traps may make it impossible for households to develop and adopt improved agricultural practices on their own; in such a case, external assistance may be needed to achieve a transition towards an improved farming system.

The process of stagnation and involution was already hinted at in the chapter on macro-demographic theories on agricultural change. Geertz (1974) originally termed the expression *Agricultural Involution* to describe such a situation of failing Boserupian intensification (and the transition to a more intensified stage of smallholder agriculture and its related farming system); *involution* describes a situation where households do not adapt to rising population density by adopting (*evolving*) a new, improved system, but by *modifying* the existing system (involution thus describes adaptations *within* the system that do not alter the basic characteristics or foundations of the system). In situations where Agricultural Involution dominates over Boserupian intensification, smallholders persist in the basic agricultural practices that determine their current farming system but invest more and more effort, often labour-wise, to increase the output produced in this system. However, as there is to real transition to a new agrarian stage of higher productivity, farmers invest more and more labour to produce the same amount of food *per capita* if seen over the entire growing population. Geertz (1974) considered this therefore as an ultimately self-defeating process. In the light of the Boserup-Ruthenberg framework Agricultural Involution describes the progression of smallholders on a pathway of gradual resource degradation and impoverishment that in the end may result in the low-level equilibrium trap described above.

1.3.3 Categorization of Farming Systems

The farming system analysis for the three study sites (chapters 1.6.1 – 1.6.3) will use various means and terms for their categorization and characterization. These will be introduced in the following section.

The first question that arises when a farming system analysis is to be conducted is: how is it possible to classify a large group of different farms into typical categories or farming systems? This is an important point, as no individual farm is organized exactly like any other. Instead, they may differ in their asset endowment, their production goals and their production strategies (Ruthenberg 1971). However, for deriving broader recommendations for agricultural development, it is necessary to group them into homogeneous clusters of similar farm-management characteristics – and this is where the so-called Farming System concept comes into play. This concept is based on the idea that "*in the process of adapting cropping patterns and farming practices to the conditions of each location and the aims of the farmer, more or less distinct types of farm organization have developed* (Ruthenberg 1971, 2)" [15].

Ruthenberg (1971) describes six major smallholder cultivation systems which can be found in the tropics. These cultivation systems are, ordered by increasing intensity of land use, shifting cultivation systems, semi-permanent cultivation systems, systems with regulated ley farming, systems with permanent cultivation on rain-fed land, systems with arable irrigation farming and systems with perennial crops. He also presents and applies a variety of approaches for the characterization of farming systems in general, which will be presented in the following.
Roughly following Boserup' (1965), Ruthenberg (1971) distinguishes between four main *rotation types*. These are:

a) *Fallow systems*, often with fire-farming (= *long-term fallow of Boserup*)
b) *Ley Systems*, where grass (which is used for grazing) is planted or establishes itself on land that has carried crops for some years. (= *bush- and short-fallow of Boserup*)
c) *Field Systems*, where one arable crop follows the other *(= annual- & multi-cropping of Boserup)*
d) *Perennial crop systems*, from field crops (sugar-cane, sisal) to bush crops (tea, coffee) to tree crops (oil-palm, rubber) (= a*nnual- & multi-cropping of Boserup*)

As especially the fallow and ley systems are characterized by highly variable land use intensities, Ruthenberg (1971) applies a complementary criterion for their analysis: the *rotation intensity*. This criterion in denoted as R (it is therefore sometimes called R-value) and indicates the proportion of cultivated land versus total available land. R is defined as *the number of years of cultivation multiplied by 100 and divided by the length of the cycle of land utilization (i.e. fallow & cultivation years).* A value of 40 would therefore indicate that a farm cultivates 40% of its available land. Low R values are typical for extensive fallow systems such as shifting cultivation while higher R values indicate more a stationary character of farming. This value quantitative represents what Boserup (1965) regards as smallholders' main means of intensification and thus represents one of the central links between both frameworks (Tab. 1.2).

[15] NB: The focus of this study is on arable farming and less on animal husbandry. Therefore, the following analysis will focus on the *cultivation systems* and consider other aspects of the farming system (e.g. livestock keeping and crop-livestock integration) only in more detail if relevant for crop production.

Tab. 1.2: Typical ranges of the R-value (rotation intensity) for three farming systems.

Typical ranges of R	Cultivation system designated as:
30 > R > 0	Shifting Cultivation
70 > R > 30	Semi-permanent cultivation OR Stationary cultivation with fallowing
300+ > R > 70	Permanent farming *Values above 100 indicate multi-cropping*

Source: Author's design based on Ruthenberg (1971).

Other means of classification are i) the degree of commercialization (Tab. 1.3), ii) the water supply (rain-fed vs. irrigation), iii) the main cropping pattern (summarizing farms who have similar requirements on climate, soils, markets and inputs and yield similar gross returns; e.g. coffee-banana or rice-jute holdings) and iv) the implements used for cultivation.

Tab. 1.3: Four main categories of smallholder commercialization.

Category of farms	Commercialization level
Subsistence farms:	Cropping to cover household needs, only surpluses sold (sales below 25 % of gross returns)
Partly commercialized farms:	Systematic cultivation of cash-crops in addition to "for-household" production (sales still below 50 % of gross returns)
Semi-commercialized farms:	Similar to above, but so much cash-cropping that sales amount to 50 – 75 % of gross returns.
Highly-commercialized farms:	Less than 25 % of agricultural output consumed by the household.

Source: Author's design based on Ruthenberg (1971).

Due to the rising importance of livestock in more stationary agriculture, e.g. for draft animal power, the means of *grassland utilization* are also an important characteristic of farming systems. The slow grass yields in the arid or semi-arid tropics typically lead to three main solutions to this problem: i) nomadism, ii) semi-nomadism and iii) the development of ranching systems. To facilitate analysis, livestock farming can be classified according to the degree of stationarity of animals and animal owners (Tab. 1.4).

Tab. 1.4: Degree of stationarity of animal husbandry.

Total nomadism	owners no permanent residence, no regular cultivation, families move with the herds
Semi-nomadism	owners have permanent residences with supplementary cultivation and travel for long periods with herds to distant places
Transhumance	permanent residences; herds tended by herders and sent to distant grazing areas for long time periods
Partial nomadism	farmers live continuously in permanent settlements; herds stay in vicinity and at owners disposal
Stationary animal husbandry	animals remain on holding or village throughout the year

Source: Author's design based on Ruthenberg (1971)

1.4 Boserupian intensification and smallholder agriculture in contemporary Sub-Saharan Africa (SSA)

The preceding chapters introduced the theoretical background needed for analyzing peasant societies and their respective farming systems. In order to confirm the validity of the theoretical framework, the following chapter will use literature review to compare predictions of the theory with the actual development of Sub-Saharan Africa (SSA) over the last century, both in terms of peasant agriculture and on a wider, macro-economic level. The second goal of this chapter is to introduce contemporary trends or drivers of change that may affect future land use in Sub-Saharan Africa. Both aspects will then be used for making reasonable assumptions on the future of smallholder agriculture in this region. The chapter ends with an overview of policy recommendations for a pro-smallholder approach to agricultural development, which one the one hand indicates important constraints to contemporary smallholder agriculture and on the other hand lays the theoretical foundations for the interpretation of results in chapters 1.6.5 and 2.6.

1.4.1 Boserupian intensification in SSA – historical evidence

Over the past century, African decision-makers applied a variety of policy approaches to meet the food needs of the continents rising population. Their success at inducing agricultural intensification was, however, limited (see Nin-Pratt & McBride (2014) for a review of these approaches). Instead, most increases in food production were achieved by smallholders (as the dominant land users) via the spatial expansion of agricultural land, i.e. via converting natural land into farm land (Binswanger & Pingali 1988, Brink & Eva 2009). This was possible mainly due to the relative land abundance of Sub-Saharan Africa during the 20th century. Additionally, increases in agricultural productivity were also achieved via traditional methods of intensification. This usually took the form of rising cropping intensities and reduced fallow periods (Nin-Pratt & McBride 2014, Scherr & Hazell 1994). Another contribution came from the increased application of industrial inputs, albeit to a much more limited degree (Scherr & Hazell 1994). It consisted mainly of improved seeds and investments into land-improving measures, such as irrigation or drainage infrastructure (ibid.).

At a first glance, the simultaneous occurrence of agricultural expansion and intensification in SSA appears to contradict the conceptual framework presented before. This contradiction results from considering all of SSA at the same time and from regarding the continent as a homogeneous land unit. In fact, recent research has misinterpreted SSA as still being land abundant, which nowadays is true only at the continental scale (Jayne et al. 2014). Although a considerable proportion of the continent's lands are either un- or underutilized, these areas are concentrated in only eight countries[16]. At the same time, a considerable proportion of Africa's rural population is clustered in densely populated smallholder farming areas facing land shortages (Chamberlin et al. 2014).

[16] None of which include the three riparian countries Angola, Namibia, Botswana. They include countries such as: Ethiopia, Kenya, Malawi, Nigeria, Uganda, Rwanda (Headey & Jayne 2014). In fact, Angola is one of the countries with the highest remaining cropland availability in Sub-Saharan Africa (Chamberlin, Jayne & Headey 2014).

A look at the current population distribution helps to illustrate this fact: the most densely populated 1 % of Sub-Saharan Africa's rural land area contains 21 % of the rural population and 20 % of its areas still contain 82 % of the rural population (Jayne et al. 2014). This result persists even when correcting for the impact of the natural environment on the distribution of the rural population, i.e. when considering only those countries that receive more than 400 mm annual precipitation; even here, 74 % of the population resides in 20 % of the rural land.

The effects of these clustered populations may be easily illustrated by analyzing the changes in farm structure over the last decades of the 20th century. During this time, average holding size in high-density Africa shrunk from 2 ha in the 1970s to 1.2 ha in the 2000s, while remaining constant in low-density Africa (Headey & Jayne 2014). The declining land availability in high-density Africa was correlated to a shortening of fallow periods, a rise of land markets and changes in land allocation institutions – which is in line with Boserup's (1965) predictions (Jayne et al. 2014). Here, increasing population densities induced a conversion of natural and fallow land into cultivated farm land (expansion) as well as an intensification of food production on already converted land. This resulted in a simultaneous expansion of croplands and agricultural intensification in high-density Africa. A similar process was not observed in low-density Africa. Jayne et al. (2014) conclude that SSA has to be considered as being divided into a land abundant- and a land constrained rural Africa[17] - and for both regions, fundamentally different approaches are needed to increase agricultural output.

But what do these empirical findings mean for the accuracy of Boserup's (1965) theory?

When comparing the general agricultural development pathways of African as well as Asian countries, Headey & Jayne (2014) found that Boserup's theory receives very strong support from the data. On both continents, higher-density regions are cultivated more intensively, regardless of which time period is analyzed (Headey & Jayne 2014). However, while Asia experienced a highly successful Green Revolution with increasing rates of input application, mechanization and irrigation, high-density countries in Africa have intensified mainly via traditional technologies, such as increasing the cropping intensity via the reduction of fallow periods, the increasing use of cattle or oxen for draught-animal-power and a focus on the production of non-cereals (ibid.). They thus conclude that while the process of Boserupian intensification appears to dominate agricultural development trajectories over the long run, in the short-term they can also be affected by exogenous drivers (Headey & Jayne 2014). These include agro-ecological factors that shape the speed and form of intensification and that may for example direct the process in one case towards perennials and in another case towards cereals; it may also include occurrence of zoonotic diseases and disease vectors such as the *TseTse*-Fly that inhibit the spread of animal traction (Ruthenberg 1971, Headey & Jayne 2014). Apparently, these external trends have the power to slow down efforts towards Boserupian intensification and may therefore also play a role in inducing Agricultural Involution (Geertz 1974).

[17] Which include according to Headey & Jayne (2014) countries with rural population densities in excess of 100 people per square kilometer, i.e.: Rwanda, Burundi, Comoros, Malawi, Uganda, Ethiopia, DRC, Benin, Kenya, Gambia, Nigeria, Sierra Leone.

1.4.2 Other means of adaptation to population pressure

Apart from *Boserupian intensification*, peasant households are expected to respond to rising land constraints via three other main means of adaptation, i.e. via i) reduction of fertility rates, ii) livelihood diversification into the non-farm sector and iii) migration (see chapter 1.2.5). In reality, however, there is little evidence that these means have been applied successfully in SSA.

Although households under land constrained conditions desire to reduce family sizes by controlling fertility, actual *fertility rates* remain above desired rates (Headey & Jayne 2014). This indicates that most households do not seem to benefit from family planning policies and experience continuously high fertility (ibid.).

Off-farm livelihood diversification in SSA is limited, yet the few successful cases are in line with the theory of Haggblade et al. (2007) of a U-shaped relationship between farm size and the extent of household involvement in the off-farm sector (Headey & Jayne 2014). On the one hand, smaller holdings and landless labourers seem to be *pushed* into diversification by adverse conditions such as declining agricultural productivity and household income, related to soil degradation and gradual household impoverishment. The result is a diversification into low-return, labour-intensive non-farm activities such as handicrafts or foraging (Jayne et al. 2014). On the other hand, larger holdings appear to be able to reap the benefits of diversification and use it to increase and diversify their income sources (Headey & Jayne 2014). Contrary to the smaller holdings, they are thus *pulled* into the off-farm sector. Although it remains unclear which factors (*push* or *pull*) do currently dominate which region of Sub-Saharan Africa, it appears that push factors are certainly important (Jayne et al. 2014).

Migration seems to face similar constraints as non-farm diversification. On the one hand, Headey & Jayne (2014) could not empirically link rural population density to urbanization. They explain this phenomenon with the focus of African cities on low-skill low-return services, the so-called "consumption cities" that cannot offer a wide variety of jobs in various industries, as for example the so-called "production cities" in Asia were able to do. Another explanation for the low employment chances in African cities is push-migration of rural un-skilled labour to urban centers, which is caused by declining farm sizes and limited success in increasing agricultural productivity and which results in a decline in urban wages (Jayne et al. 2014). Theoretically, low wages could also attract investments in manufacturing and thus provide new employment opportunities, yet that does not yet seem to be the case in Africa (ibid.). On the other hand, there is also limited evidence of migration from rural high-density areas towards rural low-density areas (Chamberlin et al. 2014). This may partly be caused by the high risks and transaction costs that African households face when moving to other regions with a different national or ethnic background (ibid.), but also indicate a land- or labour market failure (Jayne et al. 2014).

The findings presented here indicate that currently, smallholders in SSA rely mainly on unsustainable forms of agricultural intensification as a means of adaptation to rising land constraints. In high-density regions, this is likely to result in ongoing soil degradation and a growing danger of rural households' impoverishment.

1.4.3 Soil degradation and Agricultural Involution

In the past, a relative abundance of land and other natural resources allowed for the regeneration of (damaged) renewable resources in SSA. Nowadays, however, population density has often reached levels where this regeneration became impossible and serious resource degradation occurs (Scherr & Hazell 1994).

Under these conditions, traditional intensification needs to be regarded as an unsustainable intensification pathway (at least in high-density Africa; Headey & Jayne 2014). This assumption seems to be confirmed by a broad literature that relates population growth to nutrient mining loss of soil organic matter in Sub-Saharan African (e.g. Drechsel et al 2001, Stoorvogel et al. 1993, Marenya & Barret 2009). It has been suggested that these degradation processes initiated vicious cycles of soil degradation and decreasing returns on the use of fertilizers and improved seeds (Marenya & Barret 2009), thus lowering the likelihood of their adoption even further. Together with the higher cost of fertilizer relative to other regions of the world, these vicious cycles may explain the low responsiveness of fertilizer use to land constraints in SSA (which has been found by Headey & Jayne 2014).

A trend that is increasingly becoming a problem for agriculture in SSA is that nowadays, more and more ecologically fragile *marginal land* is being put into production to sustain rising rural populations (Scherr & Hazell 1994, Barbier 2011, Pichon 1997). Marginal lands have been defined as "*lands unsuitable for continuous tillage or lands where there were major constraints to economic use of industrial inputs* (Scherr & Hazell 1994, 2)". In the past, the higher land- & natural resource availability mentioned above allowed for land expansion to occur on more fertile soils where utilized resources were better able to regenerate. Fragile or marginal lands therefore rarely needed to be cultivated and if they were, than only extensively. Nowadays, this has changed. As the traditional African intensification pathway is characterized by rising cropping intensity, i.e. also by more and more continuous tillage, it may be expected that the speed of soil mining in smallholder agriculture will rather increase than decrease in future.

At the same time, even in the more fertile areas of Africa, population growth and poverty have reached levels where serious resource degradation is occurring (Scherr & Hazell 1994). After decades of intensified production, many of the high potential areas do now suffer under various forms of environmental stress. Nowadays, in some high-density African countries, population densities appear to have surpassed the maximum carrying capacity of the respective agro-ecological systems (Holden & Otsuka 2014). Here, a Malthusian threshold may have been reached that can possibly result in food scarcity and increasing danger of famines.

To stop these trends, it appears of utmost importance to induce a sustainable intensification of smallholder production in rural areas of SSA (see Jayne et al. 2014b). However, it has been shown that, although Boserup's (1965) theory seems to hold over the long run, it cannot be expected that population growth automatically triggers Boserupian intensification. Instead, Agricultural Involution may be the more likely development in SSA, at least in in high-density countries (Headey & Jayne 2014). The following chapter will summarize important recommendations on how a sustainable intensification of smallholder farming may be induced in SSA. To do so, it starts with an overview of emerging trends and land users in rural SSA.

1.4.4 The future role of smallholders in SSA

1.4.4.1 The rise of new land use actors

This overview begins with a look at the new land users and institutions that are currently entering the stage of Sub-Saharan Africa. This is important, because competition for fertile land and water will not only take place within peasant societies, but also among peasant societies and other groups of land users. Of the latter, particularly three groups are of rising importance in Sub-Saharan Africa: foreign investors, national governments and the so-called medium-scale farmers (Jayne et al. 2014a).

The large-scale acquisition of land by foreign investors may affect a big proportion of Africa's remaining arable land. But the most novel and revolutionary trend in African rural land use is the rapid rise of medium-scale commercial holdings, which in countries such as Ghana, Kenya and Zambia already control more land that both domestic and foreign large-scale holdings combined (Jayne et al. 2014a). In other countries, they already control more arable land than do smallholders (Sitko & Jayne 2014), leading to an increase of average farm sizes in official statistics and thus masking the ongoing decrease of smallholder farm-size (Jayne et al. 2014). Currently, these medium-scale farmers are predominantly African men, whose primary occupation lies in the non-farm sector and especially the government (Sitko & Jayne 2014) and that are often relatively well educated urbanites. A smaller group is comprised of relatively privileged rural-born men who could build on a relatively large initial land endowment of above five hectare. These medium-scale farmers provide a challenge for agricultural development insofar as they tend to regard agricultural land rather as a relatively secure investment opportunity for their financial capital, and not as a resource to be put into maximal production; thus, in many cases members of this group cultivate only a fraction of the land they acquired and thus contribute to the problem of land inequality and the underutilization of the scarce but potentially available land resource. Due to the high initial land endowment that seems to be a prerequisite for developing a holding to a medium-sized commercial farm, this trend furthermore provides little chance for assisting the average smallholder. In fact, Mellor (2014) predicts that medium-scale commercial farmers will come to dominate the growth of agricultural productivity in Africa and at the same their rise will facilitate the development of a class of landless or nearly landless rural laborers. First hints at this development can be observed in the land-abundant study site Cusseque, Angola (chapter 1.6.1). They imply that large-scale land use changes may occur here sooner and swifter than what may be expected when focusing only on local population density and land users.

1.4.4.2 Does smallholder farming in SSA have a future?

Even when disregarding the danger of falling into a poverty trap, the ongoing economic development of Africa and the rise of new actors of land use may lead to wonder whether smallholder agriculture will remain a dominant livelihood source over the long run. This study has argued along the lines of a growing body of literature (e.g. Barrett 2007, Holden & Otsuka 2014, Mellor 2014, Sitko & Jayne 2014), which is convinced that smallholder agriculture will persist and that it, in fact, presents the best chance of securing the food needs of Africa's rising population.

A first argument for this assumption lies in the specific characteristics of urbanization in SSA. As has been shown before, African urbanization does currently not succeed in boosting formal employment and thus cannot offer an alternative lifestyle for a larger part of the rural population (Jayne et al. 2014). Instead, there are nowadays indications of slum-based poverty traps in urban Africa (UN 2010). The limited success of urbanization can also be deducted from the fact that urban households still regularly depend on farming as part of their livelihood strategy and seasonal migration from urban to rural areas during the growing season is a widespread phenomenon (Jayne et al. 2014). Therefore, it is unlikely that the urbanization of Africa will result in a significantly reduced importance of farming as a livelihood source (ibid.).

A second argument for the ongoing importance of smallholder agriculture is based on SSA's changed potential for future economic development. In past centuries, Africa underwent a resource-based development that was strongly associated with the expansion of cultivated land (Barbier 2011). Today, it is unlikely that developing countries follow the same pathway (Barbier 2014). In fact, the rural poor are not anymore the main driver of land conversion in developing countries. Instead, it are rather commercial economic activities (which are encouraged by governmental policies and which are carried out by plantation owners, large-scale farmers, ranchers or mining operators) that drive this conversion (FAO 2006, DeFries et al. 2010). Both features lead to what Barbier (2014) describes as the *dualistic frontier economy* of the marginal lands. In this *dualistic* economy, a traditional smallholder sector continues to convert and use land for subsistence production, while a fully developed commercial sector converts and exploits available natural resources for producing various traded outputs (such as timber from plantations or cereals on agro-industrial enterprises). Although both sectors follow dramatically different economic activities and may even be spatially separated, they are linked by labour. This allows the commercial sector to rely upon a pool of unskilled surplus labour for its commercial frontier activities while peasants are able to derive a certain cash income from this additional livelihood option. The outcome of this dualistic process of frontier expansion is the coexistence of a highly developed and profitable commercial sector with a more traditional, relatively poor peasant sector which survives on marginal lands. The rise of a (subsidized) commercial sector within a frontier region may occur rapidly and result in an impressive economic boom, with growth in traded outputs and improved rural well-being (Barbier 2014). However, this boom is typically short-lived and as soon as the frontier resources have been fully exploited or converted, a certain degree of economic retrenchment will invariably occur and rural standards of living may drop to levels similar to levels of the pre-frontier economy (ibid.). Due to these boom-and-bust cycles, it is unlikely that a sustained economic developed can nowadays be achieved by a natural resource based economic development. Smallholders may benefit from the short-term economic boom, but in the end they may have to revert to subsistence agriculture for their survival.

These two findings hint at the persistence of peasant agriculture Africa as a main livelihood source of rural (and even urban) households in many regions of Sub-Saharan. In fact, Holden & Otsuka (2014) are convinced that smallholder farming will remain the main livelihood activity for a majority or rural households in Sub-Saharan Africa under a wide range of population densities. At the same time, the absolute number of agriculturally dependent

people is expected to grow in many regions of Sub-Saharan Africa for at least four decades (Headey & Jayne 2014). This is acerbated by the fact that the most rapid population growth is taking place in those countries that are already characterized by high population densities; scarcity of farmland is becoming an increasingly critical issue in these areas if other livelihood sources are limited, such as off-farm employment opportunities, are limited (Holden & Otsuka 2014). Furthermore, as Africa is only at the beginning of its demographic transition, the share of the young population will be high for the next several decades (Jayne et al. 2014b). The enduring lack of off-farm labour opportunities in urban centers will necessitate farming to provide employment for at least a third of Sub-Saharan Africa’s young population (Losch 2012).
It has been shown before that degradation or Agricultural Involution may be more likely to occur in contemporary smallholder communities in SSA than endogenous intensification. It remains unclear which conditions may trigger a change away from farm-based livelihoods. However, the findings presented here illustrate clearly that the fate of African smallholders is and will be tightly connected to the development of the continent as a whole - it is therefore crucial to conduct research towards the development of sustainable, intensified smallholder farming systems.

1.4.4.3 A smallholder-led development strategy for Sub-Saharan Africa

Recent research stresses that a smallholder-led approach to agricultural development may provide the best available means for a sustainable increase in food production (Holden & Otsuka 2014, Mellor 2014, Sitko & Jayne 2014). The reason for this lies in the widespread occurrence of smallholder agriculture as well as in the inverse relationship between size of holdings and land productivity (which was observed in Sub-Saharan Africa – in order to meet their food needs, peasants reacted to increasing land fragmentation and decreasing farm sizes via increasing productivity; Holden & Otsuka 2014). The peasant mode of farming seems i) to be able to effectively mitigate negative effects of population growth on farm structure and ii) to allow for intensification more efficiently than other mode of production. Sitko & Jayne (2014) therefore call for sustained investments in a smallholder-led development; they explicitly caution against focusing development efforts on the emergent group of medium-scale commercial farmers, which use (or rather under-utilize) a disproportional part of arable land, yet have only a limited employment effect on traditional smallholders. They doubt that aiding this group will contribute to a wide-spread improvement of rural livelihoods and an increase in agricultural productivity (ibid.).
Mellor (2014) expresses concerns about a development strategy which focuses on large-scale farmers. In the past, this may have achieved trickle-down effects which could have benefitted the rural poor, e.g. by reducing food prices due to increased productivity. Mellor (2014) argues that today, globalization is resulting in an ongoing transition from closed economies to open economies. In this situation, a rise in the agricultural productivity of a specific country will not anymore cause an automatic decrease in food prices for the rural poor and potential trickle-down effects are greatly reduced.

SSA’s scope for a successful and sustainable smallholder-led intensification is considerably lower than it was in Asia and increasing land constraints may easily cause Agricultural

Involution. When considering the lack of alternative off-farm income source, this presents a major obstacle for both poverty reduction and intensification (Headey & Jayne 2014). In fact, as Agricultural Involution appears as likely as Boserupian intensification, policies may be needed that nudge peasants towards sustainable intensification (ibid.). To achieve such a peasant-led development, a multi-sectoral policy approach is needed as well as more effective public support for smallholder agriculture (Headey & Jayne 2014; Jayne et al. 2014a). These approaches need to be aware that impoverishment processes and factors such as land scarcity & degradation, market access, the gap between potential and realized agricultural yields, seasonal agricultural labour demand and the availability as well as the effectiveness of fertilizer use (to name just a few) are highly interconnected and cannot be regarded separately; instead, they need to be considered in a more holistic way (see Jayne et al. 2014). It may be of highest importance to consider adaptation efforts to rising land constraints as part of every future agricultural development policy for Africa (Headey & Jayne 2014).

General recommendations for increasing the likelihood of a successful smallholder-based approach often include infrastructure investments and market development (e.g. Holden & Otsuka 2014), or increased access to water as well as investments in all-weather roads and rural electrification as well as the establishment of public research institutions (e.g. Mellor 2014). However, policies also need to take into consideration whether the respective peasant farming systems operate in *land constrained* or *land abundant* conditions, as this will dramatically alter intervention-avenues. For instance, given the same (low) market access, smallholders operating in a land-scarce environment are usually more likely to adopt labour-intensive practices than those operating in land-abundant conditions (where other, less labour intensive practices may ensure basic food needs). Another example relates to the resource endowment of smallholder households: poor rural households rely mainly on two major assets for their livelihoods, i.e. *land* and *family labour* (Jayne et al. 2014a). With decreasing land availability, labour becomes increasingly important to farm management. Thus, smallholders become more likely to undertake efforts to increase labour productivity. The success of a policy intervention towards labour-saving technologies may be more likely in land-scarce than land-abundant environments.

In land constrained conditions, especially where rural households have few livelihood alternatives to farming, a land concentration among domestic or foreign investors cannot be regarded as a pro-poor development policy. Under conditions of land abundancy, it may be argued that investments in smaller-scale commercial farms may have a strong positive effect on poverty reduction (Mellor 2014). In such an instance, *improving the road network* or facilitating the adoption of *agricultural technologies which offer increased returns to underutilized land* may in the short-term benefit smallholders more than intensification (ibid.). Furthermore, efforts towards sustainable intensification (i.e. raising land-productivity), are more likely to fail in these land-abundant areas.

1.4.5 Summary: theory and reality of smallholder farming in SSA

The previous chapters provided evidence that smallholders, given the right frame conditions, have the inherent potential to on their own develop and adopt sustainably intensified farming practices. This is the process known as *Boserupian*, or *endogenous intensification*.

It has also been shown that the speed and the direction of these adaptation efforts vary and that they may strongly depend on various external factors, such as e.g. smallholders' degree of market access, the speed of degradation process or government intervention in the form of disaster relief.

Especially nowadays, these external factors may have such an impact or be the cause of such quick dynamics that smallholders are struggling to adopt to these changes in time. This may lead to agrarian stagnation or *Agricultural Involution* and set off *vicious cycles of resource degradation and household impoverishment*. In these cases, external intervention may be needed to *induce sustainable intensification* of smallholder agriculture.

The preceding review also hinted at the central important that rising land constraints and an adequate management of soil fertility and households' family labour pool have for agricultural change in Sub-Saharan Africa. These issues will be considered in detail in the site-specific analyses of chapters 1.6.1 – 1.6.3.

However, before the study sites are analyzed in the light of the theoretical framework and the wider socioeconomic trends of Sub-Saharan Africa, the next chapter will inform on empirical data gathering in the research area and subsequent data computation.

1.5 Empirical data gathering and analysis

1.5.1 Overview

This study was accomplished within the wider TFO (The Future Okavango) project. This interdisciplinary research project was dedicated to developing recommendations for sustainable land and resource management in the Okavango River Basin (ORB), which is shared by the countries Angola, Botswana and Namibia. The project consisted of over 130 scientists, stemming from natural sciences, social sciences and economics. It included universities of the three riparian countries as well as from Germany. In order to synthesize results, empirical field research was focused on three study sites, i.e. rural communities within the Okavango basin which were chosen either due to their site specific characteristics (e.g. Seronga in Botswana due to an emerging human-wildlife-conflict) or because they were assumed to be representative of their wider region (see chapter K). These are *Cusseque* in the up-river catchment in Angola, *Mashare* in the mid-river catchment in Namibia and *Seronga* at the Okavango inland delta in Botswana.

Apart from the expert interviews, all empirical research was carried out within these three village communities. From here on, these three communities will be called *study sites*, while the term *research area* refers to the wider Okavango River Basin.

While the general research area was described in chapters F – J, the individual study sites will be described in more detail in the introductory paragraphs of the following chapters (1.6.1-1.6.3). These introductions present the results of a literature review conducted on the study sites as well as results of a livelihood analysis. However, as literature on the study sites was scarce, the site-specific analyses rely largely on empirical data. The following chapter will give a detailed description of the empirical data gathering conducted in the three study sites and elaborate on the computation, analysis and limitations of these data.

This first part of the dissertation is a farming system analysis, which aims at:

i) the evaluation and comparison of the dominant smallholder farming systems in the study sites

as well as at the identification of:

ii) major constraints to farming, and
iii) likely future development trajectories for these farming systems.

To achieve these goals, the following data (quantitative and qualitative) was gathered:

1) information on smallholders’ farming practices and field inputs, with special focus on soil fertility management and the labour economy, which allows for both a classification of farming systems as well as for the analysis of farmers’ perceptions in light of the theoretical framework.
2) agricultural output generated under each smallholder farming system
3) smallholder perceptions on constraints to farming as well as important dynamics and developments affecting rural livelihoods.

The Boserup-Ruthenberg framework (presented in the previous chapters) was used to interpret the empirically gathered data. To be able to successfully apply the theoretical framework, special attention was given to the following indicators: 1) the R-value or rotation intensity, 2) access to productive assets such as draught animal power as well as 3) smallholders' approach to soil fertility management and (family-) labor use.

Each of the methods mentioned below was carried out three times, once for each study site. To increase the validity and reliability of the research, quantitative and qualitative assessments were combined in a mixed-methods approach. This allowed for combining the strengths of both approaches, i.e. the ability of quantitative data to allow for standardized comparisons based on statistical analysis with the ability of qualitative data for an in-depth, explorative analysis of relevant topics (see Walliman 2005, Maher et al. 2015).

Data gathering can be roughly divided into two steps (detailed information given in Tab. 1.5):
In step 1, various qualitative semi-structured farmer and expert interviews were conducted at each study site to create a general understanding of rural livelihoods and conditions of smallholder farming in the study sites. Additionally, quantitative household surveys were conducted in each study site. They aimed to generate information on household composition, asset ownership, productive activities and annual cash income/expenses.
The information created in this first step was used as the basis for designing the second step of empirical data gathering, which consisted of focus group interviews with farmers and a yield assessment of dominant farming practices in each study sites. The focus groups had two main purposes: on the one hand, they were used to validate the results of the semi-structured interviews and the insights generated by the analysis of the household survey. On the other hand, they aimed at generating quantitative data on the mean annual labour needs of a typical household as well as on the amount of field inputs required by the various dominant farming practices (inputs into farming and household-resource availability). The output of these dominant farming practices was assessed via the mentioned yield assessment. It has to be noted that farm-holdings such as the agro-industrial irrigation project in Mashare, Namibia, were excluded from this analysis, because data gathering and analysis focused solely on smallholders in the three study sites.

Tab. 1.5: Overview of applied data assessment methods, generated data as well as sample size and time of data assessment.

Data assessment method	Goal / Data generated	Sample Size				Date of data gathering
		Namibia	Botswana	Angola	CA	
Semi-structured farmer interviews	General understanding of smallholder farming in the research area - focus on: *farm management / constraints to production / dynamics & challenges / labour economy / soil fertility management*	15	7	8	1	2011/2012 (Namibia & Botswana) and 2013 (Angola)
Semi-structured expert interviews	General understanding of issues of importance to smallholder farming. Experts included: *anthropologist interviewed on impact of witchcraft on farmers' decision making / Agronomist interviewed on Conservation Agriculture in Namibia / Extension workers interviewed on smallholder farming / Members of land boards interviewed on land allocation / Village headmen interviewed on history, land allocation and challenges to farming / Managers of agro-industrial projects interviewed on their projects interaction with smallholders / scientists from a community based rangeland management programm in Namibia interviewed on traditional and improved cattle management in rural communities / Charcoal-makers in Angola.*	10	5	4	1	2011/2012 (Namibia & Botswana) and 2013 (Angola)
Socio-economic household survey	Generate data for livelihood analysis & for creating clusters of "typical farm-households"	291 (56% of all households)	326 (35% of all households)	60 (= 63% of total population)	n/a	2011 (Namibia & Botswana) and 2012/13 (Angola)
Focus Group interviews	1) Validate results from semi-structured interviews. 2) Interview members from "typical farm-household cluster" to generate qualitative and quantitative data; specifically: seasonal calendars of household activities and identify mean labour needs for non-crop household activities & mean labour needs for all agricultural tasks carried out on a 500m² field as well as amount of other inputs needed for this field.	4 focus groups with 6-8 participants respectively	3 focus groups with 6-8 participants respectively	2 focus groups with 6-9 participants respectively	1 focus group with 6 participants	2012 (Namibia & Botswana) and 2013 (Angola)
Yield assessment	Identify mean smallholder yields for non-input / manure input / NPK-fertilizer input farming	20	27	30	0	2013
Exchange with expert on CA	Gather data that complement yield assessment on: yield level of CA plots & of traditional (= control) plots	24	n/a	n/a	8	2012/2013

Source: Author's design.

1.5.2 Household surveys

Three socioeconomic household surveys (one for each study site) generated the bulk of the quantitative data used in this study. The surveys were a joint project of TFO's anthropologists, agricultural economists and institutional economists and aimed at generating a joint household-data base. The questions covered a range of topics, namely:

- A household census
- Asset ownership and access to infrastructure
- Crop production
- Livestock production
- Natural resource use
- Annual cash expenditures and income sources, including remittances and food aid

Each of the three disciplinary teams mentioned above conducted the survey in one of the three study sites, following similar procedures for the training of the interviewers and practical fieldwork. In October – December 2011, the surveys were carried out parallel in both the Namibian study site *Mashare* and the Botswanan study site *Seronga*. In Angola, the survey was carried out in 2012 in a settlement that lies closer to the urban market of Chitembo than Cusseque (20 km vs. 40 km) - it is therefore characterized by a higher population density and better market access. Thus, this study conducted its own, additional household survey in *Cusseque*. As this survey had to be carried out parallel to other scheduled field work, it was constrained in time and some of the topics mentioned above had to be omitted. This includes 'cash expenditures/income' and 'livestock production'. The choice to ignore these topics was based on literature review and expert knowledge, which had revealed that livestock ownership was of much lesser importance than in the other core sites and that basically no farm-household in the study site was engaged in formal wage labour. These strong assumptions were later confirmed both during the farmer interviews and the focus group discussions.

After obtaining a list of all households living in each of the study sites, a random sample of 300 households (60 in Cusseque) was chosen. Due to missing data, only 291 households could be included in the analysis of Mashare, accounting for 56% of all households. The sample size in Seronga amounted to 326 households, which represents 35% of all households. In Cusseque, 63% of the study site's population was covered (a reliable household lists was not available for this study site, only a count of the total population which amounts to 788 individuals).

In all study sites, a team of interviewers capable of the main local idiom was trained for a few days; the following pre-testing lasted one day. The surveys were computer based and carried out with the household head or its' spouse. During the main data gathering period, the data was checked for consistency and logical errors at the end of each day. This allowed for a constant feedback between researchers and interviewers and the early elimination of many error sources.

1.5.3 Cluster analysis

Literature review and semi-structured interviews revealed that in Mashare and Seronga, access to oxen was a main determinant of agricultural productivity and household wealth. Cusseque, on the other hand, appeared relatively homogeneous in terms of farming practices and productivity. The farming analysis and following field research was therefore based on the assumption that smallholders in Cusseque can be organized as a relatively homogeneous group, while those of Mashare and Seronga need to be separated into a group of wealthier ox-owners and poorer non-ox-owners.

For Mashare and Seronga, the household data base was re-organized by conducting a two-step cluster analysis in SPSS. It was built on the categorical variable "*Ox-ownership*" and the continuous variables "*Gross monetary value of livestock, agricultural and natural resource harvest"* and "*Gross annual disposable household income*" (in Seronga the additionally variable "*ownership of donkeys*" was used, as donkeys are here sometimes used as drought animals as well). To achieve the desired number of two clusters, the maximum number of cluster was restricted to two. Thus, the cluster analysis did not represent a tool for statistical data analysis, yet rather a tool for ordering the data base. The clusters identified here formed the basis for the later focus group interviews and the bio-economic modelling exercise in part two of this study. The descriptive statistics of the respective clusters will be presented in the introductions to the site-specific analyses.

1.5.4 Semi-structured *farmer* and *expert* interviews

The next step in empirical data gathering consisted of semi-structured farmer and expert interviews. These interviews aimed at using an explorative approach for getting a first overview of smallholder farming in the research area. Special attention was given to issues of labour use and soil fertility management, the role of the livestock economy for crop production and livelihoods, means of risk management and expected future trends & challenges for rural livelihoods.

For the *farmer* interviews, three pre-tests and 30 semi-structured interviews were carried out, 15 in *Mashare*, Namibia, 7 in *Seronga*, Botswana and 8 in *Cusseque*, Angola (see tab 1.5). The choice of farmers to be interviewed was based on the clusters created from the household survey, yet later extended to also include knowledgeable farmers (which were identified using snowball sampling). An interview-guide with open-ended questions was used to aid in the farmer interviews. As the interviews were semi-structured, this interview-guide served rather as a mental checklist for the interviewer. In order to allow for a natural flow of the conversation, the questions were not always asked in a pre-scribed pattern but their order was adapted to the specific interview situation and the direction the conversation was taking. The interviews were conducted with the help of local assistants who were trained in basic interviewing techniques and who also served as translators. The interviews were audio-recorded and the main information noted directly in the field. A short interview summary was compiled after the interviews, usually at the end of the working day. The interviews were carried out between 2011 and 2013 (see Tab. 1.5), either parallel to the quantitative household survey (= Mashare, Namibia) or directly prior to the focus groups (= Seronga, Botswana and Cusseque, Angola). The time available for the interviews was constrained and general interviewing was stopped as soon as two to three respondents began to report similar

information as previous respondents (instead of new insights). Ultimately, this was the case for all topics with the only exception of soil fertility management in Seronga and especially Mashare. Here, farmers combined various means of fertility management to create individual fertility management strategies. The interviews also revealed that a difference in farm management existed between farm-households that owned oxen and could this animal traction for field preparation versus those farm-households that had to regularly hire oxen (which was a justification for the cluster exercise described before).
For the *expert* interviews, 20 interviews were carried out between 2011 and 2013, 11 of which concerned the study site *Mashare*, 5 *Seronga* and 4 *Cusseque*. Again, the expert interviews were semi-structured and used an open-ended interview-guide. The interviews were audio-recorded and summarized in short reports. In those cases where respondents were not able to answer in English, a local assistant aided in translation. The goal of the interviews was to gather, in an exploratory way, detailed qualitative information on issues related to smallholder farming. This included:

1) An anthropologist who was interviewed on impacts of witchcraft and envy on smallholders decision-making in the mid- and lower-catchment as well as on whether management practices related to conservation agriculture (i.e. fencing, collecting biomass and manure as field inputs or mulch) had negative cultural connotations that might inhibit their adoption by farmers.
2) An agronomist supervising the conservation agriculture field trials in Mashare.
3) A scientist from a community-based-rangeland-management project was interviewed on traditional and improved grazing management and their potential impact upon crop production and state of the soils of communal rangelands.
4) Local traditional authorities on historical developments within the rural communities of the study sites as well as on land allocation and current trends and challenges that affect rural livelihoods.
5) Local extension workers and their view on smallholder farming in the study sites.
6) Members of the rural communities who were considered as knowledgeable by their peers (i.e. former traditional authorities and priests) and their view on rural livelihoods and smallholder farming.
7) Members of statal institutions and their view on important issues in the study sites. This especially refers to Seronga, Botswana, where the central government has stronger influence on smallholders than in Mashare and Cusseque with their influential traditional authorities. It specifically includes the land board, departments of wildlife and department of agriculture in Seronga.

The interviews complemented the smallholders’ view on rural livelihoods and farm management with expert knowledge information on the respective socio-ecological systems and the relationships between the system components (for example: on how open grazing on communal rangelands and the state of the rangeland-vegetation affect each other). Together, both types of interviews allowed for understanding the complex relationships between various productive activities (arable agriculture, animal husbandry and natural resource use) and the natural system. This knowledge facilitated the analysis of the data generated in the second step of the empirical data gathering, i.e. the household survey presented above, and lay the foundation for the preparation of the subsequent focus group interviews.

1.5.5 Focus group interviews

Focus group interviews represent the third method of empirical data gathering of this study. They were carried out within each study site and had two main goals: First, to validate the information obtained in semi-structured farmer interviews and second, to gather both qualitative and quantitative data on mean labour-use within farm-households and on inputs into smallholder production.

The idea behind complementing the qualitative semi-structured interviews and the quantitative household survey with focus groups interviews is *data triangulation* (Walliman 2005, Maher et al. 2015). Each of the methods described has its own strengths and limitations, yet by combining them and cross-checking their results, more reliable information may be gained. Following Wolff et al. (1993), this study uses focus groups in data triangulation to:

i) illustrate and confirm conclusions from survey analysis, and to
ii) determine new explanatory categories by examining a topic from different dimensions, thus arriving at a better understanding than would be possible using either of the triangulated approaches alone.

To increase the degree of triangulation success, all three methods were designed concurrently and implemented to provide asymmetrical but independent observations of the study sites (see Wolff et al. 1993). This strengthens a researcher's ability to draw conclusions as well as the confidence in the conclusions themselves (ibid., 133). Furthermore, the choice of smallholders included in both the focus group- and semi-structured interviews was based on the household data base created via the quantitative survey.

In both Mashare and Seronga, separate focus groups were conducted with smallholders that were purposively selected from both the poorer, non-ox-owning cluster and the wealthier, ox-owning cluster. In Cusseque, the survey sample was not grouped into two clusters but regarded as one set or cluster of households (which follow comparable farming practices and that rely on a comparable resource base). For each cluster, two focus groups were planned: one concerning traditional smallholder agriculture and agricultural labour needs and a second one dealing with non-agricultural household tasks and livelihood activities (gathering data on mean annual labour-needs for household chores, natural resource use and animal husbandry). Both focus groups were supposed to be conducted with the same participants. In Mashare, an additional focus group focused on conservation agriculture (CA) and in Seronga, a complementary focus group focused on animal husbandry. In the end, a total of ten focus groups was conducted, five in Mashare (two on arable agriculture, two on non-agricultural tasks, one on CA), three in Seronga (two on arable agriculture, one on animal husbandry) and two in Cusseque (one on arable agriculture and one on non-agricultural household activities).

However, in Mashare, the focus group dealing with non-agricultural household activities of the wealthier cluster needed to be aborted, because participants lacked enthusiasm to lead a lively discussion and the validity of the answers began to appear questionable. As there was no time to conduct the focus group a second time, labour-data on mean non-agricultural household activities in Mashare are based solely on the information provided by the poorer cluster. This had implications for Seronga as well. Here, another researcher from the TFO project (Eigner 2012) had already collected mean annual labour-data on household activities. As the non-agricultural labour data in Mashare were used for both clusters of households, the same approach was chosen for Seronga. To increase data fit, Eigner's (2012) assumed mean household size (and resulting labour needs) were adapted to each cluster's mean household size[18]. In Seronga, the time saved by skipping these two focus groups was re-invested into a focus group on animal husbandry and additional semi-structured interviews.

For the choice of focus group participants, random stratified sampling was chosen. This means that the site- and cluster-specific samples were differentiated by gender of the household head, its education (not higher than successful completion of primary school vs. attending secondary school or higher) and its age (using the age median of the respective study site to divide the samples into an older and younger group). This allowed for creating a total of 8 sub-samples for each site and cluster, from each of which one household head was randomly selected to participate in both focus group (i.e. the agricultural and the non-agricultural). In order to ensure that each focus group participant could freely express his opinion, it was ensured that no person of official acknowledged authority, e.g. priests or traditional authorities, were included in the interviews. However, potential non-official power relationships could not be controlled for in the choice of participants.

All focus groups were carried out using a uniform set of guidelines, as well as a local moderator. This moderator was an employed member of the TFO project who was originating from the study sites' wider area and who understood the local cultural context. This study's researcher was responsible for introducing the project and specific tasks to the participants and for documenting the process, while the moderator was responsible for ensuring a smooth discussion and a general understanding of the tasks required from the participants.
In general, a relatively high level of control was maintained over the discussion and new tasks and topics were regularly introduced by both the moderator and the researcher. They kept the conversation focused, but also provided check-up questions or interjected in the discussion to make sure the participants elaborated on all topics of interest and did not forget any important topic in the course of the discussion. Special attention was paid to ensure that all participants could clearly voice their opinion and that no idea or objection was discarded by more dominant participants. To ensure a smooth flow of the discussion, these interventions happened rarely and only if a participant was clearly ignored in the discussion.

A central task of the focus groups was to provide quantitative data on mean annual labour-needs per household (for non-cropping activities) or per area (for crop production). This was achieved by creating two main outputs per focus group, namely: i) a seasonal calendar of all tasks carried out within a typical households (as defined jointly by the focus group participants) throughout the year, based on a brainstorming exercise and, for non-cropping activities, on ii) a table indicating which of the tasks identified in step one is carried out in which months, for how many days each month and for how many hours on that day by how many household members, separated into adults and children. These products represented the condensed output or results of the focus group and no transcript on what was said by which

[18] Eigner (2012) assessed the labour needs of a household of ten members, consisting of three adult males, three adult females and four children. Acording to the household survey in Seronga, the mean household size of all crop-producing households is 3.85. The actual household size is therefore 38.5 % of the value used by Eigner (2012). Therefore, the labour needs of all non-crop-production related activities reported by Eigner (2012) were multiplied by 0.385 and only then used for this analysis.

participant was created (also due to the different languages). All subsequent analysis focused on these products.

For creating this output for the crop-production related activities, this was achieved by leading the focus group participants to a field of 20m*25m (=500m²). Here, they were asked to estimate (individually), which agricultural tasks they would carry out on that field, how many days each task would last and how many hours per day how many household-members (of which gender) would have to work to finish this task. After 20 minutes, the focus group commenced within a nearby building. It entered into a discussion phase where participants were asked to discuss and jointly agree on which tasks needed to be carried out and how much time was needed for each task (considering an average work speed of a healthy adult, while always being aware that some smallholders might work quicker than others). The final output of this exercise was a value on labour hours needed per task upon which all participants could agree. A similar discussion took place on the next day for the non-crop production related tasks.

The validation of semi-structured interview results took place via probing into the main agricultural tasks mentioned by the focus group participants and on how commonly they were applied. The degree to which the moderator scrutinized a task depended largely on the degree to how quickly and unanimous the participants agreed on this task’s timing and mean labour-needs. Those tasks mentioned in the semi-structured interviews, but not during focus group, were introduced by the moderator and their importance discussed within the group. If the group assumed that this task was relatively common to the study site, it was added to the seasonal calendar. If it was unheard of or basically non-existent, it was not added to the calendar (such as irrigation in Mashare and Seronga, which was carried out by only a handful of farmers in both study sites).

In Mashare and Seronga, where households were differentiated into two clusters, the mean value of the labour-needs stated by the two clusters was used for all subsequent analysis. This means that for all tasks which both clusters were considered to be experts on (such as weeding, planting, harvesting), the mean was used for gaining a credible approximation of what could be the specific tasks actual labour-need. In cases where one of the clusters was assumed to be an expert (such as the poorer cluster and *soil preparation by hoe* or the wealthier cluster and *manure & fertilizer application*), only the value reported by the “expert”-cluster was used for subsequent analysis. In the end, the approximated labour needs were validated by comparing them with similar smallholder farming systems of the tropics. The results of this comparison can be found in the site-specific analyses (see tables 1.14, 1.21 and 1.30 in chapters 1.6.1 – 1.6.3).

In general, the labour-data generated in the focus groups closely resembled those reported in literature for similar farming systems (see site specific analyses). This confirms that trustworthy results on agricultural labour-needs per hectare can be obtained by having homogenous farmers’ groups discuss and compromise on a set of plausible labour-values for an exemplary, clearly demarcated field.

It is likely that basing the labour-values on individual farmer interviews would have resulted in less accurate results, because these values would have relied on farmer recall only. In general, the longer ago an activity was carried out, recall becomes more blurred (Spencer 1991). In order to avoid these significant memory lapses in individual interviews, they have to be carried out via frequent visits and surveys (ibid.). However, I had not sufficient time and resources to carry out regular visits. Therefore, focus group discussions provided the best available means to collect reliable data - with the one exception of conservation agriculture; this issue and corrected labour data will be presented at the end of the chapter. Both the consideration of study site and the choice of conducting separate focus groups for the identified clusters introduced a simple level of analytical control, which might be similarly accomplished in a quantitative analysis through the use of statistical methods (see also Wolff et al. 1993).

1.5.6 The challenge of empirically assessing *conservation agriculture*

The post-fieldwork analysis revealed, that the labour needs stated by the participants of the focus group on conservation agriculture appeared surprisingly high (see Tab. 1.6). They were therefore compared with values of similar, planting-basin-based CA approaches of semi-arid Africa (see Tab. 1.7). This comparison revealed that farmers in Mashare stated much higher labour needs than what was found in comparable studies. Subsequent literature review revealed that this overstatement is most likely connected to the fact that farmers in the study site have only limited experience with CA. Furthermore, they carry it out on very small experimental plots, i.e. on a few square meters. In general, it should be avoided to up-scale labour-data from experimental plots to the field level (Spencer 1991)

However, as no other source of empirically gathered labour-data was available for CA in Mashare, this study tried to do exactly that. As this led to relatively unreliable data, it was decided to replace the empirically measured value of a certain task with the highest value found in literature, whenever the empirical value was higher than the highest value reported in literature. The only exception is *digging planting basins*, the labour-needs of which were assessed by the responsible researcher in the CA program. Tab. 1.8 depicts the values that will be used in the subsequent analyses. It has to be noted that the problem of up-scaling results from small experimental plots arises mainly for labour-data and not for agricultural yields.

Tab. 1.6: Empirically assessed labour needs of the main agricultural tasks of CA in Mashare

Variable labour needs (i.e. proportional to field-size)	Working-**hours** needed per ha /activity /a
Gathering mulch material	1080
Collecting and transport manure (by oxen or hand)	860
Gathering & making of field inputs	**1940**
De-bushing	**320**

OPTION 1: Manual CA

Digging or re-digging planting holes	556
Applying manure into holes and mix with soil (15 t)	920
Applying fertilizer	220
Sowing in holes	220
SUM of labour needs for field preparation & planting (manual CA**)**	**1916**

OPTION 2: Ox-based CA

Ploughing CA field with oxen	30
Applying manure into rip-line (15 t)	180
Applying fertilizer	180
Sowing in rip-line	170
SUM of labour needs for field preparation & planting (ox-based CA**)**	**560**

Applying mulch	**240**
Planting sunhemp	**120**
Cutting sunhemp and applying as additional mulch	**420**
Weeding	**160**
Harvesting a mixed CA field	**40**

Total field size-related labour needs of **MANUAL CONSERVATION AGRICULTURE** (hours/ha)	**5156**
Total field size-related labour needs of **OX-BASED CONSERVATION AGRICULTURE** (hours/ha)	**3800**

Non-variable labour needs (i.e. not-proportional to field-size)	Annual working-**hours** needed
Maintaining wire fence	211
Maintaining traditional fence	133
Chasing away birds	289
Total annual non-variable labour needs (hours/a)	**633**

Source: Author's design based on empirical data.

Tab 1.7: Comparison of labour needs for CA in semi-arid Africa, including the unreliable empirical data for study site Mashare (light brown for manual CA, darker brown for draught-animal-power based CA).

Labour needs in hours / ha per task

Location of CONSERVATION AGRICULTURE SYSTEM	Digging planting basins	Preparing organic inputs	Applying organic & inorganic inputs	Planting	Applying mulch	Weeding	Harvesting	Other
Study Site Mashare, Namibia* Manual CA	556	1940	1140	220	240	160	40	860
Study Site Mashare, Namibia* Draught-animal-power based CA	n/a (30 ploughing)	1940	360	170	240	160	40	860
Burkina Faso	450	174	150	40	n/a	95	50	n/a
Niger	300	n/a	120	n/a	n/a	n/a	n/a	200
Zambia	420	n/a	108	96	n/a	486	96	54
Zambia	420	180	150	n/a	n/a	60-180	128	234
Zimbabwe	221	n/a	141	48	n/a	385	78	n/a
Zimbabwe	169	n/a	230	57	n/a	344	75	n/a
Zimbabwe	412	n/a	60	n/a	n/a	522	n/a	n/a

Total labour needs

location	hours/ha
Study Site Mashare, Namibia* Manual CA	5156
Study Site Mashare, Namibia* Draught-animal-power based CA	3800
Burkina Faso	959
Niger	720
Zambia	1266
Zambia	1260
Zimbabwe	109
Zimbabwe	122
Zimbabwe	994

Inputs per ha

Fertilizer use	Manure use
500 kg/ha	15 t/ha
500 kg/ha	15 t/ha
n/a	3 - 12 t/ha
n/a	n/a
n/a	n/a
n/a	n/a
83 kg/ha	n/a
176 kg/ha	n/a
0 - 80 kg/ha	n/a

Source:
own data
own data
Kabore & Reij (2004)
Hassane, Martin & Reij (2000)
Haggblade & Tembo (2003b)
Haggblade & Tembo (2003a)
Mazvimavi & Twomlow (2009)
Mazvimavi & Twomlow (2009)
Rusinamhodzi (2015)

Source: Author's design based on literature review (sources indicated above).

Tab. 1.8: Corrected labour needs of CA in Mashare

Variable labour needs (i.e. proportional to field-size)	**Working-hours needed per ha /activity /a**
Gathering mulch material	1080
Collecting and transport manure (by oxen or hand)	***180***
Gathering & making of field inputs	1260
De-bushing	320

OPTION 1: Manual CA

Digging or re-digging planting holes	556
Applying manure into holes and mix with soil + fertilizer application	***150***
Sowing in holes	***96***
SUM of labour needs for field preparation & planting (manual CA**)**	802

OPTION 2: Ox-based CA

Ploughing CA field with oxen	30
Applying manure & fertilizer into rip-line	***150***
Sowing in rip-line	***96***
SUM of labour needs for field preparation & planting (ox-based CA**)**	276

Applying mulch	240
Planting sunhemp	***96***
Cutting sunhemp and applying as additional mulch	***128***
Weeding	160
Harvesting a mixed CA field	40

Total field size-related labour needs of **MANUAL CONSERVATION AGRICULTURE** (hours/ha)	**3046**
Total field size-related labour needs of **OX-BASED CONSERVATION AGRICULTURE** (hours/ha)	**2520**

Non-variable labour needs (i.e. not-proportional to field-size)	Annual working-**hours** needed
Maintaining wire fence	211
Maintaining traditional fence	133
Chasing away birds	289
Total annual non-variable labour needs (hours/a)	**633**

Source: Author’s design based on empirical data and sources quoted in previous table 1.7.

1.5.7 Yield assessment

In 2013, a yield assessment was carried out for the smallholder farming systems in each study site. The yield assessment included all crops encountered in the sampled fields (i.e. primary, secondary and other crops) and the following characteristics: field age in years / sowing date / % of pre-harvest (e.g. maize cobs harvested for consumption before final ripening) / amount of manure and/or fertilizer applied / yield per crop in kg / total biomass per crop in kg.

Initially, the goal was to assess the yields of those farmers participating in the household survey and focus groups. However, this approach did not work out as planned: The time available for yield assessment covered about three weeks. Due to miscommunication and early harvesting, some of these fields could not be visited at a ripe stage. Also, the chosen farmers did not apply all desired management- and field characteristics mentioned above. Therefore, a snow-balling approach was applied to identify all ripe fields that were characterized by these desired characteristics. However, even then the number of households applying field inputs remained very low. Combined with the hardships of field work (some fields in Cusseque, Angola, are located deep in the forest so that only one field could be assessed per day) this led to a relatively low sample size of n=30 in Cusseque, Angola, n=20 in Mashare, Namibia and n=27 in Seronga, Botswana. These data were complemented with those obtained from the experimental conservation agriculture plots and their control plots, adding 12 measurements to the traditional rain-fed farming system in Mashare and 12 to conservation agriculture.

The detailed study design is explained in Gröngröft et al. (2013g). The basic approach was to interview the respective farmer about field characteristics. This allowed for differentiating his or her field into homogeneous units of similar management, similar soil conditions and field age. On each of these homogeneous areas, a diagonal line was laid from one corner to the farthest opposite corner. Along this line, five plots of 2*2 meters ($4m^2$) were demarcated at equal distances and all crops within these plots harvested and weighed (wet-weight). For subsequent analysis, these five plots were up-scaled to the hectare level. All harvested crops and plants were dried and weighed again, to also assess dry-matter weight of both grains and total biomass.

The author of this study trained the local TFO employee in Cusseque and partly in Mashare. TFO's soil sciences team took over training in Seronga and the main part of training in Mashare. Due to the fact that no research-team with adequate transport was available in Seronga, the interviewer responsible for that study site was not able to visit all fields in time. In the end, most of the fields he visited had already been harvested. Here, field sizes were measured by GPS and compared to the total amount of harvested bags, thus allowing for the estimation of per hectare yields.

1.6 Results of the farming system analyses of three study sites within the Okavango River Basin (ORB).

In the first chapter, this study introduced the general research area, i.e. the Okavango River Basin (ORB). The following farming system analyses focuses on three distinct rural communities, i.e. this dissertation's study sites; within these communities, all empirical data was gathered (see previous chapter). The first of these study sites is located in the upper catchment (Cusseque, Angola), the second in the mid-river area of the basin (Mashare, Namibia) and the third adjacent to the Okavango Delta in the low-river area (Seronga, Botswana). Below, they will be presented separately in the order just mentioned. For each study site, a literature review on the biophysical and socioeconomic setting will be presented. This lays the foundation for the subsequent farming system analyses.

After these study site-specific analyses, an experimental conservation agriculture (CA) approach (from study site Mashare) will be presented as an example for a sustainable intensified farming system. The final chapter (1.6.5) will synthesize the site-specific findings and deduct implications for the bio-economic in part II of this study.

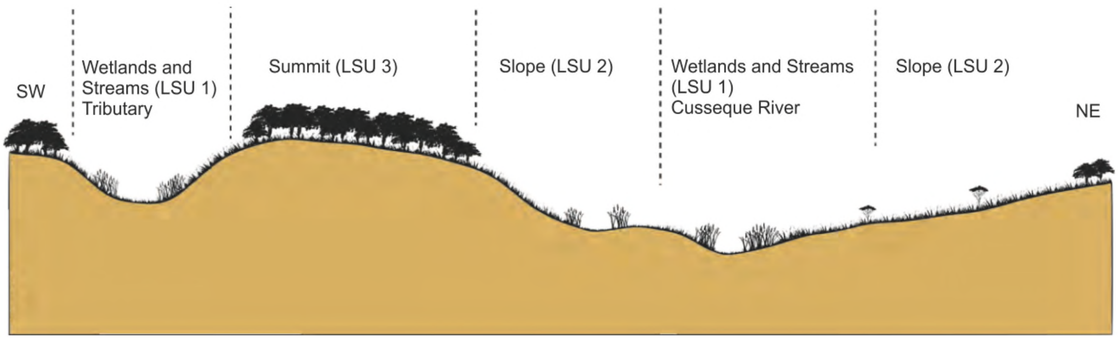
1.6.1 Shifting Cultivation in Cusseque, Angola

1.6.1.1 Climate, livelihoods and socioeconomic framework

Biophysical setting

The study site *Cusseque* is located on the southern Bié Plateau of central Angola, within a landscape of undulating hills that form part of the upriver area of the Okavango catchment. At an altitude of about 1,560 m a.s.l., these hills are mostly covered by a mosaic of pristine vegetation, consisting of *Miombo*-woodland on the summits, grassland on the slopes and small fringes of peatland along the many fast-flowing creeks and rivers in the valley bottoms (Fig.1.2). Cusseque River - the name-sake of the study site and of one of the four local villages- is one of many tributaries to the Okavango River.

Fig. 1.2: Landscape catena of Cusseque



Source: Gröngröft et al. 2013a.

Climatic conditions are semi-humid and characterized by a pronounced rainy season between November and April (Weber 2013b). In the period from 1971 to 2000, mean annual rainfall amounted to 987 mm, yet there was a high inter-annual variability and a trend of decreasing annual precipitation levels (ibid.). Mean annual temperature in Cusseque amounts to 20.4 °C, with October being the hottest (23 °C) and July the coldest month (16.1°C). The hilly topography results in more frequent frost days in the grassy valleys (30+ nights per year of temperatures as low as -7°C) than on elevated and forested summits; this limits the potential for irrigated horticultural or agricultural production in the valley bottom during the dry season (Pröpper et al. 2015). Another obstacle to farming on the grassy slopes is a wild plant called *Cassamba*, the woody shoots of which present an obstacle to non-mechanized soil preparation. Arable agriculture in Cusseque is almost exclusively practiced within the *Miombo* woodlands on the summits. Dominating soils here are slightly loamy, deep and developed *arenosols* (Gröngröft et al. 2013b). Their soil chemical parameters are highly variable, but on the summits relatively high temperatures and precipitation levels have resulted in leaching and low pH-values of 3.4 – 4.4. These parameters change only slightly with increasing soil depth (Gröngröft et al. 2013b).

Socioeconomic setting

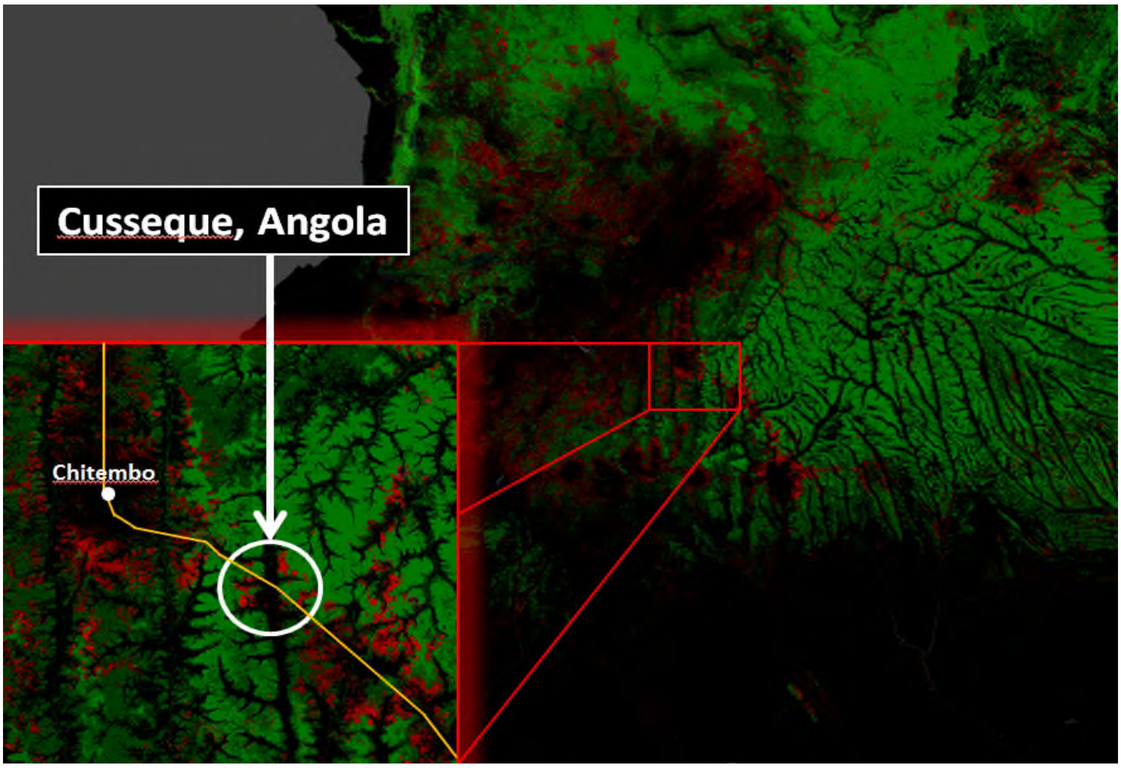
Cusseque is situated in the Angolan Municipaltiy of Chitembo, which has a population of 68,581 inhabitants and a low population density of 3.6 persons per km² (Pröpper et al. 2015). As 46 % of population is concentrated in and around Chitembo-town (Abdelli & Jouen 2012), rural population densities are even lower. In both study site and the region's urban centers, population is undergoing rapid growth (Holden 2015); re-migration from urban to rural communities is a widespread phenomenon (mainly of people who were displaced during the war), but also from rural communities to urban centres (ibid.).

Angola suffered through four decades of civil war (1975 - 2002). This bloody conflict left its mark on the study site. The agricultural sector was severely affected by the war, especially in Bié province, where fighting was fiercest (Abdelli & Jouen 2012). According to interviews with village elders, before the outbreak of the war, the entire region was dotted with fields and small settlements. Yet by the end of the conflict, landmines and aerial bombardment had led to a drastic decline in agricultural activities. The war furthermore forced farmers into quasi-nomadism or to cultivate small plots hidden deep in the forest (Abdelli & Jouen 2012). Others gave up on their holdings and fled to the relative safety of the cities, which were guarded by the different military factions. This massive rural exodus occurred mainly towards the end of the conflict in the 1990's and created countless and as of yet unresolved issues about natural resource management, tenure and use of rural lands (ibid.). According to interviews, it also allowed for the *Miombo*-vegetation to reclaim the formerly cultivated lands in the forests and give these areas their current appearance of primary vegetation.

After the war in 2002, refugees gradually returned to their former villages in Bié to re-build what had been lost – yet without government assistance and lack of initial capital most households struggled (Abdelli & Jouen 2012). Up to today, high levels of poverty characterize the province and limited knowledge contributes to the fact that subsistence agriculture still remains by far the dominant livelihood source (ibid.).

The end of the war also initiated a trend of on-going forest conversion to other land uses. Nowadays, a frontier of forest conversion appears to be approaching the study site from the northwest, which is likely to be fueled by rising population densities and improving market access (see Fig. 1.3). During times of colonial rule, a similar frontier of (semi-)permanent farming swept across Angola's central highlands and turned local swidden cultivators into sedentary farmers (Pössinger 1968). This may be indicative of the future awaiting Cusseque.

Fig. 1.3: Deforestation in southern Angola and Cusseque between 2000 and 2012.



Source: Author's design, based on Hansen et al. (2013). Note: The stock of remaining woodland in 2012 is indicated by the green area, while areas deforested between 2000 and 2012 are indicated by red areas. A strong decline in forest area can be observed coming both in the eastern communities as well as coming from north-west, along the main road axis (orange) and around the urban hub of Chitembo.

During the conflict, the village *Cusseque* (one of the four villages in the study site) was established by one of the war parties. It served as a replacement for a small military post which had protected a nearby bridge over Cusseque river and consists mainly of inhabitants who are not native to the study site (*Nganguela*, while the three original villages belong to the *Tchokwe* – Holden 2015). The Nganguela are still seen as outsiders and are forced to *borrow* the land from the Tchokwe (for free). This is a common phenomenon in shifting cultivation (see Ruthenberg 1971) and thus used here as a first indication of Cusseque's classification as a society practicing shifting cultivation.

Since 2010, an all-weather tar road and irregular public busses connects Cusseque to the provincial capitals of Menongue in the south and Cuito Bié & Huambo in the north, all of which lie at a distance of more than 130 km. Except for the nearby township Chitembo (40 km to the north), there are only a few other, small settlements along the main road. Apart from a network of footpaths (which crisscross the hinterland), there are no secondary roads in the area. Water for domestic consumption is taken directly from the river or from a small well; there are no water treatment facilities. The study site is not connected to an electricity network, yet cellphone coverage has recently reached all settlements along the tar road (Pröpper et al. 2015). Primary schools up to grade 8 are accessible from all four villages of the study site and a higher school in the nearby municipal center Chitembo (Holden 2015). Small shops at the roadside meet the local demand, yet manufacturing is virtually non-existent (ibid.).

Today, Cusseque represents an early stage of an agrarian society, where the use of natural resources plays an important role for livelihood strategies (Holden 2015) and where manual labour is the main energy source for productive activities. Fossil fuel based energy sources still play only a minor role: although 67 % of household do own a flashlight, wood remains the main energy source for cooking, heating and light. Furthermore, only 15 % of households own a small diesel generator and the use of chemical field inputs virtually non-existent.

Livelihood strategies in Cusseque

The results of my livelihood analysis (based on the household survey) revealed that livelihood strategies within Cusseque are relatively homogeneous. Arable agriculture represents by far the most important livelihood source and is practiced by 100 % of all households. This may be connected to the favourable environmental conditions (compared to the lower catchment in Namibia and Botswana) and land abundance, making crop production a worthwhile activity. Households regularly achieve crop surpluses, which are sold at the roadside or on nearby markets. Natural resources are a widespread livelihood source; they are used by 96 % of all households. *Wild fruits* are the most commonly collected resource (87 % of households HH), followed by *honey* (83 %), *game* (81%), *fish* (68 %) and *roots* (63 %). However, of highest importance for subsistence (in terms of amounts extracted) are fish, honey and game. Livestock keeping is of only minor importance and concentrates mainly on poultry (60 % of all HH), pigs (20 %) and goats (8 %); all of these animals are kept in small quantities for domestic consumption (Holden 2015).

In the wake of Angola's rapid economic development in the post-war period, a gradual livelihood diversification is taking place. The newly-tarred road provides relatively reliable access to the small but growing urban market of Chitembo and has induced a commodification of natural resource use. Nowadays, sales of honey and bushmeat are the most widespread natural resources for cash income generation; since 2006, motorcycles allow hunters to advance up to 35 km into the hinterlands, using the existing network of foot-paths (Holden 2015) and resulting in considerably declined game populations since 2007 (Pröpper et al. 2015). Growing market access has also induced a few families in each village to become involved in charcoal production; this relatively recent activity is seen as a quick, non-seasonal cash source, which can be marketed either at the road side or in Chitembo. From 2013 to 2014 alone, charcoal production more than doubled[19] (Holden 2015) and led to localized forest degradation, which can become detrimental to both agriculture and honey production, both of which depend on non-degraded forest ecosystems.

Tab. 1.9 shows the current characteristics of a typical smallholder household in study site Cusseque. However, today's apparent homogeneity of livelihood strategies in Cusseque stands in contrast with the strong socioeconomic and socio-demographic dynamics that are increasingly affecting the study site. Most villagers returned to the study site only after 2002 to take up their economic activities and rising market access will provide both opportunities and threats to rural livelihoods. The following farming system analysis will take these trends into account for its analysis of likely and potential pathways of agricultural development.

[19] To a total of 5.5 t for one of the small villages (Caololo) alone.

Tab. 1.9: Characteristics of a typical household in Cusseque, Angola.

Household characteristics	Mean /proportion	Std. dev.
Household (HH) size in persons	6.2	2.59
Number of producers (aged: 16 - 59)	3	1.73
Share of producers on HH size	0.48	0.20
Share of males on entire HH	0.5	0.19
Female household head, %	13	
Average Age of a household head	45	
HH with HH members who finished secondary school, %	2.5	
HH with HH members who finished primary school, %	25	

Source: Author's design based on empirical data. Note: Information on cash income and livestock ownership is not available for Cusseque, but only for the other study sites Mashare and Seronga. However, livelihood strategies are homogeneous and farmer interviews revealed that both livelihood sources are of only minor importance for households in Cusseque (aside from the few charcoal producers and shop owners).

Land tenure in Cusseque

Officially, land tenure lies with the national state; it is currently administered communally. Although community members have no formal land rights, local customary law has effectively allocated land and avoided conflicts within the community (Pröpper et al. 2015). Nowadays, villagers hold informal *general use rights* to all of their community lands, e.g. for activities such as the collection of natural resources or honey production. Furthermore, they hold exclusive *household-specific use rights* to specific plots of land, which allow for exploitative use such as forest clearing for agriculture, cultivation or charcoal making. Although not formally recognized, these plots are permanently allocated to households by traditional authorities within the communities. As mentioned before, the non-native inhabitants of the village Cusseque depend upon land and land rights that are *borrowed-for-free* from the three native villages of the study site.

1.6.1.2 Results of the farming system analysis in Cusseque

The dominant smallholder farming system in Cusseque

The farming system of Cusseque represents an archetypical system of shifting cultivation under forest fallow in the African savannahs[20]. On average, cultivation periods on plots of lower soil fertility last for 3-5 years and on plots of higher soil fertility for 5-10 years. After this period, fields are abandoned for many decades during which natural succession processes lead to a restoration of the original *Miombo*-vegetation. Fields are cleared from the surrounding *Miombo*-woodlands on the hilltops via slash-and-burn; they are never established in the swampy valleys nor on the grassy slopes (due to the dense root-network of a plant called *Massamba).* See Tab.1.10 for an overview of the main results of the farming system analysis.

[20] The *Miombo*-woodland belt, in which Cusseque is situated, is the dominant type of savanna woodland in the local ecoregion, the Zambezian regional ecocentre of endemism (White 1984).

Peasants at the study site follow very similar farming strategies. Differences in the choice of cereal crops stem mainly from soil conditions. Most widespread is mixed cropping of maize (*Zea mays*), manioc (*Manihot esculenta*) and various kinds of tertiary crops, such as beans, pumpkins and sweet potatoes on more loamy soils of relatively higher soil fertility. Only on the rarely cultivated sandy soils, maize is replaced by millet (*Pennisetum glaucum*).

Currently, most fields are located within the forests a few kilometres away from the permanent villages and along the tar road. Households typically establish temporary huts and crop storages next to these fields, where they spend the greater part of the growing season taking care of the crops.

Horticulture is practiced only to a limited degree and mainly to produce leafy vegetables, because regular frosts in the grasslands and the villages restrict garden-crops to non-perennials. At the location of an abandoned village in the forest, the surrounding forest allowed for some frost protection and thus for the cultivation of fruit trees. These nowadays overgrown fruit tree gardens are still used and have gradually been expanded by a few of their former owners.

On the other hand, the so-called *nacas*, garden plots in the peatlands along the streams, are found rarely in Cusseque. These *nacas* are common in other communities in southern Angola. Apart from frost, farmers mentioned the lack of knowledge about vegetable cultivation and lack of cash resources for purchasing seed as the main obstacles for establishing garden plots. In the future, rising availability of cash may allow some farmers to diversify into horticulture.

In Cusseque, a total of 20 different crops are cultivated. While maize, millet and manioc/cassava play the most important role for subsistence purposes, manioc/cassava and beans are of highest importance for cash income generation. Manioc/cassava play a third important role as a backup food source for rural households , as it can be left un-harvested in the ground for several years and then be used in case of harvest losses. As maize, manioc/cassava and beans are cultivated by more than 80 % of smallholder households, they also play a central role for the local diet. They are closely followed by sweet potatoes, cucumbers, pumpkin, tomatoes and chili (Domptail et al. 2013).

Crop rotation, mixed cropping, and phased planting

Crops in Cusseque are planted simultaneously, except for manioc which needs two to three years to mature and is usually planted only once, during field establishment. The different maturing ages of the planted crops spreads the harvest season over many months, with the main period starting in May, but some form of harvesting occurring up to the first week of September. This increases the period during which fresh food is available.

Crop rotation is carried out only insofar as that after 4 - 5 years, mixed cropping on the more fertile fields is abandoned in favor of a manioc monoculture. Upon manioc maturity in years 3-4, the entire field is harvested and the crop residues burned in order to again establish the original crop mixture for a period of 1-2 more years. After a total cultivation period or rarely less than 10 years, the field is abandoned and cultivation shifted to another plot within the woodlands. Some manioc is left on the field to become part of the fallow vegetation and thus

Tab. 1.10: Main results of the farming system analysis in Cusseque, Angola.

Aspect of farming system	Results for *Cusseque*, Angola	SC	SPC	PC
Mean yield/ha	374 kg/ha (manioc) + 315 kg/ha (maize) + 188 kg/ha (tertiary crops)			
Mean field sizes[a]	1.8 - 3.0 ha			
Main types of crops	Roots, cereals & legumes	X		
Rotation intensity (R-value)[b]	4 – 14	X		
Mean fallow period length	many decades	X		
Mean cultivation period length	4 or 10 years	X		
Degree of land scarcity (as *perceived* by smallholders)	Very low (confirmed via satellite date by Holden 2015)	X		
Cultivation tools & techniques	Hoe-cultivation and manual soil preparation / ridge-planting	X		
Soil fertility management	1. Long-term fallow and ash from burning fallow vegetation 2. Ash from burning manioc residues between years 4-6 3. Incorporation of organic material from weeding, crop residues and de-bushing of annuals into ridges 4. Cutting additional organic material from trees (rarely) 5. Chemical fertilizer (rarely)	X		
Seasonality of labour demand	Low	X		
Labour division	Pronounced, household members cultivate individual plots	X		
Role of livestock for crop prdctn.	None	X		
Land tenure	State property but administered locally. Household-specific use-rights to fields and forest-areas for shifting of fields. Informal ownership.	X		
Heterogeneity of livelihoods	Low, livelihood sources and strategies very similar with only few rural entrepreneurs (shops and charcoal)	X		
Animal husbandry	Partial nomadism for cattle, stationary animal husbandry for goats, pigs & poultry.			

Source: Author's design based on empirical data. Note: Based on the theoretical framework presented in chapter 1.3, the observations are classified as being typical of Shifting Cultivation (SC), Semi-permanent Cultivation (SPC) or Permanent rain-fed cultivation (PC). The results indicate that the farming system in Cusseque is a typical system of shifting cultivation. [a] Data available only for one village, i.e. Caulolo: Total cropped land of 75 ha of this community. Two calculations: survey based: 75 ha divided by 252 inhabitants and multiplied by 6.2, the mean household size from survey; the other calculation is based on Holden (2015): 75 ha divided by 25 households (he assumed mean size of 10 household members). [b] Assuming fallow period of 60-100 years and cultivation periods of 4 or 10 years.

to serve as a food safety-net for times of need. Field of lower soil fertility are rarely cultivated with manioc but rather abandoned directly after 3-5 years. Yet even here, some manioc is generally left in the ground to become part of the fallow vegetation. An important reason for this sophisticated inclusion of a short-term manioc fallow in the cultivation period is a growing weed infestation of the fields over time, which can be countered to some extent via fallowing. Another reason is related to soil fertility and its regeneration via fallowing and the subsequent incorporation of manioc residue ash into the soil.

Due to the relatively long cultivation period of up to 10 years farmers in Cusseque follow a relatively intensive form of hoe-based ridge cultivation– at least when compared with other systems of shifting cultivation. At the beginning of the growing season, raised earthen seed beds or ridges are established by using the hoe to incorporate green biomass (sometimes) as well as the annual weeds that have been cut during the last growing season (always) into the soil. During the course of the growing season, emerging annual weeds are again cut and placed between the ridges to be incorporated into the soil during the next growing period. This and other means of soil fertility management will be discussed below.

Tab. 1.11: Use of field inputs in Cusseque

Field inputs	% of HHs using respective input at least sometimes
Improved seeds	12
Inorganic fertilizer	0
Pesticides	0
Animal manure	2.4

Source: Author's design based on empirical data.

Labor needs within an agricultural cycle in Cusseque

The labour-requirements of agriculture in Cusseque are typical of shifting cultivation, where field clearing and harvesting belong to the most labour-intensive tasks (see Tab. 1.13). The harvest of manioc especially, but also its' transport from the fields to the rivers for post-processing and subsequent storage take a considerable amount of time, partly due to the great distances between fields and homesteads. The part of the harvest that is not sold remains in storage facilities near the fields; food for domestic consumption is periodically collected from here throughout the year.

However, Cusseque's hoe-based ridge cultivation and long cultivation periods turn both field preparation and weeding into uncharacteristically labour-intensive tasks – at least when compared to shifting cultivation systems of the humid-tropics. This results in slight peaks of labour-demand at the beginning and the end of the growing season.

Division of labour is quite pronounced, insofar as most household members take care of their own plot of land and assist the other members only after they have finished their own work. This appears to hold true for all tasks from planting to weeding, which are therefore carried out by all household members irrespective of gender. This division of labour between household members is complemented by division of labour in regards to gender: while the majority of cultivation work is generally carried out by both genders; maintenance work and forest clearing are the tasks of male household members while harvesting and post-processing of crops are tasks of female members.

The seasonal calendar of the main agricultural activities in Cusseque (Tab. 1.12) starts with the creation of the ridge-lines and planting, which occurs after the onset of rainfalls in October and November. From January to March, this is followed by a relatively labour intensive period of weeding, the regular covering of crop-roots that have been exposed by rainfall with soil and guarding the field against birds and insects. From April, i.e. prior to harvesting, and all through the main harvesting season in May to June, this is replaced by less frequent visits to the field that aim at spotting any arising problems. While the main harvesting period is April and May, some harvesting can take place up until mid-September, which considerably extends the period of fresh food availability. The same holds true for beans and millet, which can both be harvested prior to the main harvest period, from January to mid-March. Transporting the relatively heavy manioc-harvest from the field to storage can takes place mainly between May and September, after which smallholder begin to prepare for beginning of the next growing season in October.

It has to be noted that a minority of households (less than 7 %) uses oxen for field preparation and thus does not carry out ridge cultivation; one stated reason for doing so was the fact that these farmers perceive a gradual reduction of the growing and planting period due to changing rainfall conditions; they decided to revert to oxen labour because it forces them to carry out their field preparation at a faster and more disciplined pace then what is typical under manual field preparation. However, most farmers are reluctant to do so due to the high labour needs that are connected to livestock keeping during the year and for field clearing: for oxen-drawn plough cultivation, tree stumps need to be removed or at least shortened to ankle level, while under manual cultivation trees can be cut with much less effort at hip level. Nowadays low importance of cattle keeping is therefore related to the incompatibility of shifting cultivation and oxen-drawn ploughing. Those few households owning cattle combine kraaling at night with herding in the forest and the grasslands during the day.

Tab. 1.13 depicts the mean per-hectare labour-demand of agricultural activities in Cusseque, while Tab. 1.14 compares these values (summarized into the main agricultural tasks) with those of other shifting cultivation systems in the tropics. It has to be kept in mind that labour-needs do not only differ between systems, but also between individuals of the same systems – some farmers may work at a more leisurely pace or work slower because they are malnourished, other may work quicker and more effectively. These numbers serve only as a rough reference frame for the comparison.

Tab.1.12: Seasonal calendar of natural resource-based livelihood activities in Cusseque

	August		September		October		November		December		January		February		March		April		May		June		July	
Main annual cultivation activities:	*1st half*	*2nd half*	*1st*	*2nd*	*1st*	*2nd*	*1st*	*2nd*	*1st*	*2nd*	*1st*	*2nd*	*1st*	*2nd*	*1st*	*2nd*	*1st*	*2nd*	*1st*	*2nd*	*1st*	*2nd*	*1st*	*2nd*
Soil preparation (= making ridges)						■	■	■	■															
Planting into ridges						■	■	■	■															
Re-planting								■	■															
Weeding & covering exposed roots with soil											■	■	■	■										
Cutting insect damaged maize leaves											■	■												
Chasing away birds													■	■	■	■	■							
Visiting the field and checking on crops																	■	■	■	■	■	■		
Main harvest period of a mixed field	■	■	■																■	■	■	■	■	■
Harvesting-period beans												■	■	■										
Harvesting-period millet															■	■								
Transporting manioc to river & treatment	■	■																	■	■	■	■	■	■
Transporting manioc from river to storage			■	■																				
Main non-annual cultivation activities:																								
Clearing of vegetation																	■	■	■	■	■	■	■	
Burning cleared vegetation for 1st time	■	■																						
Piling of unburned vegetation & 2nd burning			■	■																				
Harvesting a pure manioc field (year 5-7)	■	■																	■	■	■	■	■	■
Burning manioc residues after manioc fallow	■	■																						
Main natural resource use activities:																								
Fishing (done by women)	■	■	■	■	■	■																		
Fishing (done by men)																	■	■						
Collecting wild vegetables													■	■	■	■	■							
Collecting grass																	■	■	■	■	■	■		
Collecting wild fruits	■	■	■	■														■	■	■	■	■	■	■
Collecting & transporting of honey to village				■	■	■	■	■	■	■	■	■												
Making Charcoal	■	■													■	■	■	■	■	■	■	■	■	■
Transporting charcoal to village	■	■	■	■	■										■	■	■	■	■	■	■	■	■	■

Source: Author's design based on empirical data.

Tab. 1.13: Mean labour-demand of agricultural tasks per ha & year.

Agricultural activities of the dominant cultivation system in Cusseque	Total working-**hours** needed per ha / activity / a
Clearing vegetation (at hip-level for hoe cultivation)	180
Burning cleared vegetation for 1st time	24
Piling of unburned vegetation & 2nd burning	80
Total labour-needs: Slash-&-Burn	**284**
Soil preparation (= making ridges)	440
Planting into ridges	320
Re-planting	70
Total labour-needs soil preparation & planting	**830**
Weeding & covering exposed roots with soil	230
Cutting insect damaged maize leaves	70
Total labour-needs weeding & pest-control	**300**
Chasing away birds *(not prop. related to field size)*	450
Visiting the field to check crops *(not prop. related to field size)*	10
Harvesting maize (503 kg)	45
Harvesting manioc from a mixed field (347 kg)	16
Harvesting beans (67 kg)	15
Total labour-needs for harvesting a mixed field	**77**
Transporting maize harvest to storage (503 kg)	101
Transporting millet harvest to storage (503 kg)	84
Transporting bean harvest to storage (67 kg)	12
Total labour-needs transporting harvest/ha (excl. manioc)	**196**
Transport manioc from field to river (347 kg)	27
Prepare of manioc at river (347 kg)	35
Transport manioc from river to storage (347 kg)	21
Total labour-needs post-processing manioc (347 kg)	**82**

Irregular activities:

Applying chemical fertilizer	260
Clearing vegetation at knee-level for plough cultivation	220
Ploughing by oxen & subsequent planting	100
Burning manioc residues after manioc fallow	20
Harvesting a pure manioc field (8 t)	430
Harvesting millet (503 kg)	54

Source: Author's design based on empirical data.

Tab. 1.14: Overview of labour needs of main agricultural tasks in various shifting cultivation systems in working-hours/ha.

Case study	Slash-&-Burn of vegetation	Soil preparation & planting	Weeding & pest-control	Harvesting a mixed field	Guarding the field	R-value	Characteristics of the system
Miombo-woodlands, Cusseque, Angola[a]	284	830	300	77	450	**3 - 14**	Long-term forest fallow with relatively labour intensive ridge cultivation
Climax forest on the Philippines[b]	599	305	450-550	300 (rice) or 80 (maize) or 500 (non-cereals)	400	**17 - 33**	Relatively intensive shifting cultivation of rice, grain and root crop rotations. Three weeding cycles per growing period;
Secondary forest on the Philippines[b]	392	305	675	300 (rice) or 80 (maize) or 500 (non-cereals)	200		
Virgin jungle in Malaysia[c]	325 - 408	147	195 - 260	228-326	*n/a*	**< 12**	Less intensive shifting cultivation of rice with a diversity of interplanted catch crops
Secondary jungle in Malaysia[c]	179 - 262	147	244 - 326	228-326	*n/a*	**< 6**	
Savanna in Congo[d]	474 - 655						
Pennisetum grasslands in Congo[d]	372						

Sources: [a] = empirical data, [b] = Conklin (1957) in Colin & Haswell (1967), [c] = Freeman (1955) in Colin & Haswell (1967), [d] I.N.E.A.C. (1958) in Ruthenberg (1971).

The comparison of labour needs in different shifting cultivation systems revealed the specific characteristics of the labour economy in the study site. Cusseque's low labour-needs for weeding are similar to those of a Malaysian case study and may be connected to a low weed infestation caused by low rotation intensity (R-value, see chapter 1.3). The relative ease of land clearing in *Miombo*-forests is comparable with secondary forests in the tropics and significantly lower than in pristine and dense tropical forests. Cusseque's high labour-needs for soil preparation and planting are a result of labour-intensive ridge-cultivation. These ridges may also facilitate harvesting, thus leading to the relatively low labour-needs of harvesting of 77 hours/ha. However, the higher labour-needs for harvesting in the other systems are also related to the fact that rice is the main crop. When looking at just the maize-harvests in the Philippines, one finds a comparable value of 80 hours/ha.

Tab. 1.15: Mean annual household labour-demand for natural resource use & household chores in Cusseque, separated by month & season.

<table>
<tr><th></th><th colspan="9">Dry Season</th><th colspan="15">Rainy Season</th><th></th><th></th></tr>
<tr><th></th><th colspan="2">June</th><th colspan="2">July</th><th colspan="2">August</th><th colspan="2">Sept.</th><th colspan="2">Oct.</th><th colspan="2">Nov.</th><th colspan="2">Dec.</th><th colspan="2">Jan.</th><th colspan="2">Feb.</th><th colspan="2">March</th><th colspan="2">April</th><th colspan="2">May</th><th rowspan="2">Gender specificity of task</th><th rowspan="2">Estimated share of producer labour</th></tr>
<tr><th>Seasonal activities:</th><th>1-15</th><th>16-30</th><th>1-15</th><th>16-31</th><th>1-15</th><th>16-31</th><th>1-15</th><th>16-30</th><th>1-15</th><th>16-31</th><th>1-15</th><th>16-30</th><th>1-15</th><th>16-31</th><th>1-15</th><th>16-31</th><th>1-14</th><th>15-28</th><th>1-15</th><th>16-31</th><th>1-15</th><th>16-30</th><th>1-15</th><th>16-31</th></tr>
<tr><td>Fishing (done by women)</td><td></td><td></td><td></td><td></td><td colspan="2">60</td><td colspan="2">60</td><td colspan="2">40</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>Female</td><td>0.5</td></tr>
<tr><td>Fishing (done by men)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2">48</td><td colspan="2">48</td><td>Male</td><td>0.5</td></tr>
<tr><td>Collecting honey</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>60</td><td colspan="2">60</td><td colspan="2">60</td><td colspan="2">60</td><td colspan="2">60</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>Male</td><td>0.5</td></tr>
<tr><td>Transporting honey from bush into village</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>160</td><td colspan="2">160</td><td colspan="2">160</td><td colspan="2">160</td><td colspan="2">160</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>Male</td><td>0.5</td></tr>
<tr><td>HH specific: Making Charcoal</td><td colspan="2">12</td><td colspan="2">12</td><td colspan="2">12</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2">12</td><td colspan="2">12</td><td colspan="2">12</td><td>Shared</td><td>1</td></tr>
<tr><td>HH specific: Transporting charcoal to village</td><td colspan="2">8</td><td colspan="2">8</td><td colspan="2">8</td><td colspan="2">8</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2">8</td><td colspan="2">8</td><td colspan="2">8</td><td>Shared</td><td>0.5</td></tr>
<tr><td>Collecting grass</td><td colspan="2">20</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2">70</td><td colspan="2">30</td><td>Male</td><td>0.5</td></tr>
<tr><td>Collecting wild vegetables</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2">40</td><td colspan="2">40</td><td>40</td><td></td><td></td><td></td><td>Female</td><td>0.5</td></tr>
<tr><td>Collecting wild fruits</td><td colspan="2">24</td><td colspan="2">12</td><td colspan="2">12</td><td colspan="2">12</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>24</td><td colspan="2">24</td><td>Female</td><td>0.5</td></tr>
<tr><td>Plastering walls</td><td colspan="2">18</td><td colspan="2">18</td><td colspan="2">18</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2">18</td><td colspan="2">18</td><td>Male</td><td>0.5</td></tr>
<tr><th colspan="27">Regular & daily activities</th></tr>
<tr><td>Hunting</td><td colspan="2">75</td><td colspan="2">75</td><td colspan="2">75</td><td colspan="2">75</td><td colspan="2">75</td><td colspan="2">75</td><td colspan="2">75</td><td colspan="2">75</td><td colspan="2">75</td><td colspan="2">75</td><td colspan="2">75</td><td colspan="2">75</td><td>Male</td><td>0.5</td></tr>
<tr><td>Collecting firewood</td><td colspan="2">18</td><td colspan="2">18</td><td colspan="2">18</td><td colspan="2">18</td><td colspan="2">18</td><td colspan="2">18</td><td colspan="2">18</td><td colspan="2">18</td><td colspan="2">18</td><td colspan="2">18</td><td colspan="2">18</td><td colspan="2">18</td><td>Shared</td><td>0.5</td></tr>
<tr><td>Fetching water</td><td colspan="2">60</td><td colspan="2">62</td><td colspan="2">62</td><td colspan="2">60</td><td colspan="2">62</td><td colspan="2">60</td><td colspan="2">62</td><td colspan="2">62</td><td colspan="2">56</td><td colspan="2">62</td><td colspan="2">60</td><td colspan="2">62</td><td>Female</td><td>0.25</td></tr>
<tr><td>Drying maize meal</td><td colspan="2">2</td><td colspan="2">2</td><td colspan="2">2</td><td colspan="2">2</td><td colspan="2">2</td><td colspan="2">2</td><td colspan="2">2</td><td colspan="2">2</td><td colspan="2">2</td><td colspan="2">2</td><td colspan="2">2</td><td colspan="2">2</td><td>Female</td><td>0.5</td></tr>
<tr><td>Pounding stored food</td><td colspan="2">120</td><td colspan="2">120</td><td colspan="2">120</td><td colspan="2">120</td><td colspan="2">120</td><td colspan="2">120</td><td colspan="2">120</td><td colspan="2">120</td><td colspan="2">120</td><td colspan="2">120</td><td colspan="2">120</td><td colspan="2">120</td><td>Female</td><td>0.5</td></tr>
<tr><td>Taking care of chilrden</td><td colspan="2">20</td><td colspan="2">20</td><td colspan="2">20</td><td colspan="2">20</td><td colspan="2">20</td><td colspan="2">20</td><td colspan="2">20</td><td colspan="2">20</td><td colspan="2">20</td><td colspan="2">20</td><td colspan="2">20</td><td colspan="2">20</td><td>Shared</td><td>0.5</td></tr>
<tr><td>Counseling sad/distressed/... people</td><td colspan="2">2</td><td colspan="2">2</td><td colspan="2">2</td><td colspan="2">2</td><td colspan="2">2</td><td colspan="2">2</td><td colspan="2">2</td><td colspan="2">2</td><td colspan="2">2</td><td colspan="2">2</td><td colspan="2">2</td><td colspan="2">2</td><td>Shared</td><td>1</td></tr>
<tr><td>Visiting sick people in the village</td><td colspan="2">9</td><td colspan="2">9</td><td colspan="2">9</td><td colspan="2">9</td><td colspan="2">9</td><td colspan="2">9</td><td colspan="2">9</td><td colspan="2">9</td><td colspan="2">9</td><td colspan="2">9</td><td colspan="2">9</td><td colspan="2">9</td><td>Shared</td><td>0.5</td></tr>
<tr><td>Welcoming visitors (social obligation!)</td><td colspan="2">16</td><td colspan="2">16</td><td colspan="2">16</td><td colspan="2">16</td><td colspan="2">16</td><td colspan="2">16</td><td colspan="2">16</td><td colspan="2">16</td><td colspan="2">16</td><td colspan="2">16</td><td colspan="2">16</td><td colspan="2">16</td><td>Shared</td><td>1</td></tr>
<tr><td>Ironing</td><td colspan="2">16</td><td colspan="2">16</td><td colspan="2">16</td><td colspan="2">16</td><td colspan="2">16</td><td colspan="2">16</td><td colspan="2">16</td><td colspan="2">16</td><td colspan="2">16</td><td colspan="2">16</td><td colspan="2">16</td><td colspan="2">16</td><td>Female</td><td>0.5</td></tr>
<tr><td>Repairing clothes</td><td colspan="2">0.3</td><td colspan="2">0.3</td><td colspan="2">0.3</td><td colspan="2">0.3</td><td colspan="2">0.3</td><td colspan="2">0.3</td><td colspan="2">0.3</td><td colspan="2">0.3</td><td colspan="2">0.3</td><td colspan="2">0.3</td><td colspan="2">0.3</td><td colspan="2">0.3</td><td>Shared</td><td>0.5</td></tr>
<tr><td>Sweeping house and yard</td><td colspan="2">60</td><td colspan="2">62</td><td colspan="2">62</td><td colspan="2">60</td><td colspan="2">62</td><td colspan="2">60</td><td colspan="2">62</td><td colspan="2">62</td><td colspan="2">56</td><td colspan="2">62</td><td colspan="2">60</td><td colspan="2">62</td><td>Female</td><td>0.5</td></tr>
<tr><td>Homestead organization (preparing beds, etc.)</td><td colspan="2">90</td><td colspan="2">93</td><td colspan="2">93</td><td colspan="2">90</td><td colspan="2">93</td><td colspan="2">90</td><td colspan="2">93</td><td colspan="2">93</td><td colspan="2">84</td><td colspan="2">93</td><td colspan="2">90</td><td colspan="2">93</td><td>Female</td><td>0.5</td></tr>
<tr><td>Washing dishes</td><td colspan="2">60</td><td colspan="2">62</td><td colspan="2">62</td><td colspan="2">60</td><td colspan="2">62</td><td colspan="2">60</td><td colspan="2">62</td><td colspan="2">62</td><td colspan="2">56</td><td colspan="2">62</td><td colspan="2">60</td><td colspan="2">62</td><td>Female</td><td>0.5</td></tr>
<tr><td>Preparing & washing chilrden for school</td><td colspan="2">105</td><td colspan="2">109</td><td colspan="2">109</td><td colspan="2">105</td><td colspan="2">109</td><td colspan="2">105</td><td colspan="2">109</td><td colspan="2">109</td><td colspan="2">98</td><td colspan="2">109</td><td colspan="2">105</td><td colspan="2">109</td><td>Shared</td><td>0.5</td></tr>
</table>

Source: Author's design based on empirical data. Note: Each task's gender specificity and estimated share of producers involved in each task indicated. Note: Average labour-demand refers to a household of two adults and seven children, differentiated by gender usually responsible for each task and the share of producer labour involved.

In the presence of diversified livelihood strategies, the analysis of agricultural labour-demand needs to be complemented by working-hours invested in other livelihood sources. In Cusseque, this concerns mainly the use of natural resources and household chores, while tasks such as maintenance of homesteads and uncommon wage-labour are ignored in this analysis. Tab. 1.15 presents an overview of households' mean monthly labour-needs for these livelihood activities. Tab. 1.16 sums the average family labour needed per household per year over both dry and rainy season, converted into household producer labour[21], i.e. only that labour that needs to be invested by household members aged between 15 and 59 years. This allows for a more meaningful comparison of labour-needs over all three study sites. For the case of Cusseque, season lengths of on average 139 days for the dry season and 226 days for the rainy season have been assumed.

Tab. 1.16 indicates that in the dry season 50 % of the available family labour is on average invested in household chores and natural resource use, while in the longer rainy season only 37 % of the available labour is invested in these tasks. This results in a mean availability of 1804 family-labour hours in the dry season and 3810 family-labour hours in the rainy season which can be invested in leisure, agriculture or wage-labour.

Tab. 1.16: Annual family-labour budget of a typical household in Cusseque

	Dry Season	Rainy Season
Total available household producer labour (working hours /HH/a)[a]	3616	6019
Mean HH labour demand for activities in working hours/HH/a (corrected to producer labour)		
- Shared	480	530
- Male	371	586
- Female	961	1094
= Sum	1812	2209
Total remaining labour available for agriculture, wage-labour & leisure	1804	3810

Source: Author's design based on empirical data. Note: Calculation of producer labour available for arable agriculture, wage-labour or leisure carried out by deducting mean labour needs of natural resource use and household chores from total producer labour pool. Based on assumption that a household consists of two adults and seven children and that it produces both charcoal and honey. [a] Calculated by multiplying 4 producers with respective season length in days and a mean working-day of 6.6 hours (based on Conklin 1957).

[21] This conversion was done by multiplying the labour needs of a specific activity with its estimated share of producer labour invested in this activity. The estimated share of producer labour was derived from focus group results. If an activity was reported to be carried out by adult males, adult females and the children, it was assumed that only 50% of the labour hours needed for task need to be carried out by producers. If an activity was reported to be carried out by adult females and both underage boys and girls, it was assumed household producers were needed to carry out only 30 % of the working hours required.

Soil fertility management

Long-term forest fallow represents farmer's main means of restoring soil fertility. The exact duration of these fallows cannot be observed empirically, because four decades of war have broken the agricultural cycle in Cusseque. According to farmers, many areas in the study site which are nowadays covered by forest were in fact cultivated during colonial times; after the outbreak of the war, most of these fields were abandoned and natural succession led to a re-growth of forest vegetation. The importance of farming as a livelihood source for local households could rise only after the conflict had ended; also, many farmers returned to Cusseque only in the years following the end of the war. Therefore, most holdings in Cusseque are still very young and remain in the first or second cultivation period. Farmers are convinced that sufficient forest area is and will be at their disposal even in the far future. They therefore state that after the end of a cultivation period they will abandon the land "forever"; others are aware that one day in the future, their descendants will have to return nowadays cultivation areas and re-start the cycle of forest clearing and shifting cultivation. Yet all farmers expressed their believe that in their lifetime they would not need to return to formerly cultivated lands and always be able to clear mature forest.

The other widespread means of soil fertility management is the already described ridge cultivation, i.e. the annual construction of raised seed beds into which organic matter is incorporated. Most of this matter comes from weeding or annual de-bushing before field preparation, yet a few households even add some green leaves that are cut from nearby trees (coming from both on and off-field trees and carried out to a limited degree only, thus not critically affecting the labour economy). A very small minority of households did in the past participate in a government program that one-time only provided free inorganic fertilizer. In subsequent years, a few of these households even irregularly used private cash resources to again buy inorganic fertilizer, yet at the time of data gathering this could not be observed.

1.6.1.3 Conclusion: Current trends and likely development pathways

The current shifting cultivation system in the study site Cusseque represents an ecological sustainable farming system that balances the temporal exploitation of soil nutrients with their regeneration via long-term forest fallow. This leads to relatively high and stable yields, allowing smallholders to sell a regular crop surplus.

Smallholders in the study site continue to perceive land to be available in abundance, as can e.g. be seen in the temporary relinquishment of land rights from the native communities Cambuela, Caulolo and Calomba to the non-native community Cusseque. Univocally, farmers expressed their firm believe that also in the future sufficient land will be available to cover the villages demand. Only members of the traditional authorities and some village elders, especially of the eastern-most village Calomba, expressed a certain anxiety about future development. This anxiety is connected to the fact that Calomba ceded land to another community from east of the study site called Satchijamba which subsequently degraded this land at a rapid pace for charcoal production. The strong increase in charcoal production in the study site since the tarring of the main road in 2010 may mark the beginning of a similar forest degradation process in the study site which could in the near future critically reduce the availability and quality of the available land for other uses, particularly agriculture. This trend towards rising competition for land between different economic activities is even likely to increase in the future. For example, a few urbanites are considering opportunities for investments into agricultural production in the study site. Additionally, the Angolan government plans to massively invest into large-scale irrigation agriculture in currently natural lands. Combined with an ongoing and strong population growth in the study site, all of these trends indicate that it may be unrealistic to assume continuing land abundance in the study site.

As of yet, the typical farm-household in Cusseque appears to be unaware of this danger. If not countered by appropriate policy interventions, the currently sustainable shifting cultivation system of Cusseque is therefore unlikely to adapt to these trends. Instead, already over the next decade it may turn into a semi-permanent cultivation system[22] with the typical phenomena of ongoing soil degradation and social stratification of rural households into more and less successful ones.

[22] Pössinger (1968) mentions a similar process in central Angola for the first half of the 20th century

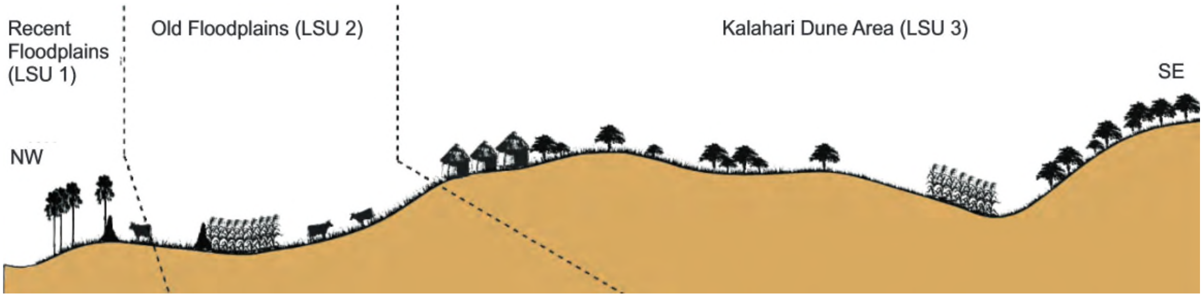
1.6.2 (Semi-) Permanent rain-fed agriculture in Mashare, Namibia

1.6.2.1 Climate, livelihoods and socioeconomic framework

Biophysical setting

The study site *Mashare* lies at the Okavango's middle reaches in northern Namibia, within extensive woodland savannah. At a mean altitude of 1090 m a.s.l., the vegetation is dominated by *acacia* tree-communities. It can be distinguished into the Kavango riverine vegetation and the thorn bushes of the Kalahari plain (De Cauwer 2013). While the riverine forests have largely been converted into agricultural lands, large tracts of thorn bush savanna do still remain in the study site. The area can furthermore be subdivided into three major landscape types (see Fig. 1.4 and Gröngröft et al. 2013c): i) the regularly flooded *recent floodplains* adjacent to the Okavango river (5 % of the area), ii) the *old floodplains* which are never or only very rarely affected by flooding (15 % of the area) and iii) the *Kalahari dune area* in the hinterlands, the dominating landscape type in Mashare (80 % of the area).

Fig. 1.4: Landscape catena of Mashare study site.



Source: Gröngröft et al. 2013c.

The *recent floodplains* show the highest variability in soil properties due to a regular input of sediments and thus nutrients by flooding events. Conditions in both the *old floodplains* and the *Kalahari dune area* are less variable and soils are generally characterized by low nutrient levels. This phenomenon is particularly pronounced in the Kalahari dune area, where the majority of still unutilized cropland is located (Gröngröft et al. 2013d). Currently, agricultural production is carried out mainly in depressions within the old floodplains and within dried-out river beds in the Kalahari dune area (Mendelsohn 2009, Gröngröft et al. 2013d), the so-called *omurambas*. Here, soils are slightly loamy, have less acidic pH-values and significantly higher total nutrient reserves than the dominating *Arenosols* of the Kalahari Dune Area (ibid.). However, to meet rising food demands in the study site, agricultural production is slowly expanding even onto these less fertile soils.

Climatic conditions in Mashare and the surrounding middle reaches of the catchment are semi-arid, with a pronounced rainy season from October to April (Weber 2013c). Mean annual rainfall amounted to 571 mm between 1971 and 2000 and showed a high inter-annual variability, whereas mean annual temperature was 22.3°C with October being the hottest (26.2°C) and July the coldest (16.2°C) months for the same period (Weber 2013c). Inter-annual temperature variability was moderate, with a slight increase since the late 1970s (ibid.).

Socioeconomic setting

Mashare is situated in the former north-Namibian region of Kavango, which was separated into West- and East-Kavango in 2013. Together, both Kavangos contain 222,500 people living on an area of 48,742 km² (Pröpper et al. 2015), resulting in a mean population density of 4.5 persons/km². However, because the Okavango river remains by far the most important and in many cases the only available source of drinking water in the region, the majority of households (68% of all rural residents) is forced to settle in a 10 km wide strip along the river (Mendelsohn 2009).

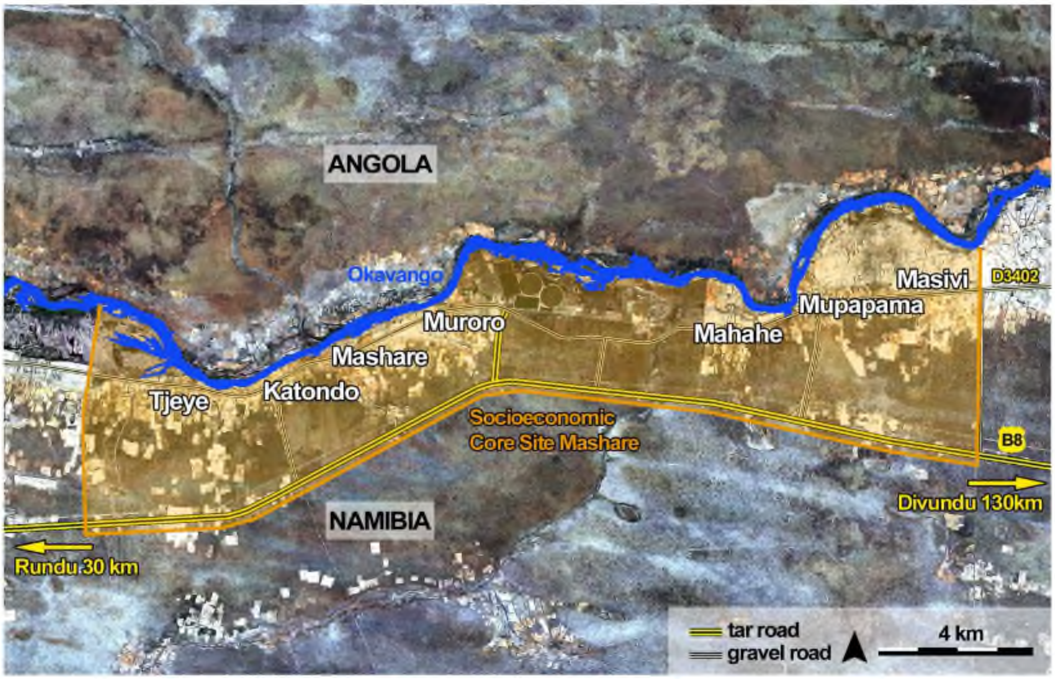
Thus, a look at the study site Mashare may provide a more realistic picture of actual population densities: here, an estimated population of 3216 persons or 518 households is living on an area of only 96.33 km², resulting in a mean population density of 33 persons/km² (Kowalski et al. 2013). Furthermore, homesteads are concentrated along the main roads and the Okavango river, indicating even higher densities in the fertile and well-connected areas. Strong competition for natural resources has long served as a driver of household migration to the hinterlands, yet migration possibilities depend on infrastructure, water availability and land rights/leasehold policies (Pröpper et al. 2015). As most boreholes and large tracts of land in the deeper hinterland belong to private leaseholders, migration potential to these areas is limited and most smallholders remain within walking distance of the river.

Natural population fertility in the study site is high and assumed to remain high in future (Pröpper et al. 2015). It thus acts as the main driver of population growth. Other contributing factors are in-migration of relatives (which is balanced to a certain degree by out-migration to urban centers of especially the younger generation - ibid.).

The study site consists of seven settlements which lie mainly within the more fertile *old floodplains* along an old gravel road running parallel to the river (see Kowalski et al. 2013a for more details). According to interviews with local *headmen* (traditional local authorities), these settlements have been established fairly recently: In the pre-1920's, the area was used mainly by the hunter-gatherer society of the *San*; agriculturalists entered this area mainly after the 1920's, the majority probably coming from the up-river Angolan highlands, but some presumably also from eastern regions. Between 1940 and 1962, large tracts of the study site was reserved for government use only and subsistence farming was not allowed in these areas. A second wave of settlement dates from the 1960's, when the current villages were established along the river. This is reflected in the reports of older smallholders who stated that in their youth only a few households could be found at the location of today's settlements, which were separated from each other by many kilometers of natural vegetation.

This allows for the following conclusion: the origins of Mashare's farming practices are likely to be found in the shifting cultivation system of the Angolan highlands (see chapter 1.6.1), where soil conditions and precipitation is more beneficial to farming. Due to this, current livelihoods and farming practices cannot be seen as the result of long-term adaptation processes to local biophysical conditions. In fact, considering the rapid increase of population densities over the last half century, it is possible that the "traditional" farming system in Mashare presents a farming system that is badly adapted to local growing conditions.

Fig. 1.5: A map of study site Mashare and its seven settlements.



Source: Kowalski et al. (2013).

An all-weather tar road connects the study site to Namibia's fast-growing urban hub *Rundu* in the west (30 km), as well as to other urban settlements such as *Divundu* in the east (130 km +) – see Fig. 1.5. Relatively reliable public transport is available on a gravel road that runs parallel to the tar road and connects the many rural settlements along the river with Rundu. Efforts towards electrification can be observed along the gravel road and provide a small number of shops, bars and households with electric energy (3.75 % of households). Cell-phone coverage is available throughout the study site. Otherwise, access to markets and public infrastructure can be regarded as very limited.

The following livelihood analysis proofs that Mashare represents an agrarian society (where animal or human labour are the main energy sources - see Sieferle 1997). It can therefore be analyzed using the Boserup-Ruthenberg framework. At the same time, the rising availability of fossil fuels and globally traded commodities has a limited, but increasing influence upon livelihoods. While 3.75% of households are connected to the electricity grid, Diesel generators, gas stoves or solar panels are used by less than 1% each as energy sources for cooking, heating or lighting. Fuel wood remains by far the dominant energy source; it is used by 98% of households. For 62% of households, the river remains the main source of drinking water, while 29% rely mainly on tab water and 8% on a borehole. Less than 2% of households use chemical fertilizer at least sometimes and less than 1% applies pesticides.

Livelihood strategies in Mashare

The following livelihood analysis is based on the household survey conducted in Mashare (see Kowalski et al. 2013). It revealed that smallholder households rely upon a variety of livelihood sources. However, arable agriculture remains the main livelihood source for the majority (practiced by 88% of households). Livestock keeping is another central livelihood source; yet, surprisingly, it is practiced by only 58% of all households. In fact, only 33% of all households actually own cattle and herd sizes are highly skewed (three out of four livestock-owning households have cattle herds of less than 20 animals, while only a few households own cattle herds of up to 200 animals). An important complementary livelihood source for 100% of households is the use of natural resources. Key resources for both subsistence and cash income generation are fish, nuts and roots. Additionally, reeds represent the second most salient cash resource that is used within the study site (Domptail et al. 2012).

As is typical for many sedentary agriculturalist societies (Ruthenberg 1971), keeping cattle is of high importance for households in Mashare. For reasons related to social status, risk aversion in case of droughts and ensuring contribution duties in traditional feasts, households generally aim at owning the biggest possible herds (Domptail 2011). To be more specific, cattle ownership serves as an indicator of wealth and pseudo-bank account (Matanyaire 1997, Pröpper 2009). Traditionally, few animals are slaughtered for commercial sale (MAWRD 2010). With only 42% of households in Mashare stating to have sold cattle during the preceding year, the study site lies even below the national mean of 53 % (MAWRD 2003).

The livelihood analysis also reveals that only a minority of households benefits directly from the ORB's economic transition: 78% of households rely mainly on the traditional livelihood sources mentioned above; for them, the only cash-based livelihood sources are pensions, remittances and governmental disaster relief. A few very poor households (12 %) depend exclusively on a very small cash income (often from old-age pension) and conduct no agriculture at all. Wage labour is mainly limited to casual agricultural labour. Only a few households (36%) receive a regular yet low salary from formal employment, e.g. in the military or in a local bar. Other households run businesses of their own, e.g. the mentioned bars or small local shops (14%).

Any livelihood strategies in the study site may rely on subsistence production. Nevertheless, Mashare cannot be characterized as a society that is based solely on subsistence production for its survival, because the role of government pensions (derived by 46 % of households) and drought relief (29 % of households) is too important for livelihoods. In fact, these external interventions and service flows may very well have started to disrupt or even have stopped processes that would be expected in true agrarian societies – including Boserupian intensification of agriculture. The following farming system analysis will take this development into account.

In summary, Mashare is characterized by a few wealthy and a majority of poorer households. Its social stratification is relatively advanced. As will be shown in the farming system analysis, ox-ownership and access to cash are not only important indicators of wealth; they also determine the farming strategies available to a household. Thus, for the following analysis, households have been clustered into the categories *wealthier ox-owning-* and *poorer non-ox-owning households* (see chapter 1.5). Their descriptive statistics are given in Tab. 1.17. The farming system analysis will emphasize the differences in farming practices between both categories.

Tab. 1.17: Characteristics of typical farm-household categories in Mashare, Namibia.

		Wealthy Cluster	**Poorer Cluster**
Household size (Nr. of persons per HH)		7 (SD: 3.9)	6 (SD: 3.1)
Number of Producers (aged: 16 - 59)		3.1 (SD: 2.1)	2.7 (SD: 1.9)
Share of Producers on HH size		0.48	0.46
Gender of HH head (% of female HHs)		30	50
Average age of HH head		52	55
% of HH heads who finished sec. school or higher		11	9.5
% of HH heads who finished primary school		26	29
Sample size		99	156
Livestock ownership:			
Goats (average herd size of HHs)		9.6	2.0
Cattle (average herd size)		16	0.4
Cattle **(quartile)**	25	2	0
	50	11	0
	75	20	0
	100	200	19
Ox-ownership (% of HHs owning the asset)		98	0
Use of Inputs (% of HHs using this at least sometimes):			
Fertilizer		3	0.6
Pesticides		1	0
Improved seeds		55	32
Manure		5	0.6
Mean annual cash-income (in US-$/HH/a)			
from Salary		1007	314
from Own Business		216	58
from Remittances		503	16
from Pensions		263	205
Mean annual cash income (US-$/HH/a)		**1846**	**721**
Mean annual cash expenditures (US-$/HH/a)		**1621**	**883**
Quartiles of annual cash income:	25	505	121
	50	868	535
	75	1904	920
	100	15848	3396

Source: Author's design based on empirical data. Note: The fact that the poorer cluster has higher expenditures than cash income may be explained by high data variability or un-assessed cash income sources.

Land tenure in Mashare

All land in Namibias part of the basin is designated as non-private communal land (Falk 2008, Pröpper 2009). Although land ownership is vested in the state, it is of restricted form and the state administers the land in trust for the benefit of the local traditional communities (Falk 2008). Namibia is characterized by the co-existence of statutory and both local and regional traditional authority.

What is important for the purpose of this study is that the permanent allocation of land to smallholders is granted by consent of local and regional authorities (Pröpper 2009). This provides smallholders with exclusive use rights to their land as long as it is cultivated (Low & Kamwi 1998). They can decide to leave the field in fallow for up to five years without forfeiting their use rights (MAWRD 1997) and even longer if this is agreed upon with the traditional authorities. According to El Obeid & Mendelsohn (2001), about 79% of all households in the Kavangos own fields, while 12% have to use fields which belong to other people. The rest of the households might not be involved in crop production at all (In Mashare, e.g., 12% of households is not involved in agriculture). Non-allocated communal land can be used by the community under open access conditions for activities such as grazing, fuelwood or thatching-grass collection (Low & Kamwi 1998). These lands lie within village boundaries, which commonly rest on oral agreements only – therefore they are a frequent matter of debate (Pröpper 2009).

1.6.2.2 Results of the farming system analysis in Mashare

Challenges to smallholder farming in northern Namibia

To better understand the challenges to smallholder agriculture in Mashare, it is worthwhile to first put it into its regional context. Smallholder agriculture in northern Namibia is rain-fed and characterized by low and declining productivity, stemming from a combination of insufficient and erratic rainfall, poor soil quality (Vigne & Whiteside 1997, MAWRD 1997, MAWRD 2010) and high distance from markets (MAWRD 2010). Extreme income inequality and poverty, under-nutrition, out-migration of labour and high population growth rates exacerbate this situation even further (Vigne & Whiteside 1997). Additionally, under current farming systems and due to the high rainfall variability, only pearl millet is resilient enough to yield a relatively reliable harvest (MAWRD 2010). Farmers are therefore forced to constantly replant pearl millet on the same field, thus causing soil degradation (ibid.). Due to the Kavango’s long dry season and limited rainfall, only one harvest of staple cereals can be obtained per year (Mendelsohn 2009). As irrigation of cereal fields occurs to a very limited degree only (3.5 % of households in Mashare), the majority of fields is by necessity left in seasonal fallow during the dry season. Mean per hectare yields in the Kavango’s are very low and lie between 100 and 300 kg (MAWRD 1997, MAWRD 2003, Low & Kamwi 1998, Low, et al. 1999, Mendelsohn 2009)[23].

[23] During the interviews, smallholders in Mashare claimed that their soils are of even lower natural fertility than those of their neighbouring communities, which for the east of the study site could be confirmed by visual checks on colour and texture of the soil. This may contribute to below-average yields in Mashare (see below).

Tab. 1.18: Main results of the farming system analysis in Mashare, Namibia.

Aspect of farming system	Results for *Mashare*, Namibia	SC	SPC	PC
Mean yield/ha[a]	221 kg/ha (millet)			
Mean field sizes[b]	1.5 - 2.5 ha			
Main types of crops	Cereals & legumes		X	X
Rotation intensity (R-value)[c]	91 - 100			X
Mean fallow period length	One season (if at all)			X
Mean cultivation period length	Continuous			X
Degree of land scarcity (as *perceived* by smallholders)	Very high			X
Cultivation tools & techniques	hoe-based cultivation / ploughing via animal traction / land clearing via slash-and-burn-techniques / fence-construction uncommon but promoted by traditional authorities		X	X
Soil fertility management	No sophisticated management, some HHs combine some of the following practices: 1. Short-term fallow (1-2 years) 2. Acquisition of fresh soil by clearing forest 3. Application of chemical fertilizer 4. Application of HH waste near homestead 5. Burning of dry season's fallow vegetation 6. Planting of legumes 7. Incorporation of crop residues or their ash into the soil via ploughing 8. Regular rotation of livestock kraals on fields aiming at fertilization with animal manure.		X	X
Seasonality of labour demand	Pronounced, especially before rainy season			X
Labour division	Division of tasks by gender, yet blurring		X	
Role of livestock for crop prdn.	Central for ploughing / limited use of manure		X	X
Land tenure	Communal land tenure with household-specific use rights to land allocated by traditional authorities (as long as land is under management, including fallow periods of more than 10 years)		X	
Further observations	Breakdown of cattle economy in last decade		X	X
Heterogeneity of livelihoods	Pronounced: Individual combinations of a limited choice livelihood sources			
Animal husbandry	Mainly partial nomadism for cattle and goats co-existing with stationary animal husbandry for goats & poultry.			

Source: Author’s design. Based on the theoretical framework presented in chapter 1.3, the observations are classified as being typical of Shifting Cultivation (SC), Semi-permanent Cultivation (SPC) or Permanent rain-fed cultivation (PC). The results indicate that the farming system in Mashare shows characteristics of both semi-permanent and permanent rain-fed cultivation. Note: [a] represents a conservative estimation because yields were assessed in a below-average rainfall year; [b] based on an interview with a village headman (local traditional authority in Namibia); [c] assuming a fallow period of 1 year every 10 years or even less.

The most important factor affecting agricultural yields is rainfall. Ideally, there are regular falls of sufficient amount throughout the growing season. Low & irregular rainfalls, on the other hand, do lead to crop failure and lower yields (El Obeid & Mendelsohn 2001). Namibia as a whole can be regarded as having a high propensity to drought (Vigne & Whiteside 1997). The resulting rainfall variability and differences in resource ownership lead to greatly varying inter-year and inter-household yields in the Kavangos (Mendelsohn 2009). Often, yields remain insufficient to provide for a household's basic needs (Mendelsohn 2009, MAWRD 1997, MAWRD 2003). Accordingly, Low et al. (1999) call the common rain-fed farming system in the Kavangos a low-potential agricultural system. Here, due to continuous, long-lasting cultivation and due to the low clay and loam content of the soils, a nutrient equilibrium of depletion & replenishment is achieved fairly quickly (Vigne & Whiteside 1997).

The dominant smallholder farming system in Mashare

The dominant smallholder farming system in Mashare represents a transitional stage between semi-permanent cultivation and permanent rain-fed cultivation (see chapter 1.3). The subsistence-oriented system combines the cultivation of millet (*Pennisetum glaucum*) and a variety of secondary crops, mostly legumes, on a few hectares with the keeping of small numbers of cattle and goat. Some households cultivate additional plots of maize (*Zea mays*) or sorghum (*Sorghum* spec.), yet millet dominates due to its superior drought-resistance.

Agricultural yields are highly variable and depend strongly on the amount and distribution of rainfalls; in 2013, a year of sub-average rainfall24 and incidentally the year of this study's yield assessment, millet yields averaged at only 221 kg/ha. Fallow periods are rare and occur mainly out of necessity, i.e. when in a certain year not all of the available arable land can be put into production due to drought, illness of family members or lack of draught animal power for ploughing. But even if used intentionally do fallow periods seldom last more than one or two years.

Households in Mashare live in scattered, permanent settlements along the river and the main roads. Their homesteads are typically located within their main field, although many do own additional fields which can lie at some greater distance. Field sizes in Mashare are generally small and range from 1.5 to 2.5 ha, which is typical for the entire region with its mean field size of 1.9 ha (Mendelsohn 2006). Horticulture is of lesser importance in Mashare: only 5.47 % of households do own a garden of their own, 75% of which are irrigated.

In total, households in Mashare cultivate 27 different crops. Yet as indicated before, most households cultivate only a fraction of this range of options (Fig.1.6). For example, only nine of these crops are cultivated by more than ten households and only four by more than 50% of the households. These are pearl millet (*Pennisetum glaucum*), maize (*Zea mais*), beans and groundnuts (Kowalski et al. 2013). They also represent the most important crops for cash income generation, although crop sales occur only occasionally and are done by just one out of three households. Instead, households in Mashare produce mainly for self-subsistence, with millet, beans and hibiscus being the most important crops for domestic consumption (ibid.). To cope with adverse climatic conditions, 38 % of households' plant improved seed varieties (obtained from local extension services or agricultural research stations). The crop diversity

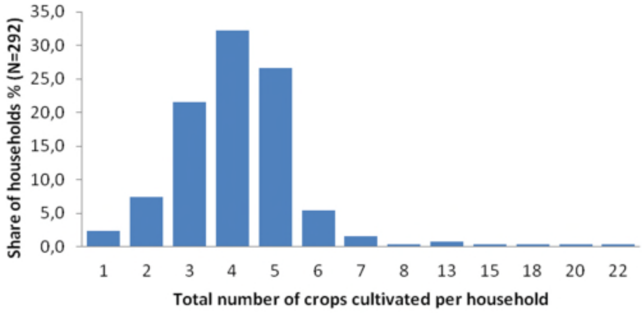
[24] Mean precipitation between October and April in the nearby urban center Rundu lies at about 575 mm, while in 2012/2013 it averaged at only 475. Source: Haeseler (2013).

within Mashare has been interpreted as a sign of an adaptation process to the major challenges to arable agriculture in the study site:

"*The high total diversity of crops cultivated in the research area, combined with a low average number of crops produced within the individual farms, indicates a variety of production strategies followed by local smallholders. The low within-farm crop diversity can be explained by the fact that under local rainfall and soil fertility conditions (erratic and extremely low, respectively), only pearl millet and pulses may yield a low yet stable production. While relying on these staple crops, some farmers experiment with other crops on field patches of slightly higher soil fertility* (Kowalski et al. 2013, 127)".

Attempts at the diversification of crop rotations aim at coping with declining soil fertility, while crop diversification itself contributes to reducing labour peaks for field preparation and risks from erratic rainfalls.

Fig. 1.6: Crop diversity in Mashare: share of households vs. total number of crops.



Source: Adapted from Kowalski et al. (2013).

Although the choice of secondary crops may vary, households in the study site rely upon the same basic agricultural practices and carry out largely the same agricultural tasks by using the same tools, i.e. oxen-drawn ploughs for land preparation and hoes for all other tasks. Even those households that do not own any oxen typically refrain from field preparation via hoeing. Instead, they prefer to wait until oxen-owners have completed ploughing their respective fields to then hire these oxen in exchange for cash or labour.

In general, the farming strategies in Mashare aim at adapting crop production to the environmental conditions of the study sites and not the other way around. They thus show some of the typical characteristics of systems with higher permanency of cropping, especially those of semi-permanent cultivation systems (see also tab 1.18).

Crop rotation, mixed cropping, and phased planting

As has been described in chapter 1.3, formalized crop rotations typically develop only in later stages of permanent cultivation. This is not yet the case in Mashare, where rotations are not fixed. Here, only deteriorating growth of cereals such as millet, maize or sorghum causes the rotation of that cereal with legumes such as groundnut in the next season. This lack of formalized rotations may also be connected to the fact that most plots are sandy and of low fertility. Thus, they cannot be cultivated with anything but the drought-resistant millet or legumes; only on those few plots of higher soil fertility can rotations of millet, maize and sorghum be found. This observation appears to hold true for the wider region in general (Vigne & Whiteside 1997). Here, due to a lack of alternative crops which are suited to local

growing conditions, crop rotations can be applied to only 5 % of the land cultivated with millet (ibid.). Nevertheless, these constraints do not seem to affect rotations of secondary (i.e. non-cereal) field crops, which are reported to take place with bean, pumpkin and melon on two thirds of all fields (MAWRD 1997).
Mixed cropping is facing a similar challenge. While the combination of millet and legumes on the same plot is common, other combinations are rare. This may be connected to the soil fertility issue described above. It may also help explain, why more sophisticated farming practices have not yet been adopted, although Mashare according to its high R-values of above 90 should represent a system of permanent rain-fed cultivation.
Phased planting is a luxury that is rarely practiced intentionally. Rainfalls are so scarce that as soon as the soils are sufficiently moist, farmers put as much land as possible into production (see section on labour economy below). Yet as the high rainfall variability of the region does regularly cause crop failures, most households are forced to replant at least some parts of their field, thus leading to a phenomenon that might be called unintended phased planting. Furthermore, the dominant mixture of legumes and millet, and more importantly that of maize and sorghum on relatively fertile plots, leads to a period of phased harvesting lasting from February to mid-July, with May being the most important harvesting season.

Labor needs within an agricultural cycle in Mashare
As is typical for semi-permanent and permanent cultivation systems, the most labour-demanding tasks of crop production in Mashare are weeding and field preparation, the latter of which includes various sub-tasks such as removing the annual weeds, tilling and planting (tab 1.20). Tilling occurs primarily via the help of ox-drawn ploughs, with oxen representing the primary source of draught-animal-power in Mashare; their use allows for a great reduction in labour-demand for ploughing as compared to manual tilling (20 hours/ha vs. 280 hours/ha). This is of critical importance for the functioning of the study site's current farming system, because the time-window available for ploughing is short and dependent on (erratic) precipitation. Typically, the on-set of the rainy season is marked by a few days of rainfall only. Only after the soil has been sufficiently moistened by rainfall can farmers start to till their fields. However, rainfalls rarely last more than a few days and subsequent transpiration quickly reduces the soil's moisture content to a level where tilling is not anymore possible. Farmers are thus faced with a short and erratic time window during which they have to carry out the main part of all ploughing and planting activities. This results in a pronounced peak in labour-demand at the beginning of the rainy season which sometimes restricts the size of cultivated land and thus farm productivity in a given year. Reliable access to oxen for ploughing is thus crucial for the current farming system's ability to feed the local population. Lack of draught animal power may not only result in smaller cultivated areas but also in late planting and thus higher rates of crop failure as well as the wasting of earlier rainfalls. Aside from ploughing and transporting, all other agricultural tasks in Mashare are carried out manually. Another means of dealing with peaks in labour-demand, at least for wealthier households in the Kavango regions, is the strengthening of the household workforce by hiring external workers (El Obeid & Mendelsohn 2001).

Households in Mashare pool their labour to jointly manage their family holding. The main form of division of labour concerns gender – males are for instance responsible for ox-based ploughing, while women carry out most weeding. However, this division has started to blur and can be abandoned during peak seasons in labour-demand. This phenomenon is typical for both semi-permanent and permanent cultivation systems. However, the pronounced contrast of very high labour-needs at the beginning of the rainy season and relatively low labour-needs during the dry season indicates, that Mashare's labour economy is more typical of permanent rain-fed cultivation than of semi-permanent cultivation.

Another phenomenon that is typical for higher permanency is that the concept of working groups, where neighbours gather to jointly carry out certain tasks within each other's holding or for communal tasks that benefit the entire village society, has been abandoned. These working groups are more typical for shifting cultivators. In Mashare, however, they were abandoned only so recently that farmers are still able to remember them.

The annual agricultural cycle in Mashare begins in the dry season in August with what farmers call de-bushing, i.e. the clearing and burning of annual weeds. Afterwards, a few farmers go through the effort of transporting and applying manure to the field. The majority, however, waits for October to carry out a task called pre-planting. This refers to the planting of pumpkin seeds in the fertile mounds of ash that were creating by de-bushing, around tree-stumps in the field where the plough where the plants will not be damaged by the plough, or in former homesteads as well as directly around the cattle kraals where household wastes and manure lead to increased soil fertility. This task is done before the first rains start to fall. It provides households with an early ripening food source that is available already by January.
The vast majority of farmers now waits for the on-set of the rainy season between November and January. As soon as precipitation has sufficiently moistened the soil, ox-owners start to carry out ploughing and planting at the same time (with males managing the ploughs and females following directly behind and planting seeds in the plough furrows). Household's that do not own any ox typically wait for ox-owning households to finish their field preparation. Once this is done, they hire both the ox-owner as well as the ox for field preparation, remunerating them typically in cash but sometimes also in kind or in exchange for later labour, e.g. for weeding on the ox-owners fields.
Planting/Sowing is carried out either by broadcasting (where the seeds are generously scattered over the field), or by so-called pot-by-pot planting (where a few seeds are planted within the oxen furrows or holes that are created by a hoe). Pot-by-pot planting was the only type of planting encountered during the yield assessment; it is characterized by higher labour-needs than broadcasting (80 h/ha vs. 1 h/ha) but slightly lower seed needs. The reason for its dominance over broadcasting may lie in the fact that carefully planted seeds are less prone to crop failure than seeds that are sown on the topsoil – broadcasting could thus be a risk that Mashare's farmers cannot afford to take.
Between November and December, households are often forced to re-plant patches of withered crops, which were lost due to erratic rainfalls. A few households will now install bird traps against guinea fowl, yet the majority will start with the long lasting task of chasing away any birds from their fields. This needs to be done from directly after planting (mainly in December) until harvesting (the main season of which is in May). It is done either by children or parallel to any cultivation task which adults carry out at this time. Weeding occurs during the same time period and is normally done only once (yet, depending on weed infestation, up

to three times per growing season is possible). Harvesting can last from February to mid-July, yet the main harvest period of millet and maize is in May.

The main tasks connected to post-processing are storing the food in especially created storage shelters, the creation of a hard-pan made out of termite-mound clay and subsequent threshing of the harvest on this hard-pan. Storage shelters can be of two kinds: while ox-owning households typically create a shelter reminiscent of a little house on stilts, non-ox-owners do rarely go through the effort of manually transporting logs for stilts to their homestead. Instead, they create an on-the-ground shelter, which is much more susceptible to rotting due to humidity or rainfall. The next agricultural cycle starts again with the removal of those weeds that regrew on the field during the dry season.

Tab. 1.19: Seasonal calendar of natural resource-based livelihood activities in Mashare

	June		July		August		September		October		November		December		January		February		March		April		May	
Main annual cultivation activities:	1st half	2nd half	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
De-bushing (the annual or bi-annual bushes)																								
Gathering and burning of bushes																								
Transporting manure to the field																								
Spreading manure																								
Pre-planting (of pumpkin on ash of burned bushes or 5 meters from kraal)																								
Ploughing with a hoe																								
Sowing with a hoe																								
Sowing via Broadcasting before ploughing with an oxen																								
Ploughing with oxen																								
Planting Maize-seed into oxen furrow																								
Planting Mahangu-seed on top of furrows into which maize was planted																								
Setting up bird traps (esp. for Guinea Fowl)																								
Sowing seeds via broadcasting on grass before weeding (=re-planting)																								
Weeding																								
Chasing away birds (starts directly after sowing)																								
Harvesting (main season = May)																								
Transporting crops from field into storage for drying																								
Collecting termite mud for building a threshing pan																								
Making a hard-pan for Threshing																								
Bringing crops to threshing																								
Threshing																								
Main non-annual cultivation activities:																								
Clearing field from forest																								
Husbandry and natural resource use activities:																								
Cutting & marketing of reeds																								
Cutting thatching grass																								
Marketing of thatching grass																								
Collecting & marketing of nuts & fruits																								
Hunting																								
Collecting *Mopane* worms																								
Collecting termite mud for huts																								
Making fish traps																								
Herding cattle																								
Milking cattle																								

Source: Author’s design based on empirical data.

Tab. 1.20: Mean labour-demand of agricultural tasks per hectare & year & gender

Regular activities of the dominant farming system in Mashare Variable labour needs (i.e. proportional to field-size)	Working-**hours** needed per ha/activity/a	Task carried out by which **gender** primarily?	Estimated **share of producer labour** involved in this task
De-bushing annual or bi-annuals	150	both gender	0,7
Gathering and burning of bushes	80	both gender	1
Pre-planting (of pumpkin on ash of burned bushes or 5 meters from kraal)	7,5	females	0,5
Ploughing with oxen	20	males	1
Planting Maize-seed into oxen furrow, Maize on top	80	(assumed) both gende	1
Re-planting (via broadcasting seeds before weeding)	1	both gender	0,5
Field preparation & planting (sum of tasks above)	**338,5**		
Weeding	**220**	both gender	0,7
Harvesting a millet field (assumed harvest of 250 kg)	**25**	both gender	0,5 (assumed)
Transporting crops from field into storage for drying	**8**	(assumed) both gende	1
Total field size-related labour needs of traditional arable agriculture (hours/ha)	**592**		
Non-variable labour needs (i.e. not proportional to field-size)	Annual working-**hours** needed	Task carried out by which **gender** primarily?	**Share of producer labour**
Chasing away birds	289	both gender	0,25
Setting up bird traps (esp. for Guinea Fowl)	40	males	0,5
Gathering & Transporting termite mound mud for building a threshing pan (by hand)	320	both gender	0,7
Making a hard-pan for Threshing	3	females	1
Threshing (350kg)	56	both gender	1
Total annual non-variable labour needs (hours/a)	**708**		
Irregular or alternative activities of the main farming system in Mashare Variable labour needs (i.e. proportional to field size) in hours/ha			
Applying manure	200	females	0,5
Transporting manure by oxen to the field	40	males	0,5
Transporting manure manually to the field	200	females	0,5
Applying fertilizer (no data; assumed 50% of manure application due to low amount)	100	both gender	1
Clearing field from forest	440	males	1
Ploughing & planting with a hoe	280	both gender	0,7
Sowing via Broadcasting before ploughing with an oxen	1	females	0,5
Collecting termite mud for building a threshing pan by oxen	100	males	0,5

Source: Author’s design based on empirical data.

Tab. 1.21 compares the family labour needed for cultivation in Mashare with those of other areas of semi-permanent or permanent cultivation, mainly in the semi-arid tropics. Again, it has to be kept in mind that labour-needs do not only differ between systems, but also between individuals of the same systems – some farmers may work at a more leisurely pace or work slower because they are malnourished, other may work quicker and more effectively. These numbers serve only as a rough reference frame for the comparison.

Tab. 1.21 suggests that labour-needs/ha in Mashare are relatively high yet still in a range that is plausible for ox-based semi-permanent or permanent cultivation. The fact that Mashare appears to be at the upper end of the scale may also be related to the fact that de-bushing was explicitly included in field preparation. Most other studies considered mainly ploughing and planting within this category, and when looking only at these tasks Mashare appears to lie well within its typical range (100 hours/ha). The labour-needs for weeding appear to lie within a reasonable range, too. The relatively low labour-needs in the Kavangos that were reported by Hecht (2010) and MAWRD (1996) may be related to the fact that these authors included or focused on the regions not adjacent to the Okavango river. Here, lower levels of land scarcity than in Mashare may allow for a regular extension of fields into former woodlands and thus lead to lower levels of weed-infestation as is typical for more permanent cultivation (see Ruthenberg 1971). This would result in reduced labour-needs for weeding. Labour needs for harvesting appear to be relatively low in Mashare. However, they are in line with other findings from the region (Hecht 2010) and may be connected to the Kavango's low mean yield-level. It just does not take as long to collect a meagre harvest as it does to collect an abundant one.

Tab. 1.21: Overview of labour needs of main agricultural tasks in various semi-permanent and permanent cultivation systems in working-hours/ha.

Location	**Field preparation & planting** (hours/ha)	**Weeding** (hours/ha)	**Harvesting** (hours/ha)	**Total labour** (hours/ha)	**Characteristics of the system**
Study Site **Mashare,** Kavango region, Namibia*	339 (20 for ploughing & 80 for planting)	220	25	**592**	semi-permanent to permanent ox-based cultivation
Burkina Faso (Upper Volta)**	88	180	208	**476**	semi-permanent cultivation of millet (hoe-based)
Burkina Faso (Upper Volta)**	152	252	64	**468**	semi-permanent cultivation of maize (hoe-based)
Tanzania, Sukumaland*****	390	250	300	**940**	semi-permanent cultivation of maize & sorghum (hoe-based)
Senegal, Kaolak**	136	110	210	**456**	semi-permanent cultivation of groundnut (plough-based)
Senegal**	66 (land preparation) + 8 (planting)	86	64	**224**	permanent cultivation of millet (plough-based)
India**	32 (land preparation) + 16 (sowing/planting)	32	56	**136**	permanent cultivation of sorghum (plough-based)
Cameroon**	136 (land preparation) + 120 (planting)	216	80	**552**	permanent cultivation of sorghum (hoe-based)
Kavango region, Namibia ***	34 (field preparation) + 31 (planting)	93	90 (incl. threshing)	**248**	plough-based cultivation
Kavango region, Namibia ***	46 (field preparation) + 31 (planting)	93	90 (incl. threshing)	**260**	hoe-based cultivation
Kavango region, Namibia ****	40 (field preparation) + 24 (broadcasting) or 27 (row planting)	10 (if plough-based in rows)	17 (harvesting) + 51 (threshing)	**142 +**	plough-based cultivation
Kavango region, Namibia ****	54 (field preparation) + 24 (broadcasting) or 27 (row planting)	65 (hoe-based without rows)	17 (harvesting) + 51 (threshing)	**211 +**	hoe-based cultivation

Sources: * = empirical data, **Bureau pour le développement de la production agricole (1967) in Ruthenberg (1971), *** = MAWRD (1996:37) in Hecht (2010), **** = Hecht (2010:119), ***** Rotenhan, D. (1966) in Ruthenberg (1971).

Tab.1.22: Mean annual household labour-demand for natural resource use & household chores in Mashare, separated by month & season.

Dry Season | Rainy Season

	June (1-15, 16-30)	July (1-15, 16-31)	August (1-15, 16-31)	Sept. (1-15, 16-30)	Oct. (1-15, 16-31)	Nov. (1-15, 16-30)	Dec. (1-15, 16-31)	Jan. (1-15, 16-31)	Feb. (1-14, 15-28)	March (1-15, 16-31)	April (1-15, 16-30)	May (1-15, 16-31)	Gender specificity of task	Estimated share of producer labour
Seasonal activities:														
Hunting	28	28	28	28	28	28	28						Shared	1
Cutting reeds	30												Shared	0.5
Collecting termite mud for huts	8												Male	0.5
Cutting thatching grass	18		18		18								Male	0.5
Collecting fruits/nuts				80	80	80	80						Male	0.5
Collecting *mopane* worms					60	60							Female	0.5
Making baskets for collecting fish			5	5	5	5							Female	0.5
Making fish traps						5							Female	0.5
Maintaining reed fence around homestead				16									Male	0.5
Herding	540						558	558	504	558	540	558	Shared	0.5
Milking livestock						15	16	15.5	14	15.5	15	15.5	Male	0.5
Regular or indeterminate activities														
Washing dishes	30	31	31	30	31	30	31	31	28	31	30	31	Female	0.5
Collecting fire wood	24	24	24	24	24	24	24	24	24	24	24	24	Female	0.5
Pounding	64	64	64	64	64	64	64	64	64	64	64	64	Female	0.5
Repairing clothes	2	2	2	2	2	2	2	2	2	2	2	2	Female	0.5
Cleaning the yard inside & outside	24	24	24	24	24	24	24	24	24	24	24	24	Female	0.5
Washing clothes	32	32	32	32	32	32	32	32	32	32	32	32	Female	0.5
Fetch water	120	124	124	120	124	120	124	124	112	124	120	124	Female	0.5
Fishing	30	30	30	30	30	30	30	30	30	30	30	30	Shared	0.5
Making baskets	90 hours per year												Female	1
Slaughtering and marketing livestock	22 hours per year												Shared	0.5

Source: empirical data. Note: Each task's gender specificity and estimated share of producers involved in each task indicated.

In order to derive a complete picture of rural households' labour economy, the analysis of agricultural labour-demand needs to be complemented by working-hours invested in other livelihood sources. The relatively higher variety of livelihood strategies in Mashare than in Cusseque makes it complicated to report average labour-needs per task for every household. However, the numbers reported in Tab. 1.22 give the average labour-needs for natural resource related activities and household chores for what local farmers perceive as a typical and realistic workload. In Tab. 1.23 and 1.24 the average family labour needed per household per year has been summed over both dry and rainy season and converted into household producer labour[25], i.e. labour that needs to be invested by household members aged between 15 and 59 years. This allows for a more meaningful comparison of labour-needs over all three study sites. Based on focus group results, season lengths of on average 200 days for the dry season and 165 days for the rainy season have been assumed. Remember, cluster analysis was used to group households into two categories – wealthy ox-owning households and poorer non-ox-owning households. As cattle are central agricultural assets (oxen) and a wealth indicator, the basic farming strategies of these two groups are likely to differ. Furthermore, the wealthy ox-owners have to invest labour into animal husbandry. As indicated by tables 1.23 and 1.24, this results in a different labour availability for each household groups. See table 1.17 for descriptive statistics.

Tab. 1.23 indicates that households that do not own any cattle spend on average 34 % of their family (producer) labour in the dry season on household chores and natural resource use activities. It becomes even less during the rainy season (30 %). The difference is caused by the higher amount of time invested in hunting and natural resource collection during the dry season.

Those households that do own cattle on the other hand invest during the dry season on average as much as 41 % of their family labour on these activities and even 60 % during the rainy season (Tab. 1.24). This strong difference can be mainly explained by the labour invested in cattle keeping, especially herding during the rainy season. This illustrates the big commitment of work time that a household has to make when engaging in cattle keeping - an investment that nonetheless appears to pay off as will be shown below.

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[25] This conversion was done by multiplying the labour needs of a specific activity with its estimated share of producer labour invested in this activity. The estimated share of producer labour was derived from focus group results as follows: If an activity was reported to be carried out by adult males, adult females and the children, it was assumed that only 50% of the labour hours needed for task need to be carried out by producers. If an activity was reported to be carried out by adult females and both underage boys and girls, it was assumed household producers were needed to carry out only 30 % of the working hours required.

Tab. 1.23: Annual family-labour budget of a household *not owning cattle*

	Dry Season	**Rainy Season**
Total available household producer labour (working hours/ HH/a)[a]	4320	3564
Mean HH labour demand for activities in working hours/HH/a (corrected to producer labour)		
Shared	267	125
Male	139	60
Female	1072	879
= Sum	1478	1064
Total remaining labour available for agriculture, wage-labour & leisure	2842	2500

Source: Empirical data. Note: Calculation of producer labour available for arable agriculture, wage-labour or leisure carried out by deducting mean labour needs for natural resource use and household chores from total available producer labour pool. [a]Calculated by multiplying the mean of 2.7 producers with 8 hours of daily working time and the respective season length. In more permanent cultivation, a longer working day is assumed than under less permanent systems (Boserup 1965) – the assumed daily working hours in Cusseque were 6.6 hours.

Tab. 1.24: Annual family-labour budget of *cattle-owning households*

	Dry Season	**Rainy Season**
Total available household producer labour (working hours/HH /a)[a]	4960	4092
Mean HH labour demand for activities in working hours/HH/a (corrected to producer labour)		
Shared	821	1489
Male	151	102
Female	1072	879
= Sum	2044	2470
Total remaining labour available for agriculture, wage-labour & leisure	2916	1622

Source: Empirical data. Note: Calculation of producer labour available for arable agriculture, wage-labour or leisure carried out by deducting mean labour needs for natural resource use and household chores from total available producer labour pool. [a] Calculated by multiplying the mean of 3.1 producers with 8 hours of daily working time and the respective season length.

The role of cattle in crop production and for field sizes

Cattle in Mashare are kept under free grazing in the dry season. With the on-set of the rainy seasons, households are forced to herd the animals. This can include leading the animals many kilometres into Mashare's hinterlands, where grazing is more abundant. At night the animals are kraaled near the homesteads. Tab. 1.23 shows that while non-cattle-owning households spend about 30% of their productive time on natural resource use and household chores, wealthier cattle-owning households spend about 40% (dry season) and 60% (rainy season) of their labour on these tasks (Tab. 1.24). This difference stems only from two main tasks related to cattle husbandry, i.e. herding and milking. Although tasks like taking care of animals or maintaining the kraal were not included here, these two tasks already result in significantly higher seasonal labour needs than those of non-cattle owning households[26].

Obviously, keeping cattle requires a lot of labour and may greatly reduce the amount of time that a household can invest in other activities. However, this drawback is offset by the benefits that cattle provides to its owner: Apart from its social role as a sign of prestige, a means to deal with production risk or its function as a pseudo-bank account (that can be tapped in times of need: Pröpper 2009), it is a critically important production asset. In fact, the results presented here confirm prior findings (Mendelsohn 2009, El Obeid & Mendelsohn 2001, MAWRD 1997) that draught animal power is one of the most important productive assets in the entire Kavango region, second only to family labour[27]. Studies also revealed that cattle ownership in Kavango is positively correlated with household size and size of cultivated areas (Mendelsohn 2009; MAWRD 2010; MAWRD 1997; Low et al. 1999).

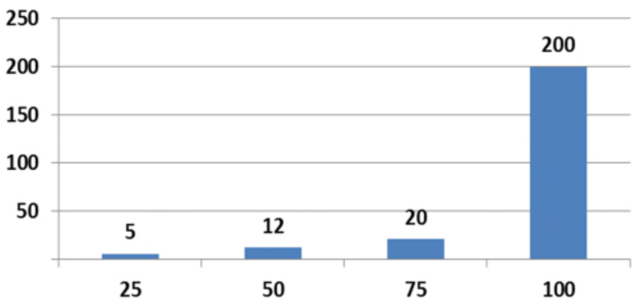
Tab. 1.25 depicts the correlation between mean cattle herd size and cultivated area for households in the Kavango regions and Fig. 1.7 the maximum cattle herd size of each percentile of cattle-owning households. These different herd sizes can now be used as an additional means for gauging average field sizes in the study site. With half of all cattle-keeping households owning less than 11.5 animals, their mean field size can be expected to lie at or below 1 – 3 ha. Larger field sizes of 3 – 7 ha are only common for those households owning bigger herds (and wealthy enough to hire workers). When considering that households not owning any cattle account for 67 % of Mashare's population, this finding is in line with a local headman's estimation that the mean field size in Mashare lies between 1.5 and 2.5 ha.

Tab. 1.25: Mean numbers of cattle per household vs. area cultivated in the Kavango region

Area cultivated (hectares)	Average number of cattle
Less than 1	5
1-3	10
3-5	16
5-7	22
7 +	25

Source: Author's design, based on El Obeid & Mendelsohn (2001).

Fig. 1.7: Maximum cattle herd size per percentile of cattle-owning households



Source: Author's design based on empirical data.

[26] In Mashare, 90% of households that own cattle *and* practice arable agriculture also own an ox; to facilitate analysis, it is assumed that ox-ownership is synonymous to cattle-ownership.

[27] This finding was also the reason for the grouping of households into a wealthier group of ox-owners and a poorer group of non-owners.

What makes these findings so important is that despite the central role of cattle in Mashare, ownership among households is highly skewed. Merely 33 % of households own any cattle and even within this group of cattle owners, only every fourth households owns a herd of more than 20 animals. Farmer interviews indicate that over the course of the last one or two decades, cattle numbers have greatly decreased and that the much skewed ownership is a relatively recent phenomenon. Farmers see the main reason for this in livestock diseases, which are spreading quickly on the communal grazing areas due to high cattle densities; they lead to increased livestock mortality. Farmers indicated also that 10 years ago, the majority of households in the study site owned at least a small cattle herd. Nowadays however, only the wealthy households are able to afford medicine to keep their herds healthy. This financial constraint makes it also impossible to rebuild the herds. Despite an increasingly skewed cattle ownership, average cattle density remains constant. As there was no change in rangeland management over the last year, pastures cannot be expected to be able to regenerate.

These findings are in line with Matanyaire (1997), who observed Hardin’s (1968) *tragedy of the commons* on the communal pastures of the Kavangos’. Other authors confirmed that rangeland degradation is taking place within the Kavangos (Sweet 1998, Vigne & Whiteside 1997, El Obeid & Mendelsohn 2001). While a few wealthier households purchase medicine and additional feed to keep their herds healthy, the poorer continue to rely on degraded pastures. They easily lose their livestock due to insufficient feed (or, alternatively, sell it due to lack of other cash sources). Over time, the owners of smaller herds are thus slowly crowded out of the pastures (Matanyaire 1997). These factors complicate the acquisition of new animals. Falling income levels reduce the alternatives of the poor and keep them in a vicious circle (ibid.). The ongoing stratification of Mashare’s society (into a few owners of larger herds and a majority of households without any cattle) suggests that is affected by this process as well. It also suggests that land degradation may be occurring in Mashare as well. It may result in reduced rangeland quality and lead to reduced cattle health.

Moreover, the breakdown of the cattle economy in Mashare is a typical phenomenon for late stages of permanent cultivation (Ruthenberg 1971). According to him, communal grazing under high livestock densities almost invariably leads to increased livestock mortality. In the end of such a typical process, limited access to oxen will force households to revert to hoe-based cultivation for their survival. Appropriate communal rangeland management plans are one of the few options that may stop this process (Ruthenberg 1971), yet households in the study site seem unaware of this possibility.

These changes in the livestock economy are typical for farming systems of higher permanence. However, they can already be observed in Mashare, which has been characterized as a transitional stage between semi-permanent cultivation and permanent rain-fed cultivation. This surprising finding may be caused by the high population and livestock density along the Okavango River and the regions biophysical conditions, which are unfavourable for crop production. For some households, lack of access to oxen is already the main bottleneck in farm productivity. Despite a relatively advanced land scarcity, some of the poorer households reported to not anymore manage to plough all of their land and that the size of their cultivated land thus differs from their maximum possible field sizes.

Soil fertility management

Households in Mashare follow a variety of individual soil fertility management strategies. However, these strategies are based on a limited set of common and well-known management options, which will be described below. Households combine these options in individual ways, depending on their resource endowment, farm managerial abilities and other factors. Although no dominant strategy could be discerned, the majority of farmers appear not to follow by any sophisticated approach. In general, the strategies applied by the majority of households appear rarely to allow for the complete regeneration of soil fertility. In total, eight main means of soil fertility management could be identified in Mashare. These are:

1. Short-term fallow (1-2 years).
2. Acquisition of fresh soil by clearing forest.
3. Application of chemical fertilizer or animal manure.
4. Application of household wastes on fields directly around homesteads.
5. Burning of dry season fallow vegetation and crop rotation/mixed cropping.
6. Planting of legumes.
7. Incorporation of crop residues or their ash into the soil via ploughing.
8. Regular rotation of livestock kraals on fields aiming at fertilization with animal manure.

Although fallow is widely recognized as a good option for soil fertility management, only a few households apply it. Even then, they do so rarely for more than one or two consecutive years - because they feel that land is too scarce to be left in fallow for long.

The most widespread approach towards increasing soil fertility is land clearing. Some households do still own small stretches of bush or forest adjacent to their fields that can be cleared. Households that do not have this option are forced to use more distant and less fertile plots in the hinterland, i.e. on Kalahari sands of low fertility. In these areas, access to water is more problematic than along the river. Some farmers even expressed their fear of the deeper hinterland, which they regarded as the *land of the animals*, where crop damages do not only occur more regularly but where more importantly mankind is not in control. Other households are just not willing to live that far away and isolated from their community. The option of clearing new land is therefore very limited within Mashare.

The same holds true for the application of chemical fertilizer. Due to its high costs and unreliable access, it is applied very rarely (3 % of wealthy ox-owning households and 0.6 % of poorer non-ox-owning households). This is typical for farmers in the Kavangos (MAWRD 1997, Mendelsohn 2009, El Obeid & Mendelsohn 2001). Animal manure is applied by very few farmers only (5 % of wealthier households and 0.6 % of poorer households).

What is practiced by virtually all households, yet not always as a conscious act of fertility management, is the discarding of household wastes on a certain area near the homestead. Usually, this has a fertilizing effect on only a small area. Practices that are applied more consciously are the burning of dry season fallow vegetation as well as crop rotations and mixed cropping. The former plays an important role for food security in the study site, as it allows for the pre-planting of pumpkin. The latter two include the rotation and/or mixed cropping of millet, maize, sorghum and legumes on plots of higher soil fertility and of millet and legumes on spots of lower soil fertility. Commonly, they are used only when crop performance has declined in the prior harvesting period.

Another option that could theoretically be followed by all households is the use of crop residues to restore soil fertility. However, crop residues are used for a variety of other purposes, and only 11% of smallholder households incorporate them into the grounds via burning or burying. Instead, 85% of households use them as construction material and for 53% as grazing material for livestock. 37% of households just leave the residues on their field, not as a means of feeding livestock although grazing occurs anyways, due to a lack of fences and herding during the dry season.
A last and important option, (available livestock-owners only), is the shifting of the *kraal's* location over the field to create a series of fertilized field plots. However, the farmer interviewed on this practice did actually stop to follow this practice because she relocated her herd to more productive pastures deep in the hinterland, where employed herders tend to the animals. Her reason to do so was the low quality of pastures in the study sites; this indicates that overgrazing may start to restrict this option for soil fertility management. Furthermore, manure transport from the hinterland to the river does not yet occur.

Another challenge to soil fertility management lies in the fact that households tend to continuously cultivate the land around their homestead while leaving only the more distant areas in fallow. The reasons are twofold: First, to protect their fields from grazing livestock, they prioritize the areas directly around their homesteads for cultivation. These can be more easily protected than distant locations. Second, if these households are forced to leave parts of their fields in fallow (e.g. due to sickness or lack of draught-animal power), households tend to choose the more distant areas. This results in a continuous cultivation of the land surrounding the homestead. If the household does not manage to plough all of its land, this is likely to result in increased rates of soil mining near the homestead than on more distant plots. On the one hand, this may describe a conscious trade-off decision of farmers between soil fertility and the risk of crop losses. On the other hand, Vigne & Whiteside (1997) suggested that under traditional farming, soils in the Kavango's quickly reach a nutrient equilibrium, indicating that the already low natural soil fertility does not allow for any significant degradation. This could be interpreted as some households in Mashare already being caught in Ruthenberg's (1971) low-level equilibrium trap, where only way out is to switch to a new, intensified farming systems (see chapter 1.3).

The practices of soil fertility management presented above are typical for late stages of semi-permanent cultivation or early stages of permanent rain-fed cultivation. It is thus in line with the assumption that Mashare may represent a transitional stage between these two systems. In general, today's main smallholder farming system in Mashare appears to have originated from a system that was relying on land abundance and the shifting of field locations via periodical clearing. It is likely that one of these origins was the shifting cultivation system practiced in Angola. Today, farmers in Mashare appear to struggle to adapt to rising scarcities of -land, -soil fertility and -livestock. Although a certain range of management options does exist, especially the poorer, non-ox-owning households are forced to rely mainly upon crop rotation and mixed cropping. It can be expected that, just as proven for the Kavango region in general, soil fertility in Mashare is degrading or that is has even stabilized at a very low level. This also helps to explain why on many fields nowadays only millet and legumes can be grown.

1.6.2.3 Conclusion: Trends of Smallholder Farming in Mashare

Mashare appears to represent a transition stage between semi-permanent and permanent rain-fed cultivation (Ruthenberg 1971). While the R-value of 91-100 clearly indicates a permanent character of crop production, some households are still able to irregularly extend their fields by clearing natural vegetation. Important farm management aspects resemble a mindset of less permanent cultivators, while certain phenomena of especially the livestock- and fertilizer-economy are typical for permanent cultivation. These observations hint at the co-existence of a late stage of semi-permanent cultivation with an early stage of permanent cultivation - which suggests that Mashare may best be characterized as a transitional stage between both systems.

The origins of Mashare's smallholder farming system appear to lie in more land abundant regions, importantly in southern Angola where shifting cultivation is practiced; When farmers moved to Mashare at the beginning and during the middle of the 20th century, they established their farms on fertile spots along the Okavango river, with distances of up to several kilometers between each holding. Over course of 20th century (and thus within the lifetime of these first farmers), population growth has led to a situation where households are now clustered densely along the river and where most fertile land has been put into production many decades ago. Despite its relatively young age, Mashare's farming system does already show phenomena that are normally encountered under late stages of permanency only – such as the gradual breakdown of the cattle economy and a low soil fertility permitting the production of only millet and legumes. The relatively high speed with which these degradation dynamics are taking place may be connected to the study sites biophysical conditions, which appear to be very vulnerable to traditional forms of agriculture.

These dynamics have set Mashare on a pathway towards a *"low-level equilibrium trap"* (Ruthenberg 1971, 125). It describes a situation where Boserupian intensification did not set in and instead *agricultural involution* (Geertz 1974) lead to a perseverance of the dominant farming system. Mashare may thus represent nothing more than a degraded form of shifting cultivation as practiced in southern Angola, yet located on drier Kalahari bushlands and not within *Miombo*-woodlands. Government intervention in the form of disaster-aid may have slowed smallholder adaptation to rising land scarcity and contributed to Agricultural Involution. Instead of developing adapted farming practices of their own, many households are today forced to put more and more infertile plots into production, where erratic rainfalls are even more likely to cause crop losses.

The benefits of the basins economic transition towards a cash-based society do not reach the majority of households – rather, it are only a few wealthy households that manage to diversify into these new, cash-based livelihood sources and who have sufficient cash-surplus to e.g. pay for livestock medicine or hire herders to graze their livestock on greener pastures which lie farer away. The rest of households lacks in resource endowment, knowledge or entrepreneurship to reap the benefits of this transition. With ongoing degradation of traditional livelihood sources and natural resources, these households may increasingly be left behind.

A typical phenomenon of later stages of permanent rain-fed cultivation is the development of a class of landless labourers and of a growing group of rural poor, which due to migration also create problems of urban poverty (Ruthenberg 1971). This cannot yet be observed in Mashare; however, if the poorest households in the study site are increasingly unable to cultivate sufficiently large areas that allow ensuring their survival, it may become a reasonable strategy for them to find an appropriate arrangement with wealthier households who aim at increasing their own cultivated area.

On the other hand, Mashare's agricultural crisis presents also a great chance for sustainable intensification and increases the likelihood of smallholders adopting improved yet more labour intensive farming systems. Although only few farmers are able to follow this pathway unassisted and thus achieve endogenous, or Boserupian intensification, the majority may be willing to voluntarily accept the higher labour needs that are a typical side effect of intensification. Given external assistance, a considerable proportion of Mashare's rural population may be willing to adopt a sustainably intensified farming system and accept the higher labour burden connected with this adoption.

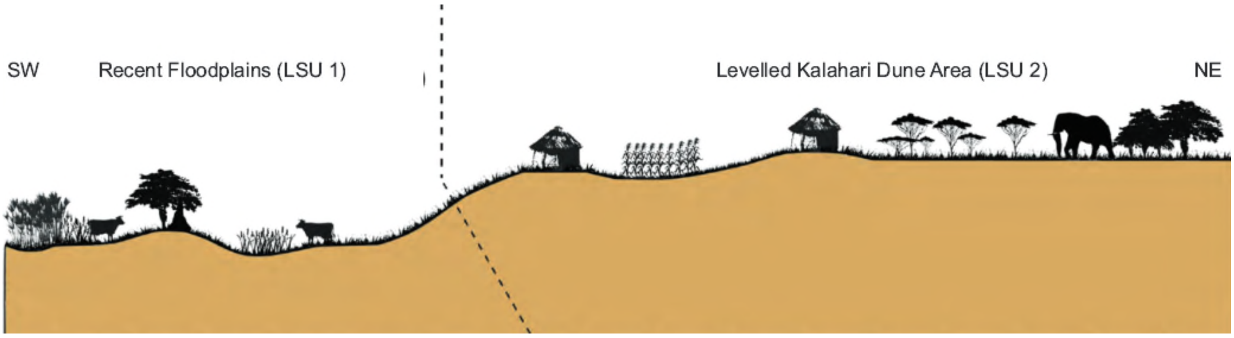
1.6.3 Semi-permanent rain-fed agriculture in Seronga, Botswana

1.6.3.1 Climate, livelihoods and socioeconomic framework

Biophysical setting

The study site *Seronga* is situated at the edge of the Okavango delta, where a swampy stretch of the river (known as the *panhandle*) opens into the delta's alluvial fan. At a mean altitude of 990 m a.s.l., Seronga's landscape is divided into two ecosystems: the panhandle's wetlands and the levelled Kalahari Dune Area of the hinterlands (Fig. 1.8 & Gröngröft et al. 2013e).

Fig. 1.8: Landscape catena of the Seronga study site.



Source: Gröngröft et al. 2013e.

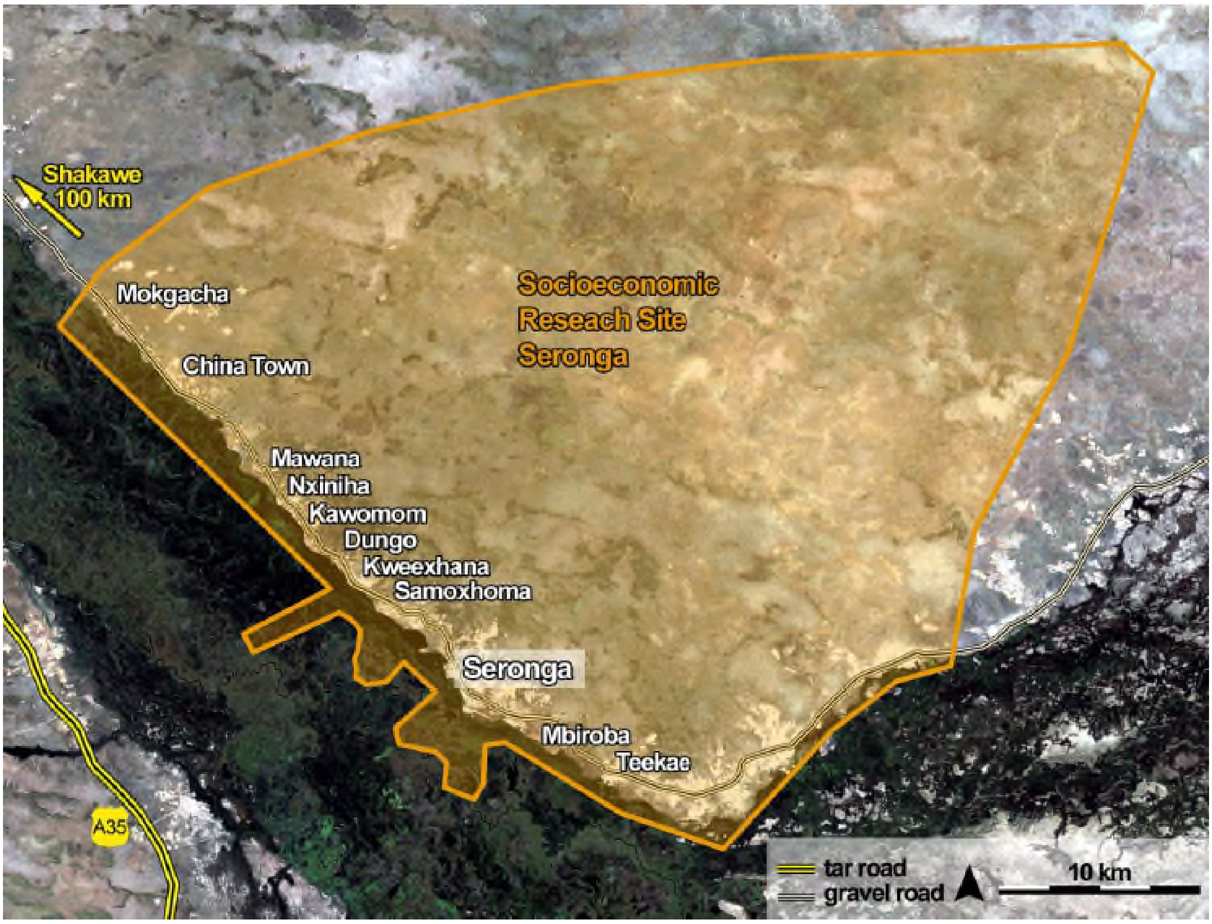
The Kalahari Dune Area is covered by extensive woodlands. It was once characterized by longitudinal sand dunes, yet flood events and changing river levelled these dunes millennia ago (Gröngröft et al. 2013e, 132). On the one hand, this resulted in the existence of former dune valleys with slightly clayish sediments, which are nowadays typically covered by *Mopane*-woodlands (mixed woodlands of *Colophospermum mopane*). On the other hand, former dunes are characterized by sandy conditions and typically covered by *Acacia* and *Terminalia*-shrubland (ibid.). Nowadays, *mopane*-woodlands in former dune valley represent an important indicator of higher soil fertility. In contrast to these woodlands, the low-lying areas of the panhandle and Okavango Delta are either seasonally flooded or permanently inundated, depending on micro-topography. Different speeds and degrees of flooding in the Okavango Delta form a wetland mosaic of river channels, lagoons, permanently covered swamps of papyrus and reeds as well as micro-islands of termite origin and sandy levees. Before the panhandle opens into this delta, it forms a similarly structured floodplain of about 12.5 km width (Gröngröft et al. 2013e).

Local ecosystems remain in a pristine state and local fauna is characterized by large herbivores such as elephants and hippopotami and top predators such as lions or wild dogs. The Okavango Delta was declared a UNESCO World Heritage Site - and the town of Seronga lies within its buffer zone just outside the core zone, with a portion of the floodplains used by the population even lying within the site's core zone (Pröpper et al. 2015). This area is furthermore classified as a Ramsar wetland of international importance.

Seronga is characterized by semi-arid conditions with a distinct rainy season during the austral summer and a dry season between May and September (Weber 2013d). Annual precipitation averaged at about 478 mm/year between 1971 and 2000, with high inter-annual variability between 1950 and 2009 (ibid.). While the mean annual temperature lies at 23.2°C, the study site experiences on average 22 days of frost per year and pronounced seasonal temperature differences, with November the hottest month (mean of 27.1°C) and July the coldest (mean of 16.5°C). Despite an only moderate inter-annual variability, an average temperature increase can be detected since the late 1970s (Weber 2013d).

The soil properties of both the Recent Floodplains in the panhandle and the Kalahari Dune Area are comparable to those in Mashare. For example, the Recent Floodplains reveal low to medium pH values and high topsoil carbon (4.1%) and nitrogen (0.38%) content (Gröngröft et al. 2015f). On the other hand, subsoil nutrient contents were found to be considerably lower in Seronga due to higher levels of groundwater-caused nutrient leaching (ibid.). The same holds true for the Kalahari Dune Area, where both Mashare and Seronga show slightly to strongly acidic pH values and very low organic carbon and nitrogen contents. However, due to missing topographic features such as fossil river beds, the levelled dunes in Seronga are characterized by lower maximum values of chemical soil parameters (Gröngröft et al. 2015f). Around Seronga-town, an extensive area of dark sediments can be found which provides suitable soil conditions for agricultural production (Gröngröft et al. 2015e). At the same time, at Seronga's location, this broad belt of relatively fertile soils is met by a main channel within the floodplain, offering access to the wetland ecosystem and its goods.

Fig. 1.9: Map of study site Seronga, incl. the location of Seronga-town & the cattle posts.



Source: Große et al. (2013).

Socioeconomic setting

Seronga is located in the North-West District of Botswana, which has a population of approximately 152,000 people (Ntesang 2015). The study site consists of approximately 950 households or 3,000 inhabitants (Pröpper et al. 2015). Both in the wider region and Seronga, population fertility is high and expected to remain the dominant driver of population growth (ibid.). Migration towards Botswana's semi-urban centres is an important trend, especially for the younger generation. However, re-migration of relatives to the rural communities mitigates its effect on local population density to some extend (ibid.).

All settlements in the region are situated along the eastern edge of the panhandle, on a low slope between the wetlands and the Kalahari Dune Area. This includes the study site, which consists of the semi-urban hub Seronga as well as many smaller settlements, the so-called cattle-posts (Fig. 1.9). The main reason for this settlement pattern lies in the reliable water access along the wetlands (Pröpper et al. 2015, Gröngröft et al. 2015e).

The region's only road connects these settlements with the rest of Botswana (apart from infrequent air and boat traffic). The nearest semi-urban center, *Shakawe*, lies 100 km to the north on the other side of the panhandle. It can be reached only via the low quality sand road and an unreliable ferry. However, for the local economy, Shakawe plays a major role in migration, trade, exchange and supply (Pröpper et al. 2015). The regions only urban hub (Maun, with ca. 60,000 inhabitants) lies on the opposite, southern end the delta. Seronga is only loosely connected with Maun via infrequent air traffic (Pröpper et al. 2015).

All tracks leading from the sand road into the hinterland are small footpaths. Thus, most infrastructure is concentrated along the road. Seronga-town offers a variety of public services and infrastructure, such as schools, land administration, a hospital, a police station, a water supply system, cell phone coverage and a small, modern supermarket. The town has been connected to the electricity grid, but as of yet only a minority of households is connected to these power lines. One household has established an improvised gas-station which provides fuel for local transport and power generators.

Despite the low quality of the public transport- and road infrastructure, access to cash markets is beginning to play an important role in Seronga-town. This can for instance be seen in the fact that a few households started to purchase modern consumer goods from regional and global markets (Pröpper et al. 2015). This development also results in a commodification of natural resources and an intensification of their use (ibid.). However, access to cash income depends strongly on employment, mainly in the public sector.

The advantage of Seronga over the other two study sites lies in its higher institutional density, which offers significantly better employment opportunities (ibid.). Furthermore, an eco-tourism lodge is located just south of Seronga and provides employment for a (small) number of community members. In general, tourism is of only minor importance for rural livelihoods. Most trips to the region are organized by external Safari companies on a fly-in/fly-out basis and independent tourist visits are rare and sporadic (Pröpper et al. 2015). Still, Seronga's community benefits from tourism via the concession fees that external tourism operators have to pay to the Okavango Community Trust (ibid.). This trust supports community projects and is able to e.g. rent out one single pick-up truck to farmers in need of transport.

The question of whether Seronga represents an agrarian society (which can be analysed via the Boserup-Ruthenberg framework) is not as easily answered as in the other two study sites. On the one hand, the use of machinery and fossil fuel-based inputs for agricultural production is minimal (e.g., both fertilizer and pesticides are used by only 4.6% of smallholders). On the other hand, in 2011, 8% of households did not rely anymore on firewood as their main energy source for cooking, heating or lighting. In fact, 17% of households were relying on gas and 7% the electricity grid. Eigner (2012) explained this phenomenon by proving that there is a small industrialized group of households living in the center of Seronga Town (teachers and government staff) which co-exists with traditional smallholders. The majority of households, remain in the stage of an agrarian society. However, her results also indicate that Seronga is on the verge of transitioning to a fossil-fuel based industrial society. However, this is unlikely to occur as long as the region remains isolated from (inter-)national markets.

Livelihood strategies in Seronga

To understand this co-existence, it helps to look at the livelihood analysis of Große et al. (2013), where we grouped local livelihoods into three main categories:

A first category captures that part of the population that does not rely on agriculture at all and relies mainly on cash-income for its survival. On the one hand, this includes a group of very small newcomer households that earn a relatively high income from salaries, e.g. in the administration or the schools (5% of all households). On the other hand, this describes a group of marginalized and mostly female-headed households that depend on a very limited access to cash income for its survival (23% of all households). These households live mainly in the centre of the town and have a low linkage to natural resources. This has been interpreted as a possible sign of urbanization (Große et al. 2013).

A second category describes those households which base their livelihoods on agriculture (58% of all households). This includes well-off and large households which live in the region for a long time and rely on both crop production and livestock keeping (36% of all households); it also include poorer households that do not own any livestock and which are mainly female-headed (22% of all households). Both groups are united by their low cash income from wage labour and their reliance on natural resources for food and construction (Große et al. 2013).

The last category does not fit in the common distinction between farming vs. non-farming households and has been interpreted as a transitional stage between both (Große et al. 2013). Again, it consists of two distinct groups, both of which possess livestock and do not carry out any crop production activities. The first and smaller group relies on business activities as well as the retail of natural resources (3.5 % of all households). It appears to enter the cash-based economy by capitalizing their knowledge of natural resources (Große et al. 2013). The second and larger group (12% of all households) captures the better-off farmers which rely on salaries from formal employment and which invest their cash into cattle, "*thus engaging in traditional pastoral activities as an opportunity rather than a necessity*" (Große et al. 2013, 148). It is likely that the minority of industrialized households identified by Eigner (2012) corresponds to the groups of salary-earning newcomer households (first category) as well as a few farmers of the last category. The majority of Seronga's crop producers, on the other hand, can still be regarded as belonging to an agrarian society.

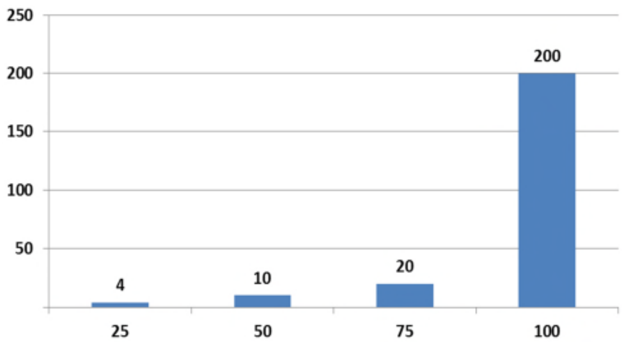
The role of livestock in Seronga

Dry climatic conditions and a relatively low population density give livestock keeping a comparative advantage over many other livelihood activities in North-West Botswana (World Bank 2001). In fact, Seronga is counted among north-west Botswana's main livestock rearing areas (Bendsen 2002). As in Mashare, cattle provide a variety of services, such as milk, meat, leather, draught-animal power and manure (Murray-Hudson & Parry 1997). Livestock herds also serve as a quasi-bank account (ibid.). However, livestock keeping as a *commercial* activity is nearly impossible and export of livestock products highly restricted. The reason for this it the regions increased chance of wildlife-transmitted diseases (from nearby protected areas - Pröpper et al. 2015).

The traditional cattle management system in Seronga differs by households' herd size. During the nights of the dry season, households owning smaller herds usually keep their animals in a kraal near to their homestead, while during the day these animals are allowed to graze the floodplains close to the villages (Bendsen 2002). However, owners of larger herds often maintain a separate and distant cattle-post, where their livestock is herded by employed herders during the dry season (Gibson et al. 1981). With the onset of the rainy season, natural pans in the hinterland fill with water and many farmers drive their cattle from the heavily grazed fringes of the Okavango into the now accessible pastures (White 1993 in Bendsen 2002).

Up to the 1990's, cattle ownership was significantly related to ethnic background (Bendsen, 1992). This pattern changed to some extent in 1996, when the outbreak of the cattle lung disease (*Contagious Bovine Pleuro Pneumonia*) led to the culling of the region's cattle population (ADRC 2000). Before this culling, 67% of households in the Botswanan Okavango owned cattle. By 1999, this value had dropped to only 29 % (Bendsen 2002). Farmers were compensated for their loss either via an immediate cash payment from the state or with the promise of a later provision of new animals – the majority opted for the quick cash income. Since then, many farmers did not managed to re-build their herds and were forced to focus on other livelihood options, such as arable agriculture (Fidzani et al. 1999 in Bendsen 2002). Consequently, cattle ownership in Seronga is highly skewed (Fig. 1.10). While only 54 % of crop producing households own any cattle at all, half of these households have a herd of 10 animals or less and 75% of cattle owners own herds of less than 20 animals. It is only a wealthy minority of 25% of households that own between 21 and 200 cattle.

Fig. 1.10: Quartiles of cattle herd sizes of cattle-owning households in Seronga.



Source: Empirical data. Note: The values indicate the largest herd sizes encountered within the 25%, 50% and 75% of households with lowest cattle numbers as well as the maximum herd size encountered in the study site (200 animals).

Changing land use patterns in Seronga

The traditional land-use pattern in Seronga was characterized by the concentration of livestock in distant cattle posts, while cropping was practiced adjacent to the settlements. Nowadays, this pattern is dissolving and cultivation is spreading along the road and around the cattle posts (Pröpper et al. 2015). The cause of this change is the increasing availability and quality of public services in the larger, permanent settlements, which, over the last decades, attracted many people from remote locations (Bendsen 2002).

This trend could also be observed in Seronga-town (Pröpper et al. 2015). Its ongoing transition to a cash-based society improves farmer's access to consumer goods, e.g. via the establishment of a supermarket in town center. Together with the culling of the cattle population in the 1990's, this resulted in a population concentration in Seronga Town.

Another driving force of this dissolution is the need to clear new fields for feeding Seronga's growing population. This clearing takes place mainly in the old inter-dune valleys on mixed *mopane* woodlands (Pröpper et al. 2015, Große et al. 2013, Bendsen 2002). As most of these areas around Seronga-town were already put into production, farmers increasingly move to distant areas. Today, farming concentrates on fertile patches along the road and around the settlements. It never extends more than four kilometers into the hinterland (Pröpper et al. 2015). Nowadays, the road connecting Seronga and the cattle-posts with the rest of the country constitutes an "*axis of transformation of Sandveld woodlands into a patchy agricultural mosaic of smallholder fields, fallows and degraded shrublands* (Pröpper et al. 2015, 49)". This fact shows that (despite Seronga's relative land abundance) scarcity of arable land is a likely future phenomenon.

An important consequence of this trend is that ecosystem connectivity between the dry hinterland and the wetlands is increasingly interrupted by human activity. This results in strong human-wildlife conflicts in the dry season (Pröpper et al. 2015), which take two main forms: first, the increasing elephant population is forced to cross the fields to reach the wetlands and causes regular crop damages (Blanc et al. 2007, Jackson et al. 2008, Bendsen 2002). It already accounts for about 30 % of the total crop loss in the area (Große et al. 2013). The second form occurs in livestock predation (Darkoh & Mbaiwa 2009). Together, these conflicts create problems for both livestock keeping and arable agriculture.

The risk of crop losses in north-western Botswana

An important characteristic of north-western Botswana is its relatively low suitability for dryland crop production. Crop production in the region is a risky business, and losses occur due to various reasons: erratic rainfalls and crop damages from livestock, wildlife and pests (Bendsen 2002). On average, only 40% of the area put into production at the beginning of the growing season can actually be harvested. Over the past decades, the region was repeatedly hit by natural disasters, which the government tried to mitigate with a variety of subsidy schemes (Bendsen 2002). As a result of this long period of interventions, farmers started to rely on government assistance for farming (Bendsen 2002). This can be expected to have reduced smallholders' propensity for agricultural innovation. Similar to Mashare, for the following analysis, farm-households in Seronga have been clustered into *wealthier ox-owning-* and *poorer non-ox-owning households*. Their descriptive statistics are given in Tab. 1.26.

Tab. 1.26: Characteristics of typical farm-household categories in Seronga, Botswana.

		Wealthy cluster	Poorer cluster
Household size (Nr. of persons per HH)		4.1 (SD: 2.3)	3.7 (SD: 2.1)
Number of Producers (aged: 16 - 59)		2.3 (SD: 1.6)	1.8 (SD: 1.3)
Share of Producers on HH size		0.6	0.53
Gender of HH head (% of female HHs)		34	73
Average age of HH head		54	48
% of HH heads who finished sec. school or higher		14	18
% of HH heads who finished primary school		42	36
Sample size		83	103
Livestock ownership:			
Goats (average herd size of HHs)		8	1,1
Cattle (average herd size)		21	1,1
Cattle **(quartile)**	25	5	0
	50	12	0
	75	29	0
	100	200	12
Ox-ownership (% of HHs owning the asset)		98	0
Use of Inputs (% of HHs using sometimes or more):			
Fertilizer		6	3
Pesticides		4,8	3
Improved seeds		77	77
Manure		7	1
Mean annual cash-income (in US-$/HH/a)			
from Salary		676	281
from Own Business		413	71
from Remittances		25	15
from Pensions		128	130
Mean annual cash income (US-$/HH/a)		**1644**	**537**
Mean annual cash expenditures (US-$/HH/a)		**696**	**170**
Disposable annual cash income (quartiles):	25	235	0
	50	560	235
	75	1940	635
	100	14890	11224

Source: Author’s design.

Land tenure in Seronga

Community land in Seronga is designated as state land. Many local farmers are beginning to hold formal land rights which are allocated to them by the land board (Pröpper et al. 2015). In the study site, there is a growing demand for land and the will to enhance commercial operations including mining. However, farmers are relatively well protected against land grabbing (ibid.). A few farmers continue to clear land on their own, i.e. without asking the local land board for permission. They do therefore not have any formal land rights. For the time being, this is tolerated by the land board – as long as the field was not located on a migratory route of wildlife. Yet at the same time, only those farmers having formal land rights are entitled to receive government assistance, e.g. in the form of subsidized inputs.

1.6.3.2 Results of the farming system analysis in Seronga

The dominant smallholder farming system in Seronga

The farming system of Seronga represents a system of semi-permanent cultivation of subsistence-oriented smallholders, practicing rain-fed mixed and mono-cropping of maize (*Zea mays*), sorghum (*Sorghum* spec.) and millet (*Pennisetum glaucum*) on a few hectares with small livestock herds of cattle and goat. Adverse environmental conditions, such as declining soil fertility near Seronga-town and high annual rainfall variability, as well as livestock and wildlife damages lead to high crop losses and make crop production a risky business that rarely covers a household's annual food needs. See Tab. 1.27 for an overview of the main results of the farming system analysis.

Fields are occasionally extended by clearing pristine woodland vegetation, if possible in mixed *mopane* woodlands of higher soil fertility. As of yet, no typical cultivation-fallow pattern has formed (see also Bendsen 2002). This may be related both to the combination of a relatively young cropping system (not older than 200 years) with a relatively low population density, as well as to the long-lasting dominance of alternative livelihoods such as natural resource use and livestock keeping. In general, farmers in Seronga prefer expanding their fields or clearing new land over applying fallow periods or any kind of field inputs such as manure.

Mean yields calculated for the study site are very low, which may be connected both to the dryness of the year of yield assessment as well as the now number of measurements that could be carried out (N=19). All fields assessed were cropped with Millet as the primary crop, yielding a mean harvest of 90 kg/ha and a standard deviation of 72 kg/ha. Total yield of both cereals and beans of a field amounted to 180 kg/ha at a standard deviation of 90 kg/ha. Considering the dry conditions of the year of assessment, these numbers are roughly in line with the region's long-term yield average of 162 kg/ha for Maize, 121 kg/ha for Sorghum and 144 kg/ha Millet (Bendsen 2002).

Due to a limited degree of land scarcity, field sizes around Seronga-town are relatively small at a mean of 0.5 ha (with the biggest at 4.5 ha), while deeper in the forest field sizes may reach 17 ha[28]. The mean field size calculated during the yield assessment was 3.1 ha, while

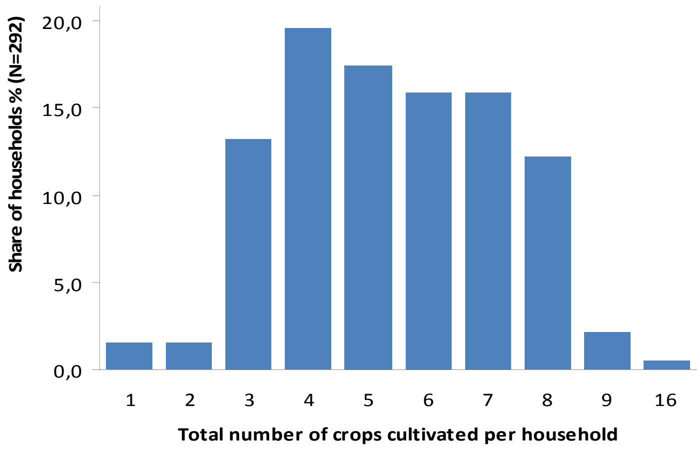
[28] Oral information from "Department for Agriculture", Seronga.

the agricultural officer stated 2.5 ha as a mean for the wider area; both values are slightly more than the region's long-term average of 2.1 ha (Bendsen 2002).

Households in Seronga either live in clustered and permanent settlements along the main road or at scattered locations within a 4 km wide strip of woodlands along the road. For most farm-households, the building material of their homestead ranges from mud-and-clay walls to brick walls and the material of the roof from thatching grass to metal. Naturally, traditional materials dominate in the more remote locations. Modern buildings of concrete walls and metal roofs can only be found in Seronga-town's center, commonly belonging to teachers and other people with formal employment. Within the settlements, homesteads are often surrounded by garden plots, while fields are generally located around the village or cattle post. In the growing season, some household construct an improvised hut near the field to protect it from wildlife at night. In the forest, homesteads are located adjacent to the fields.

In total, smallholders in Seronga cultivate 14 different crops (excluding two professional farmers who cultivate a much higher number), of which only 6 are cultivated by more than 50% (Große et al. 2013 – Fig. 1.11). Millet, beans, maize and groundnuts are the most important crops for both subsistence and cash income – although only 12% of crop producers actually sell or exchange any of their crops. The low numbers of food sales is surprising especially because of the fact that 40% of households in the study site that do not produce any staple crop and that thus rely on food imports from outside Seronga (Große et al. 2013).

Fig. 1.11: Crop diversity in Seronga: share of households vs. total number of crops



Source: Adapted from Große et al. (2013).

Tab. 1.27: Main results of the farming system analysis in Seronga, Botswana.

Aspect of farming system	Results for *Seronga,* Botswana	SC	SPC	PC
Mean yield/ha	90 kg/ha (millet) + 87 kg/ha (sorghum)			
Mean field sizes	2.5 ha, from 0.5 ha (near Seronga-town) - 17 ha (forest)			
Main types of crops	Cereals and legumes		X	X
Rotation intensity (R-value)	unknown, no clear cultivation/fallow pattern			
Mean fallow period length	unknown, no clear cultivation/fallow pattern			
Mean cultivation period length	unknown, no clear cultivation/fallow pattern			
Degree of land scarcity (as *perceived* by smallholders)	Low, except around Seronga-town		X	
Cultivation tools & techniques	hoe-based cultivation / ploughing via animal traction / land clearing via slash-and-burn-techniques / fence-construction of central importance to avoid crop losses due to livestock and wildlife		X	X
Soil fertility management	1. Acquisition of fresh soil by clearing new or extending old field. 2. Herding cattle into fenced field for a few days to fertilize with manure. 3. Incorporation of crop residues into soil during ploughing. 4. Use of a mold board plough. 5. Livestock feeding on crop residues, fertilizing to a limited degree with manure		X	
Seasonality of labour demand	Pronounced		X	
Labour division	Traditional division of tasks by gender, yet increasingly abandoned		X	X
Role of livestock in crop prdn.	Central for ploughing / limited use of manure		X	X
Land tenure	Tribal land tenure, though currently administered by governmental Land Board. Household-specific use-rights to fields. Both formal and informal ownership.		X	X
Further observations	Very high rainfall variability and crop losses due to wildlife and livestock make farming a risky business.			
Heterogeneity of livelihoods	Very heterogeneous, also caused by semi-urban character of Seronga-town.		X	X
Animal husbandry	Transhumance for cattle, partial nomadism and stationary animal husbandry for goats, donkeys and poultry.			

Source: Author's design. Based on the theoretical framework presented in chapter 1.3, the observations are classified as being typical of Shifting Cultivation (SC), Semi-permanent Cultivation (SPC) or Permanent rain-fed cultivation (PC). The results indicate that the farming system in Seronga shows characteristics of semi-permanent to permanent rain-fed cultivation. However, the occasional character of field extensions (which could not be captured quantitatively) clearly indicates semi-permanent cultivation.

Crop rotation, mixed cropping, and phased planting

Households in Seronga generally rely largely on the same agricultural tasks for field cultivation, using largely the same tools, i.e. ox- or donkey-drawn ploughs for ploughing and transport and the hoe for most other tasks. As in Mashare, households not owning any draught-animals usually hire them from their neighbors. Only a minority uses the hoe for soil preparation.

However, a look at the main farming strategies reveals a limited degree of heterogeneity. For example, households plant very individual crop mixtures and no dominant pattern could be discerned. Millet and beans generally dominate on sandy soils, often combined with water melon and pumpkin. On more loamy soils Sorghum and Maize are common, either as part of a crop mix or in monoculture.

As in the two other study sties, phased planting is not carried out in Seronga. In general, households try to put as much land as possible into production as early as possible. Lack of rainfalls at the beginning of the rainy season may lead to unintentional phased planting, though. At the same time, the diversity of crop mixes leads to phased harvesting, thus extending the period of available fresh food. Formal crop rotations are used by nearly no household in Seronga, although some households follow informal rotations in case of declining yields. On the least fertile soils, no cereal can replace the drought-resistant millet and the options for rotations are thus very limited. On more fertile soils, maize, millet, sorghum and secondary crops may be rotated. Fallow periods are applied very rarely, as farmers usually prefer to expand or re-locate their field. Some households do however state to apply fallow periods of up to two years in case of declining yields. The elsewhere wide-spread farming in the inundated floodplains (*molapo*-farming) does not occur around Seronga, because at the moment the type of floodplain required for this type of farming does not exist in the study site.

Labor needs within an agricultural cycle in Seronga

As is typical for a system of semi-permanent cultivation, weeding and field preparation are some of the most labour intense tasks (see Tab. 1.28). At the same time, the high livestock and wildlife density necessitates the construction of fences, which is a highly labour-demanding task that is carried out by all farmers. In fact, crop losses from animals are so high that farmers start to combine traditional bush fences with modern wire fences – which is also the best solution for reliably keeping goats and poultry out of the fields. However, both types of fences are regularly damaged by the animals, and especially elephants have become quite adept at pushing nearby trees directly onto fences to be able to access a field. For some farmers, fence repairs have therefore become part of the annual labour cycle. Additional efforts at protecting the fields especially from elephants include the daily burning of chilli and the incorporation of chilli-inundated cloth into the fences.

Holdings in the study site are centrally organized and all household members jointly cultivate the households' fields. A traditional division of labour between genders can be observed, although it is increasingly dissolving. In its purest form, it can still be observed in regards to the handling of oxen (which is still done only by men).

As in Mashare, animal-drawn ploughs greatly reduce the labour needs of ploughing and allow farmers to cope with the limited time window available for this task. An important difference to Mashare is Seronga's abundance of pastures, leading to a currently stable livestock population and a sufficient availability of oxen and even donkeys for ploughing. In general, most farmers prefer to use the stronger and faster oxen over donkeys, although the latter can in theory also be used by women and on smaller plots their higher mobility can make up for their relatively slower speed. However, only 43% of households practicing arable agriculture do own an ox and only slightly more a donkey. While 54% of households indicated to rent or borrow oxen, only 3% indicated to not use an ox at all. This low degree of ox-ownership in Seronga is partly a result of the culling of the cattle population in 1996, in the aftermath of which farmers experienced a shortage in draft power which forced them to reduce their cultivated area (Bendsen 2002).

For households with recently cleared fields, the annual agricultural cycle in Seronga begins in July with a task called "*de-stumping*". Normally, field clearing occurs via slash-and-burn techniques and – as some of the stronger trees may resist both flames and axes – typically results in a considerable amount of trees left standing in the field. Most of these trees died during field clearing, yet only over the course of the following decade do they slowly decay until one day they may simply be kicked over and burned – the before-mentioned "*de-stumping*". Any field clearing that needs to be carried out is also happening during the dry season, mainly between June and October.

The agricultural cycle continues with the maintenance of fences, usually starting in September. At the same time, and thus before the onset of the rains, farmers start with the de-bushing of annual plants and with pre-sowing, mostly of melons, around more fertile tree stumps or on remaining ash piles. Manual field preparation (i.e. ploughing by hoe and planting) starts earliest in mid-October, after the onset of the rainy season and lasts rarely longer than mid-November. Animal-based field preparation starts later, in November, and may last even beyond January, depending on rainfall distribution. Planting is carried out either by planting pot-by-pot or via broadcasting, the latter of which describes the manual scattering of seeds on the field via a sweeping arm-motion. During this time, a few households also apply manure to their fields. Weeding is carried out between December and March, at which time the crops have reached a stage during which they also need to be protected from birds. This can be done both by installing scarecrows as well as actively chasing them away. From March to harvesting in May, farmers also start to protect their fields from elephants by applying chili to their fences and by burning it on a daily basis at the edges of their fields, with the hope that the chili-smoke may keep the elephants at bay. The main harvesting period lasts from April to May, during which farmers usually construct a temporary crop storage shelter near their fields. While the non-ox-owning households reported to transport their harvest home in June, the wealthier ox-owning farmers often wait with transport until August, at which point they prepare the seeds needed for the following growing.

Tab. 1.29 depicts the mean per-hectare labour-demand of agricultural activities in Seronga, while Tab. 1.30 compares these values, summarized into the main agricultural tasks, with those of other semi-permanent and permanent cultivation systems of the tropics. As was the case for the other two study sites, it has to be kept in mind that labour-needs do not only differ between systems, but also between individuals of the same systems – some farmers may work at a more leisurely pace or work slower because they are malnourished, other may work quicker and more effectively. These numbers serve only as a rough reference frame for the comparison.

Tab. 1.28: Seasonal calendar of natural resource-based livelihood activities in Seronga

	June		July		August		September		October		November		December		January		February		March		April		May	
Main annual cultivation activities:	1st hal	2nd ha	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Maintain modern fence															minor repairs									
Maintain bush fence															minor repairs									
De-bushing																								
Pre-Sowing																								
Applying manure to the field																								
Ploughing by hoe												Timing & need for re-planting depend on rainfall												
Ploughing with donkeys																								
Ploughing with oxen																								
Sowing pot-by-pot													Timing & need for re-planting depend on rainfall											
Broadcasting																								
Weeding																								
Chasing away birds																								
Making and installing scarecrows																								
Applying chili to the fence against elephants																								
Burning chili in the corners of the field against elephants																								
Building a temporary grain-storage near the field																								
Harvesting																								
Threshing																								
Taking harvest home																								
Main non-annual cultivation activities:																								
Clearing a new field from the forest																								
Removing tree stumps from an existing field																								
Building a modern wire fence																								
Building a traditional bush fence																								
Cattle husbandry and chosen natural resource use activities:																								
Branding livestock																								
Herding																								
Training livestock																								
Building a kraal																								
Skinning																								
Milking																								
Castrating																								
Dehorning livestock																								
Hunting																								
Fishing																								
Cutting grass and reeds																								

Source: Author's design. Note: Collection of wild fruits, nuts and vegetables has been excluded for ease of presentation, but will be presented in Tab. 1.31.

Tab. 1.29: Mean labour-demand of agricultural tasks per ha & year, differentiated by gender.

Regular activities of the dominant farming system in Seronga Variable labour needs (i.e. proportional to field-size)	Working-**hours** needed per ha/activity/a	Task carried out by which **gender** primarily?	Estimated **share of producer labour** involved
De-bushing field of annual and biannuals	160	male	0,5
Repair traditional fence prior to growing season	26	both gender	0,7
Repair wire fence prior to growing season	44	male	0,5
Pre-sowing	11	both gender	0,5
Ploughing by hand (hoe)	270	female	0,5
Ploughing by donkey	38	both gender	0,7
Ploughing by oxen	25	male	0,5
Sowing pot-by-pot	40	female	1
Broadcasting	2	both gender	1
Field preparation & planting (sum of tasks above - ox-based ploughing pot-by-pot planting)	**307**		
Weeding (once)	**280**	female	0,5
Harvesting a millet field (assumed harvest of 200 kg)	**150**	both gender	0,5
Transporting crops from field into storage for drying (200 kg)	**2**	both gender	0,7
Total field size-related labour needs of traditional arable agriculture (hours/ha)	**739**		

Non-variable labour needs (i.e. not proportional to field-size)	Total annual working-**hours** needed	Task carried out by which **gender** primarily?	**Share of producer labour**
Apply chili to the fence	**40**	both gender	0,7
Burn chili in the corners of the field	**46**	both gender	1
Chasing away birds	**900**	both gender	0,5
Making and installing scarecrows	**6**	both gender	1
Build temporary storage on field and keep harvest there for drying	**5**	male	0,5
Total annual non-variable labour needs (hours/a)	**996,8**		

Irregular & alternative activities of the main farming system in Seronga - Variable labour needs (i.e. proportional to field size) in hours/ha	Working-**hours** needed per ha/activity/a		
Apply manure to the field	1,67	both gender	0,5
Build wire fence	1244	male	0,5
Build traditional fence	80	male	0,5
Extend field by clearing forest	390	both gender	1
De-stump field	833	male	0,5

Source: Empirical data.

Tab. 1.30: Overview of labour needs of main agricultural tasks in various semi-permanent and permanent cultivation systems in working-hours/ha.

Location	Field preparation & planting (hours/ha)	Weeding (hours/ha)	Harvesting (hours/ha)	Total labour (hours/ha)	Characteristics of the system
Study Site Seronga, Botswana	307 (25 for ploughing & 40 for planting)	280	152	**739**	semi-permanent plough-based cultivation of pearl millet, maize or sorghum
Study Site Mashare, Namibia*	339	220	25	**584**	semi-permanent to permanent plough-based cultivation
Burkina Faso (Upper Volta)**	88	180	208	**476**	semi-permanent cultivation of millet (hoe-based)
Burkina Faso (Upper Volta)**	152	252	64	**468**	semi-permanent cultivation of maize (hoe-based)
Tanzania, Sukumaland *****	390	250	300	**940**	semi-permanent cultivation of maize & sorghum (hoe-based)
Senegal, Kaolak**	136	110	210	**456**	semi-permanent cultivation of groundnut (plough-based)
Senegal**	66 (field preparation) + 8 (sowing/planting)	86	64	**224**	permanent cultivation of millet (plough-based)
India**	32 (field preparation) + 16 (planting)	32	56	**136**	permanent cultivation of sorghum (plough-based)
Cameroon**	136 (field preparation) + 120 (planting)	216	80	**552**	permanent cultivation of sorghum (hoe-based)
Kavango region, Namibia ***	34 (field preparation) + 31 (planting)	93	90 (incl. threshing)	**248**	plough-based cultivation
Kavango region, Namibia ***	46 (field preparation) + 31 (planting)	93	90 (incl. threshing)	**260**	hoe-based cultivation
Kavango region, Namibia ****	40 (field preparation) + 24 (broadcasting) or 27 (row planting)	10 (if plough-based in rows)	17 (harvesting) + 51 (threshing)	**142 +**	plough-based cultivation
Kavango region, Namibia ****	54 (field preparation) + 24 (broadcasting) or 27 (row planting)	65 (hoe-based without rows)	17 (harvesting) + 51 (threshing)	**211 +**	hoe-based cultivation

Sources: * = empirical data, **Bureau pour le développement de la production agricole (1967) in Ruthenberg (1971), *** = MAWRD (1996:37) in Hecht (2010), ****= Hecht (2010:119 ff), ***** Rotenhan (1966) in Ruthenberg (1971)

Tab. 1.31: Mean annual household labour-demand for natural resource use & household chores in Seronga, separated by month & season.

	Dry season					Rainy season							Gender specificity of task	Estimated share of producer labour
	Jun	Jul	Aug	Sep	Okt	Nov	Dec	Jan	Feb	Mar	Apr	May		
Hunting	8	8	8	8	8	8	8			8	8	8	male	0.5
Fishing	23	24	24	23	24	23	24			24	23	24	both gender	0.5
Cutting grass and reeds				22									both gender	0.5
Fetching water (in Seronga)	7	7	7	7	7	7	7	7	6	7	7	7	female	0.5
Fetching water (in a cattle post)	40	42	42	40	42	40	42	42	38	42	40	42	female	0.5
Collecting firewood (transport manually)	65	65	65	65	65	65	65	65	65	65	65	65	both gender	0.5
(transport via donkey cart)	12	30	30	30	30	30	30	30	30	30	30	30	both gender	0.5
COLLECTING:														
Water berry fruits								44	44				both gender	0
Palm tree fruits			44	44									both gender	0
Fig tree fruits	44	44	44	44	44	44	44	44	44	44	44	44	both gender	0
Wild spinach							48	48					both gender	1
Green palm trees								48	43				both gender	1
Motsinsila (local plant)										48	46		both gender	1
Water lilly roots & fruits	2	3	5	11	12	2	5	5		5	8	5	both gender	1
Orange monkey fruits				8	5	6	9						both gender	1
African mangoste fruits				46	47	46							both gender	0
Marula fruits	2,3	1,5											both gender	0.5
Jacal berry fruits			95	92									both gender	0.5
SUM: Collecting wild fruits, nuts & vegetables	117	120	259	314	179	167	177	260	196	168	167	120		
Winnowing	35	35											female	1
Making fire	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	both gender	0.5
Pounding	24	24	24	24	24	24	24	24	24	24	24	24	female	1
Making traditional shoes/ropes	96												male	1
Digging a pit	2												male	1
Making axes/hoes	8												male	1
Body hygiene	58	58	58	58	58	58	58	58	58	58	58	58	both gender	0.5
Repairing dresses	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	female	1
Cleaning the house	15	16	16	15	16	15	16	16	14	16	15	16	both gender	0.5
Cleaning dishes	19	19	19	19	19	19	19	19	18	19	19	19	both gender	0.5

LIVESTOCK-OWNER-SPECIFIC ACTVITIES:	**Dry season**					**Rainy season**								
Branding livestock	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	male	1
Herding	60	62	62	60	62	60	62	62	56	62	60	62	male	0.5
Training livestock			40	40	40	40	40						male	0.5
Building a kraal	10	10	10	10	10	10	10	10	10	10	10	10	male	0.5
Milking	60	62	62	60	62	60	62	62	56	62	60	62	male	0.5
Castrating	48	36											male	0.5
Dehorning livestock	48	36											male	0.5
SUM: Livestock-ownership related activities	363	343	311	307	311	307	311	271	259	271	267	271		

Source: Empirical data. Note: Each task's gender specificity and estimated share of producers involved in each task indicated. Note: Specialized activities like baking and marketing of fat-cakes or specialized harvesting of a local herb called *Motetlwa* excluded from this overview. Donkey ownership was also excluded, as it is carried out only by 19 % of crop producing households, or 50% by wealthy ox-owners and 10% by poorer non-ox-owners, respectively. It thus represents a specialized livelihood activity.

The data presented in Tab. 1.30 suggest that Seronga's labour-needs per hectare lie at the upper end of all compared systems but still within a reasonable range for a semi-permanent cultivation system: Above-average labour-needs characterize the task of field preparation & planting. However, as in Mashare, de-bushing was included in field preparation and this increased the labour needs of this task by 160 hours/ha. Excluding this task would result in values that lie in the mid-ranges of the compared farming systems (147 hours/ha). Also the labour-needs for weeding and especially harvesting appear to lie slightly above average. Considering the relatively low yields per hectare, the latter finding is surprising. As both focus groups on agricultural activities resulted in a similar value (140 h/ha vs. 160 h/ha), an erroneous statement or an exaggeration by the interviewed farmers appears unlikely. In fact, other semi-permanent farming systems presented in the comparison are characterized by even higher labour-needs for harvesting. Both facts indicate that the value for harvesting lies within a reasonable range and can be regarded as correct. The same holds true for the other reported labour-needs. Seronga can thus be characterized as a semi-permanent cultivation system of relatively high labour-needs per hectare.

Seronga's rural economy is characterized by the very high importance of natural resource use and livestock keeping; therefore, in order to derive a complete picture of rural households' labour economy, the analysis of agricultural labour-demand needs to be complemented by working-hours invested in these other livelihood sources. As households follow very individual livelihood strategies, it is hard to give values for their average labour demand for these tasks. However, the target-group of this analysis is Seronga's crop producers.
As has been shown in the livelihood analysis above, their majority is characterized by natural resource use as a secondary, or complementary, livelihood source. Differences in labour invested in these activities are thus less pronounced than for that group of households that focuses on retail of natural resources. Furthermore, the values reported here reflect a focus group consensus on the average labour-demand of these activities per year that all participating farmers were able to agree on. It can therefore be seen as a realistic approximation of the average labour that crop producing households invest into natural resource use and animal husbandry activities. Tab. 1.31 presents an overview of the mean monthly labour-needs, while in tabs. 1.32 and 1.33 the mean annual labour-needs per household category (wealthy and poorer) have been summed over both dry and rainy season and converted into household producer labour[29], i.e. labour that needs to be invested by household members aged between 15 and 59 years.

This allows for a more meaningful comparison of labour-needs over all three study sites. For the case of Seronga and based on focus group results, season lengths of on average 184 days for the dry season and 181 days for the rainy season have been assumed. As in the other two study sites, tasks such as maintenance of homesteads and uncommon wage-labour are ignored. Both tables indicate that farmers in Seronga do spend around half of their available family labour on natural resource use activities and household chores (cattle-owner 54% in

[29] This conversion was done by multiplying the labour needs of a specific activity with its estimated share of producer labour. The latter was derived from focus group results: If an activity was reported to be carried out by adult males, adult females and the children, it was assumed that only 50% of the labour hours needed for task need to be carried out by producers. If it was reported to be carried out by adult females and both underage boys and girls, it was assumed household producers were needed to carry out 30 % of the working hours required.

the dry season and 50 % in the rainy season vs. non-cattle owning households with 48 % in the dry season and 47 % in the rainy season). The difference between both household types is surprisingly low, considering that the most labour-intensive case of year-around, continuous livestock-herding, was considered in this comparison. It can mainly be explained by the higher mean household size of the cattle-owning households, which compensates for the higher labour demand of livestock related activities. This finding may even indicate that smaller, non-livestock owning households might be faced with certain labour shortages if they were to acquire a cattle herd of their own (apart from the high cash investment that would be needed for this). Due to the relatively high importance of natural resource use and livestock keeping, the mean percentage of family for these activities is similarly high and usually even higher than in the study sites Mashare or Cusseque. This can be explained by the proximity to the natural resource rich Okavango Delta as well as the central importance that livestock keeping has had for many of the local tribes, e.g. the Batswana.

Tab. 1.32: Annual family-labour budget of a poorer household not owning cattle

	Dry Season	Rainy Season
Total available household producer labour (working hours/HH/a)[a]	2650	2606
Mean HH labour demand for activities in working hours/HH/a (corrected to producer labour)		
- Shared	784	931
- Male	129	15
- Female	361	289
= Sum	1274	1235
Total remaining labour available for agriculture, wage-labour & leisure	1376	1371

Source: Empirical data. Note: Calculation of producer labour available for arable agriculture, wage-labour or leisure carried out by deducting mean labour needs for natural resource use and household chores from total available producer labour pool. [a] Calculated by multiplying the mean of 1.8 producers with 8 hours of daily working time and the respective season length.

Tab. 1.33: Annual family-labour budget of a wealthy cattle-owning household

	Dry Season	Rainy Season
Total available household producer labour (working hours/HH/a)[a]	3386	3330
Mean HH labour demand for activities in working hours/HH/a (corrected to producer labour)		
- Shared	784	931
- Male	680	456
- Female	361	289
= Sum	1825	1676
Total remaining labour available for agriculture, wage-labour & leisure	1561	1654

Source: Empirical data. [a] Calculated by multiplying the mean of 2.3 producers with 8 hours of daily working time and the respective season length.

Soil fertility management

Smallholders in Seronga rely on a limited choice of soil fertility management practices, but they combine them in individual ways, best suiting their needs, skills and knowledge. As is typical for a semi-permanent cultivation system, the most widespread means of 'restoring' soil fertility is to clear new land for cultivation as soon as the old plot is showing signs of decreasing productivity. In the years following clearing, *de-stumping* can be considered as a complementary means of fertility management: After clearing and burning of the initial vegetation, a few (often dead) trees remain standing within the field. Instead of investing hard labour into felling these trees, farmers let them slowly decompose on their fields (see paragraph on "labour economy" above). For *mopane*-trees, up to 10 years may pass before the farmer is able to simply push the trunk over. The ash resulting from the burning of these tree trunks as well as the slow de-composition of their organic matter over the previous years can be expected to lead to a constant inflow of nutrients over the years following field clearing.

While the study site in general offers relative land abundance, those smallholders living in Seronga-town are beginning to experience a certain degree of land scarcity. They are therefore increasingly unable to rely on these traditional, labour-efficient soil fertility management practices. As alternative practices are used only to a limited degree, they experience declines in soil fertility. In general, the attractiveness of living in Seronga-town appears to outweigh the benefits of clearing a larger tract of fertile land in the hinterland, while soil degradation does not yet present a severe enough problem to induce the adoption of alternative, more labour intensive practices.

Naturally, all smallholders follow one or another approach for the use of crop residues: Most of them (97.4%) open the gates of their fields to let cattle graze on the residues, thus gaining a small degree of manure-input. In fact, some farmers even close the gate after their (or a neighbours) herd has entered their field to keep them for a few nights within this improvised kraal, thus effortlessly fertilizing their field with a higher amount of animal manure. There are only few alternative uses of crop residues: 4.7% of households use them as building material, 0.5 % incorporate them into the soil via ploughing and 1% burn them. The last main means of soil fertility management is the relatively common use of mouldboard-ploughs. These ploughs invert the soil and thus interchange the deeper and more nutrient rich horizons with the relatively exhausted top-soil. The use of chemical field inputs is virtually non-existent and mainly limited to the study site's two commercial farmers. Informal crop rotations and irregular fallow **periods** have been reported as additional means of restoring soil fertility, but especially the latter are rarely applied in Seronga.

The following example may exemplify why no dominant strategy could be discerned in the study site: One farmer reported that he is not convinced that manuring provides more benefits than the incorporation of crop residues into the soil. Manure is harder to incorporate into the soil than crop residues and if left lying on the ground it is ineffective as a field input. He therefore protects the crop residues from grazing to later incorporate them into the soil. Farmers obviously value the different means of soil fertility management in individual ways; knowledge, experience as well as farm-managerial ability may be main determinants of their chosen strategies.

1.6.3.3 Conclusion: Trends of Smallholder Farming in Seronga

It is unlikely that the majority of crop-producers in Seronga will voluntarily attempt an intensification of their farming system in the foreseeable future. This goes beyond a mere aversion of smallholders to higher labour needs. First, due to regular government intervention in times of natural disasters, some smallholders have to a certain degree become accustomed to these types of interventions. This mind-set is potentially less conducive to innovative behaviour (see Fischer-Kowalski et al. 2011). Second, and maybe even more importantly, this is related to a growing frustration with crop production in general. To understand this, it is necessary to take a look at the shocks and trends that affected agricultural in Seronga over the last decades.

Over the last 60 years, crop producers in Ngamiland have repeatedly been affected by natural disasters and sometimes even by long-lasting changes to their biophysical environment, the latter mainly via changes in flooding patterns (Bendsen 2002). Disasters included droughts (1964-65, 1982-88 and 1995), severe floods (1978/79) as well as a massive locust and bird infestation in the 1980s. This combined with the already erratic rainfall distribution in the region to turn cropping into a high-risk activity and keep smallholders both from field expansion as well as intensification (ibid.). The ongoing increase of the local elephant population is aggravating the already high crop-losses from wildlife and livestock and has even resulted in the death of a few farmers who tried to protect their fields. All of these phenomena lead to a certain frustration of smallholders with crop production. Importantly, this also coincides with Seronga's increasing integration into national and international cash-markets, opening up to some of the smallholders new and alternative, cash-based livelihood sources.

Due to the challenges described above, only few smallholders are currently willing to produce more than what is needed to cover their household's subsistence needs. Instead, they appear more willing to diversify their livelihood strategies or focus on new livelihood sources such as formal employment. Thus, as in Mashare, the Boserup-Ruthenberg framework helps to describe the evolution and current state of the farming system in Seronga. In the future, however, in can be assumed that Agricultural Involution is more likely than Boserupian intensification.

These findings also indicate that, if at all, voluntary efforts towards an intensification of crop production can be expected only by those households that remain unable to diversify their livelihood strategies and thus are dependent on agriculture for their survival. These may include the female-headed households, who are often counted among the poorer and more marginalized households of a rural community.

The challenge that may arise for these female-headed households lies in the fact that mainly male farmers are increasingly able to access formal employment opportunities. In Ngamiland in general, male labour is therefore becoming increasingly scarce for field cultivation (Bendsen 2002). This may cause problems for ox-based ploughing, a task that is still carried out by men only. Under the current farming system, female-headed households rely on male assistance for ploughing. If it is unavailable, they may be unable to increase their agricultural output even if they wanted to. However, although a trend of declining male labour availability in the region was observed by Bendsen (2002) already more than 10 years ago, it is still not pronounced in Seronga. In fact, a sufficiently high number of external (male) workers are available which can be hired for field cultivation. It is likely that this difference between Seronga and other areas of north-western Botswana lies in the study sites remoteness and bad connection to the national economy. While other parts of the region have benefited from Botswana's general economic development, Seronga appears to have largely been left behind. This can be seen in the very limited access to alternative livelihood sources in the study site. At the same time, the culling of Seronga's livestock population in 1996 reinforced the role of arable agriculture as a safety net or baseline livelihood activity for the majority of households in the study site. Some smallholders stated that if the risk of crop production and especially of elephants destroying the harvest would not be so great, they would actually attempt to increase their production. This indicates that for many smallholders, crop production still represents the main livelihood source to which they have only limited alternatives.

However, this situation may change quickly. Once a reliable tar road & bridge connect Seronga with Botswana's national economy, the study site's transition to an industrial society may occur at a relatively quick pace. The rising availability of formal employment might then result in the lack of male labour for farming that has been observed in other parts of Ngamiland. In that case, the inability of female-headed households to intensify their crop production under the current farming system may cause certain challenges in the future.

The analysis will now turn away from the analysis of the general evolution that Seronga's agrarian society may take in the future. Instead, it will now focus on the trends and processes that are occurring within Seronga's dominant farming system.

Seronga's social stratification into a heterogeneous mix of better-off and relatively poorer households is relatively advanced; but in contrast to Mashare, this is to a large degree caused by site specific conditions: On the one hand, a variety of different tribes introduced their different lifestyles or livelihood strategies to the study site. As households' wealth in this study is approximated by using the indicators "Cash income" and "Ox-Ownership", lifestyles that are more natural resource use–based and subsistence oriented do naturally appear as those of poorer households. These indicators may therefore seem quite biased. However, for a precise grouping of the study site's crop producers into households with higher and those with more limited access to productive assets, they still represent the indicators best suited.

On the other hand, Seronga as an administrative center offers much higher formal employment opportunities than any of the other study sites, allowing for a limited number of high-income earning households and generally more heterogeneous employment opportunities. Lastly, Seronga's location adjacent the Okavango Delta probably offers a far wider variety of natural resources that can be utilized for natural resource based livelihoods than Namibia or Angola. All these aspects allow households in Seronga to follow the most heterogeneous livelihoods of all three study sites. Coincidentally, this high heterogeneity is typical for semi-permanent cultivation systems.

At the moment there is no indication that a tar road or a bridge over the panhandle will be built any time soon. The majority of Seronga's can thus be expected to remain dependent on arable agriculture for their livelihoods. As of yet, Seronga's sufficiently high land availability ensures that farmers' dominant soil fertility management strategy – the clearing of new fields – does still allow for putting sufficiently fertile fields into production. However, two potential developments might endanger the system over the next years: First, in 2012, institutions such as traditional authorities and the land board in Seronga were toying with the idea of creating a community cultivation zone surrounded by a jointly maintained fence against wildlife and livestock. Although this may prove to be an effective means of minimizing wildlife- and land use conflicts in the future, it has to be kept in mind that this enforced transition to a system of continuous cultivation will hasten soil degradation processes and necessitate an adequate new approach to soil fertility management. Second, the attractiveness of Seronga-town and the pseudo-urban lifestyle it offers may keep farmers in its vicinity despite the drawback of increasing land scarcity. If these farmers are to rely on arable agriculture for their survival also in the future, they will be forced to find new solutions to the problem of declining soil fertility.

The study site is still in a relatively good position to accomplish this adaptation - despite its adverse conditions for crop production. It is characterized by relative land abundance and offers a variety of complementary livelihood sources that households could diversify into. Both of these aspects do theoretically allow farmers to access a wider variety of potential intensification measures than what would be possible in more constrained environments like Mashare. Although currently only few farmers see a need for the adoption of intensified systems, it will be worthwhile to start laying the groundwork by educating the farmers about future challenges and by experimenting with improved methods.

However, should the transition to an industrial society actually occur, it may not be worthwhile to push for a continuation of arable agriculture in Seronga. Although the direction such a transition would take remains completely unclear, it can be expected that a few households will stay dependent on farming for their survival. Depending on the competing land uses and livelihoods that would arise in this situation, land scarcity may or may not be a central issue for these farmers anymore. Also, this transition might allow for a commercial intensification, i.e. by using cash incentives to make farmers adopt sustainable production methods. As the commercialization of farming and its potential impact upon rural communities and rural land use is not the focus of this study, the success of such as approach remains uncertain and additional research would be required.

In both cases it can be assumed that ensuring access to and success of agricultural livelihood sources will increase rural farm-households ability to partake in any form of transition or to utilize new livelihood sources, and be it only by being able to send their children to school. As in the other two study sites, change is coming to Seronga – and as Bonneuil (1994) has pointed out, the earlier the potential adaptation pathways are explored, the more options for adaptation will exist.

1.6.4 Conservation agriculture in theory and in Mashare

Incidentally, an improved farming system that might solve the problems caused by Mashare's traditional smallholder farming system does already exist within the study site. It was designed as an experimental field trial and implemented by the Polytechnic of Namibia within the framework of the TFO project in 2011. The system represents an adaptation of the concept of conservation agriculture (CA) to local conditions and aims at the sustainable intensification of smallholder production.

The preceding farming system analyses described the traditional farming practices of the three study sites. These will in chapter 1.6.5.9 be compared with the manual CA-system that is promoted in Mashare study site (yield data were not available for the animal-traction based CA system which is also promoted). In order to facilitate understanding of the chances and constraints of CA, the following analysis will begin with a theoretical review of the concept. Only afterwards will the experimental field trials that are being conducted in Mashare be described in detail.

1.6.4.1 Core concepts and ideas behind conservation agriculture (CA)

Two different perceptions of CA

Proponents of CA, such as the African Conservation Tillage Network, regard it as a solution to soil degradation and an approach to mitigate the seasonal peaks in labour-demand in smallholder agriculture. It is characterized by the three components i) use of permanent soil cover, ii) minimal soil disturbance and iii) crop rotation (FAO 2015). The first two components are realized within the field mainly via the practices of a) mulching and/or the establishment of cover crops as well as b) by direct planting through the soil cover, without or with only minimal soil preparation (Bishop-Sambrook et al. 2004).

The rationale behind this approach can be summarized as follows: Minimal soil disturbance reduces nutrient losses from mineralization that would occur under conventional tillage and is expected to increase soil organic matter. The higher weed pressure that results from reduced tillage is countered by a permanent soil cover, which reduces farmer's dependence on herbicides and benefits soil fauna, thus stimulating soil structure formation and improved soil fertility. Crop rotations contribute to both soil fertility and pest control (Bishop-Sambrook et al. 2004, Idol 2015) and work best if applied as a cereal-legume rotation (Twomlow et al. 2008). This overview indicates that there are important synergies between the three characteristics of CA. Although they may also provide certain benefits if applied individually, the system works best if all components are used at the same time.

When talking about CA, it is important to distinguish two opposing approaches that relate mainly to the role of inorganic fertilizers (Haggblade, Tembo & Donovan 2004). Proponents of inorganic fertilizers see them as the lowest-cost means of achieving increased crop yields and restoring soil nutrients to slow down agricultural extensification (e.g. Quiñones, Borlaug & Dowswell, 1997). On the other hand, opponents of this approach such as Reintjes, Haverkrot & Waters-Bayer (1992, as cited in Haggblade, Tembo & Donovan 2004) regard any use of inorganic, petroleum-based fertilizer is inherently unsustainable and thus advocate the use or organic and low-external input agriculture. They consider inorganic fertilizers as

too costly and too ineffective to offer large-scale solutions for cash-constrained smallholders as well as inappropriate to restore soil fertility (Haggblade, Tembo & Donovan 2004).
As is always the case in these discussions, there is a third, a middle way that combines both of these views by using organic methods of residue retention, minimum tillage, crop rotation as well as strategic micro-doses of inorganic fertilizers, mainly rock phosphates and inorganic nitrogen (Sanchez et al. 1997). A key trade-off between the two poles of this continuum is that the more organic the CA approach is designed, the more labour is needed, while rising levels of inorganic fertilizer are connected to rising demand for financial capital input (Haggblade, Tembo & Donovan 2004). The availability of key resources may therefore critically determine the optimal CA approach for a certain household or region. Therefore, for those regions of Sub-Saharan Africa that are characterized by limited or unreliable access to markets and low infrastructure, a more organic approach may be most appropriate while with increasing market integration, the role of inorganic inputs such as herbicides may become more important and the middle way more viable. However, as will be shown below, it is mainly the organic field input that allows for soil rehabilitation in the drier regions of Africa.

CA and soil restoration
It has been proven that CA is able to stop soil degradation and restore soil fertility (Giller et al. 2009). However, this restoration is a long-term process and its benefits are not immediately experienced by the farmer (ibid.). Also, the biophysical conditions of Africa drier regions do affect the functioning and interplay of CA's basic components and may thus alter their expected roles and outcome. For example, the practice of minimum tillage is expected to result in improved soil organic matter (SOM) content which would benefit both soil structure, - fauna and –fertility. However, the region's sandy soils typically lack the physical structure to protect the SOM that is build up in these soils (Giller et al. 2009). Most improvements in SOM content and soil fertility in the sub-humid and semi-arid regions of Africa do therefore stem from the increased input of organic matter, be it from manure that is incorporated into the soil or from the mulch cover applied on the topsoil (ibid.). A fact that still remains unclear is whether the large amount of organic input may affect N mineralization in the soil and thus whether it may necessitate the application of inorganic fertilizer to balance out this trend (Giller et al. 2009).
The low production of biomass on smallholder farms or natural vegetation in sub-humid and semi-arid Africa may make it hard to meet the optimal level of 30% mulch cover recommended for conservation agriculture (Giller et al. 2009). This challenge can to a certain extent be mitigated by the use of so-called cover crops, which are established either before, after or parallel to the main crop. While growing they shade the soil to provide additional soil cover and when slashed they may be applied to the field as additional mulch. Other potential benefits include the reduction of soil surface temperature and of water losses, the stimulation of soil life and the fixing of nitrogen in case a legume was planted (Bishop-Sambrook et al. 2004). Especially in those cases where cover crops are slashed before establishment of the main crop, they can be used as mulch and thus have a potentially labour saving effect by smothering weeds (Erenstein 1999). The more the cover-crops growing period overlaps with the main crop, the less conclusive are these labour saving benefits (Bishop-Sambrook et al. 2004).

CA and an improved labour economy

As has been shown above, there are two main schools of thought that deal with CA. These differ mainly in their view on the use of inorganic inputs. In general, it can be said that if a CA approach is designed with a focus on machinery (e.g. jab-planters) and inorganic inputs (e.g. herbicides), its labour needs are generally lower than in a more organic approach that focuses on manual labour (e.g. weeding by hoes or additional labour needs due to mulching) (Bishop-Sambrook et al. 2004, Giller et al. 2009). However, despite the variety of technologies that can be combined under the general CA framework, CA generally results in higher labour needs than under conventional tilling (Haggblade, Tembo & Donovan 2004, Mazvimavi et al. 2010). This is caused by the need to invest labour in permanent field structures, such as planting basins or terraces, as well as the higher amount of organic inputs required – which is in many times coupled with cash purchases for external field inputs (Haggblade, Tembo & Donovan 2004).

A CA approach that is especially suited to the drier regions of Africa that are affected by scarcity of animal-traction is the so-called 'basin tillage approach' (Twomlow et al. 1999, 2006, 2008). Within this approach, seeds are sown into small planting basins which are dug at regular intervals with the use of hand hoes. Basin tillage does therefore not rely on animal-traction for field preparation.

The approach abandons the basic CA concept of no-tillage in favour of minimal-tillage. No-tillage works best in sub-humid and humid regions, where annual rainfalls of >1000 mm ensure high levels of biomass production (which among others increases mulch availability and reduces competition of livestock for crop residues) (Bishop-Sambrook et al. 2004). Then again, minimal-tillage is considered as more appropriate for the semi-arid and arid regions with 300-800 mm annual rainfall of west and southeastern Africa (ibid.). Here, the use of planting basins has two main advantages: i) they enhance the capture rain water, which is especially important at the beginning of the rainy season; ii) they allow for the precise and thus resource-efficient application of both organic and inorganic field inputs (Twomlow et al. 2008). As these basins can be dug in the dry season already, they help in mitigating the peak in labour demand for field preparation which is inherent in semi-permanent and most permanent cultivation systems (Ruthenberg 1971). Theoretically, planting basins allow households to spread the labour needed for field preparation over a larger time period, during which little other tasks compete for household labour. They are therefore especially suited for situations where a shortage of draught-animals limits a farmer's ability to cultivate all of his land (Giller et al. 2009). Stevens et al. (2002) argue that this on the one hand benefits ox-owning households, as they may combine conventional tilling with CA to cultivate more land in total than what was possible before (as cited in Haggblade, Tembo & Donovan, 2004, 10). On the other hand, it allows households that do not own any draught-animals to plant soon after an effective rainfall event[30] instead of waiting for their neighbours' animals to become available several weeks into the growing season (Twomlow et al. 2008).

Nevertheless, constructing semi-permanent planting basins makes this approach more labour demanding than conventional tillage (Bishop-Sambrook et al. 2004) and turns labour availability into a main constraint to increasing plot size (Mazvimavi et al. 2010); also,

[30] According to Twomlow et al. (2008) an effective rainfall event on sandy soils in Sub-Saharan Africa is characterized by more than 30 mm of rainfall.

farmers in Zimbabwe tended to not spread this task over a long time period but tried to achieve it in one or two months, thus reducing the comparative advantages of the basins (ibid.).

The high labour needs of this approach and CA in general may force households to continue to rely on conventional tilling on some of their plots. However, Haggblade, Tembo & Donovan (2004) see this as a potential advantage, as it allows to reduce production risk: while CA generally offers higher yields in low and average rainfall years, water logging in high rainfall years may lead to a complete crop loss. It may therefore be beneficial for individual households to follow both conventional and basin tillage at the same time on different plots (ibid.).

Increasing land productivity and other benefits of CA

Apart from the basic characteristics presented above, CA over time tends to result in improved per hectare yields and returns to land (Haggblade, Tembo & Donovan 2004, Giller et al. 2009). This intensification is most likely related to investments in soil fertility and water availability (ibid.). However, these effects may occur only in the long-run and there are numerous counter-examples where, after the adoption of CA, yields even declined over the short-term (Giller et al. 2009). There appears to be large variation in the short-term benefits that CA provides for smallholder households, yet it are these short-term benefits[31], mainly yield, that determine adoption. This large yield variation may among other things be caused by how well farmers cope with increased weed competition under no-tillage and crop-residue borne diseases (ibid.). This also indicates that the adoption of CA may provide challenges that go beyond the approaches high labour needs per hectare.

Adoption of CA

Although CA provides a solution to the problem of soil degradation, which is wide-spread in Sub-Saharan Africa, is has not (yet) become a driver of land use change in this region (Bishop-Sambrook et al. 2004). It may be that degradation must reach a level where it threatens households' livelihoods before CA is adopted – as was the case with zero-tillage practices in Brazil (Evers & Agostini 2001) and which is in line with the theory Boserup (1965). However, adoption in Brazil was not spontaneous but triggered by intensive collaboration of researchers, extension officers, the private sector and participating farmers (Evers & Agostini 2001). Evers & Agostini (2001) summarized the general factors that constrain the adoption of CA in Sub-Saharan Africa, including the following: i) small farm sizes (leading to risk averse behaviour and less experimentation), ii) lack of tenure security reducing incentives for on-farm investments, iii) difficulties in making full switches in crop rotation from cereal to legumes due to food habits, missing market access and poverty, iv) traditional grazing systems that constrain the use of crop residues and the availability of biomass for mulch v) lack of infrastructure and effective input/output marketing systems and vi) low education that may inhibit farmers to participate in pro-active on-farm experiments in collaboration with extension officers and researchers (as compared to other regions of the world).

[31] Among others, reduced erosion and run-off do also provide society-wide benefits, or positive external effects, which are provided for by the farmer yet enjoyed by a larger community. This issue will not be presented here.

These general constraints to the adoption of CA are aggravated by the challenges presented above. Mazvimavi et al. (2010) found that in the drier areas of Zimbabwe, the labour burden of adopting CA may be overwhelming for vulnerable households that are affected by labour shortages (due to HID/AIDS, chronic illness) or that are child headed (ibid.). In these cases, and despite the fact that all three basic components of CA show considerable synergies and should be practiced jointly, it may be better to adopt the components in a piecewise manner (Bishop-Sambrook et al. 2004). However, other studies found that manual weed control under CA is practically impossible without a permanent soil cover and would require the use of herbicides (Vogel 1995). Giller et al. (2009) furthermore find that in many mixed farming systems of semi-arid African, where livestock is of central importance, it may be too costly for households to abstain from using the crop residues as animal fodder and instead apply them as mulch to their fields. The long-term benefits of mulching are hard to quantify and alternative fodder sources be unavailable. The authors conclude that:

> "*...under present circumstances CA is inappropriate for the vast majority of resource-constrained smallholder farmers and farming systems. We do not doubt that CA is one approach that can offer substantial benefits for certain (types of) farmers in certain locations at certain times*" (Giller et al. 2009, 31).

Recent studies on CA suggest that in order to assess the role than CA can play for smallholder livelihoods, it is of critical importance to assess its economic productivity, especially in regards to its labour productivity, i.e. the returns per unit of labour invested (Bishop-Sambrook et al. 2004, Haggblade, Tembo & Donovan 2004, Mazvimavi et al. 2010). CA should be regarded as one of many potential solutions, but not as a panacea for the challenges of smallholder agriculture in Sub-Saharan Africa (Giller et al. 2009).
The following analysis of conservation agriculture in Mashare will take these findings into account and focus on the role of labour and soil fertility management. The last chapter of the first part of this dissertation will compare indicators of land-, labour- and energy efficiency (or productivity) of both the three traditional farming systems as well as the conservation agriculture system in Mashare.

1.6.4.2 Experimental CA in Mashare

Characteristics of the system
The field trials in Mashare represent a more organic approach to conservation agriculture. Due to the semi-arid environment, this approach relies on the use of water-harvesting planting basins for the cultivation of maize, millet and cowpeas. Each of these crops is planted within a separate row of planting basins, giving the field the appearance of intercropping, while in fact this is a form of crop rotation: Each row is rotated every three years between the three crops. The approach is based on manual hoe-cultivation for both soil preparation (planting basins) and cultivation. The system's mean yields are thrice that of the traditional farming system in Mashare (in total 710 kg/ha for CA vs. 221 kg/ha for traditional farming) and average at 227 kg/ha for maize, 243 kg/ha for millet and 180 kg/ha for cowpeas.
Apart from providing higher yields per hectare, CA in Mashare aims at the rehabilitation of soil quality via a minimum tillage concept, i.e. by using planting basins. These basins are

annual re-dug by the farmers and located at always the same positions. Field inputs are applied into these basins and include annually applied inorganic NPK fertilizer and organic animal manure as well as biochar[32] and millet husks which are applied only once. While the former two provide nutrients, the biochar also contributes to increasing the basin's water retention potential. The millet husks provide further organic input, but more importantly are inoculated with isolates of the soil bacterium *Bradyrhizobium*, which acts as bio-fertilizer for legumes, increasing these crop's N-fixation (Kowalski et al. 2013b). Another expected benefit of these basins is that over the years, plant roots are expected to increasingly spread into the surrounding soil, thus gradually increasing the mean soil organic matter and fertility.

The fertilizer economy of CA in Mashare

The fertilizer economy of the conservation agriculture approach in Mashare is based largely on the application of nutrients via organic and inorganic fertilizers as well as the gradual increase of soil organic matter via minimum-tillage. Field inputs are applied to the planting basins and consist mainly of animal manure (15 t/ha) and inorganic NPK fertilizer (0.5 t/ha). An additional field input that is applied only during field establishment is biochar mixed with inoculated millet husks (3-5t & 6 t/ha, respectively).

A last aspect that differentiates CA from the traditional farming system in Mashare is that crop residues are always left as mulch in the field; they are never grazed by animals or lost in any other way. Although mulching theoretically eliminates the need for weeding, some weeding still had to be carried out by most farmers in the 2011/12 and 2012/13 growing seasons. On the one hand, farmers in Mashare are yet in the process of adopting the new cultivation techniques and may make mistakes that force them to continue weeding. On the other hand, this may also have been caused by a lack of sufficient mulch material. Generally, mulch material stems from crop residues left on the field and from biomass that is cut or gathered in the surrounding landscape. Furthermore, mulch is produced in-situ, i.e. on the field, via the relay-planting of sun-hemp; sun-hemp is sown at the beginning of the rainy season to function as a cover crop for CA's main crops and cut early in the growing season to provide additional mulch for the field. It remains unclear to what extend these combined practices allow for the production of mulch and thus to what extend farmers can expand their mulched CA areas.

Labor needs within an agricultural cycle for CA in Mashare

Conservation agriculture in Mashare tries to tackle the two most labour intensive tasks of the traditional farming system: soil preparation and weeding (see chapter 1.6.2). On the one hand, the practice of mulching aims to reduce the labour needed for weeding and is expected to make this task altogether unnecessary in the future, i.e. as soon as soil fertility is high enough to provide for sufficient crop residues and sun-hemp for mulching. On the other hand, soil preparation under conservation agriculture appears to be highly labour-intensive and involve

[32] Lehmann & Joseph (2015, 1): "*biochar is the carbon-rich product obtained when biomass, such as wood, manure or leaves, is heated in a closed container with little or no available air*". The authors consider 'biochar' as the "*appropriate term whenever charred organic matter is applied to the soil in a deliberate manner, with the intent to improve soil properties* (Lehmann & Joseph 2015, 2)". This distinguishes it from charcoal with is mainly used as fuel, a filter or reductant in iron-making (ibid.).

arduous physical efforts even beyond those of the traditional system – however, as described above, the digging of the basins (and the application of charcoal and millet husks during field establishment) can be carried out at a more leisurely pace in the dry season, when there are less other tasks competing for household labour. Compared to the traditional farming system in Mashare, the seasonality of land preparation is thus reduced and may allow some farmers to cultivate larger areas than what would be possible under traditional tillage[33]. In Mashare, this important trade-off may determine for which households this system provides a valuable alternative and for which its increased total labour-needs are just too high. For those households that own draught-animal power and that want to avoid digging basins, an alternative form of conservation agriculture has been developed. This draught animal power-based conservation agriculture (DAP-CA) abandons the strict practice of minimum tillage and carries out field preparation by oxen-drawn rippers, albeit at slightly wider distances between the furrows than under the traditional system. Here, the enrichment of the soil with organic matter is not as precise as in the manual CA approach, but the labour-needs for soil preparation are greatly reduced (see Tab. 1.36).
The higher yields of CA as compared to traditional systems attract livestock from the surrounding households and thus necessitate the creation and maintenance of fences around the fields. These fences combine traditional biomass-based bush-fences for poultry with stable wire-fences against larger livestock, which turns fencing a both labour- and capital-intensive investment.

To be able to cope with the higher total-labour needs of conservation agriculture, the concept of *division of labour by gender* is completely abandoned. Ideally, all adult household members carry out the same tasks on a jointly managed field. This ideal case will be analyzed here.

The annual agricultural cycle for CA in Mashare begins between May and July with the maintenance of fences and the de-bushing of the fields. During the same time, households collect biomass for mulching. In manual CA, the agricultural cycle continues in August with the digging of planting basins (although this task could theoretically be carried out during any month of the dry season). September is used mainly for the collection of manure and its application into the planting basins. Animal-traction based CA farmers usually rip their field in October, which is directly followed by the application of manure. All other inputs are applied in November, while sowing of both the main crops and sun-hemp is carried out between November and December. The field's mulch cover is applied between October and December and reinforced in February/March with the cutting of sun-hemp. Weeding and Chasing-away-birds occur more or less continuously between November/December and April/May and end only with harvesting in April/May, which concludes the agricultural cycle. Generally, biochar is applied only once, before field establishment, because it remains in the soil for a long time. Charring can be carried out throughout the year via the use of an easy to construct and maintain biochar stove, which double-functions as a kitchen stove for cooking. Latest in September it needs to be crushed into smaller pieces and mixed with the soil of the planting basins.

[33] See chapter 1.6.5.9 for a comparison of daily labour-demand of all farming systems analyzed in this study.

Tab. 1.34: Seasonal calendar of agricultural tasks for CA in Mashare

	June		July		August		September		October		November		December		January		February		March		April		May	
	1st half	2nd half	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Maintaining of wire fence																								
Maintaining of traditional fence																								
De-bushing the field of annual and biannual bushes																								
Gathering mulch material																								
Gathering biomass for making coal																								
Making sufficient coal																								
Crushing coal into smaller pieces																								
Mixing coal and pearl millet husks																								
Collecting and transporting manure																								
OPTION 1: ***Manual*** **Conservation Agriculture**																								
Digging or re-digging planting holes																								
Applying manure into holes and mix with soil																								
Applying coal to holes																								
Applying pearl millet husks																								
Applying fertilizer																								
Sowing in holes																								
OPTION 2: ***Ox-based*** **Conservation Agriculture**																								
Ploughing CA field with oxen																								
Applying manure																								
Applying Pearl Millet husks																								
Applying coal																								
Applying fertilizer																								
Sowing																								
Applying mulch																								
Planting sunhemp																								
Cut sunhemp and apply as additional mulch																								
Weeding																								
Chasing away birds from field																								
Harvesting																								

Source: Author's design. Note: The sSeasonal calendar of the main agricultural tasks in conservation agriculture (CA) has been differentiated into manual CA (Option 1) and ox-ploughing based CA (Option 2). The indicated months reflect the main periods during which theses tasks are carried out. However, tasks such as "Digging planting holes" could alternatively be carried out during the entire dry season, e.g. in case of labour shortages. This shows the relativity of these time windows. They become binding constraints only for those tasks that depend on sufficient humidity to be carried out, such as planting.

Tab. 1.35: Overview of labour needs of main agricultural tasks in various CA systems *(in working-hours/ha)*

Location of CONSERVATION AGRICULTURE	Digging planting basins	Preparing organic inputs	Applying organic & inorganic inputs	Planting	Applying mulch	Weeding	Harvesting	Other
Mashare, Namibia (manual CA)	**556**	**1260**	**150**	**96**	**240**	**160**	**40**	**544**
Mashare, Namibia (Draught-animal-power based CA)	n/a **(30 ploughing)**	**1260**	**150**	**96**	**240**	**160**	**40**	**544**
Burkina Faso	**450**	**174**	**150**	**40**	n/a	**95**	**50**	n/a
Niger	**300**	n/a	**120**	n/a	n/a	n/a	n/a	**200**
Zambia	**420**	n/a	**108**	**96**	n/a	**486**	**96**	**54**
Zambia	**420**	**180**	**150**	n/a	n/a	**60-180**	**128**	**234**
Zimbabwe	**221**	n/a	**141**	**48**	n/a	**385**	**78**	n/a
Zimbabwe	**169**	n/a	**230**	**57**	n/a	**344**	**75**	n/a
Zimbabwe	**412**	n/a	**60**	n/a	n/a	**522**	n/a	n/a

Total labour needs		Inputs per ha		
location	**hours/ha**	**Fertilizer use**	**Manure use**	**Source:**
Mashare, Namibia (manual CA)	**3046**	**500 kg/ha**	**15 t/ha**	empirical data
Mashare, Namibia (draught-animal based CA)	**2520**	**500 kg/ha**	**15 t/ha**	empirical data
Burkina Faso	**959**	n/a	**3 - 12 t/ha**	Kabore & Reij (2004)
Niger	**720**	n/a	n/a	Hassane, Martin & Reij (2000)
Zambia	**1266**	n/a	n/a	Haggblade & Tembo (2003b)
Zambia	**1260**	n/a	n/a	Haggblade & Tembo (2003a)
Zimbabwe	**109**	**83 kg/ha**	n/a	Mazvimavi & Twomlow (2009)
Zimbabwe	**122**	**176 kg/ha**	n/a	Mazvimavi & Twomlow (2009)
Zimbabwe	**994**	**0 - 80 kg/ha**	n/a	Rusinamhodzi (2015)

Source: Author's design. Note: including the corrected empirical data for study site Mashare.

Tab. 1.36: Mean corrected labour-demand of CA in Mashare per ha/task/year

Variable labour needs (i.e. proportional to field-size)	Working-**hours** needed per ha /activity /a
Gathering mulch material	1080
Collecting and transport manure (by oxen or hand)	*180*
Gathering & making of field inputs	1260
De-bushing	320

OPTION 1: Manual CA

Digging or re-digging planting holes	*556*
Applying manure into holes and mix with soil + fertilizer application	*150*
Sowing in holes	*96*
SUM of labour needs for field preparation & planting (manual CA**)**	802

OPTION 2: Ox-based CA

Ploughing CA field with oxen	30
Applying manure & fertilizer into rip-line	***150***
Sowing in rip-line	***96***
SUM of labour needs for field preparation & planting (ox-based CA**)**	276

Applying mulch	240
Planting sunhemp	96
Cutting sunhemp and applying as additional mulch	128
Weeding	160
Harvesting a mixed CA field	40

Total field size-related labour needs of **MANUAL CONSERVATION AGRICULTURE** (hours/ha)	**3046**
Total field size-related labour needs of **OX-BASED CONSERVATION AGRICULTURE** (hours/ha)	**2520**

Non-variable labour needs (i.e. not-proportional to field-size)	Annual working-**hours** needed
Maintaining wire fence	211
Maintaining traditional fence	133
Chasing away birds	289
Total annual non-variable labour needs (hours/a)	**633**

Source: Empirical data corrected by literature values of Tab. 1.33.

Tab 1.37: Labour needs for biochar application during field establishment

Biochar application (done only once at field establishment)	Working-**hours** needed per ha
Gathering biomass for making biochar	260
Charring (= making biochar)	0 (carried out parallel to other activities)
Crushing biochar into small pieces	200
Mixing biochar and pearl millet husks	30
Applying biochar (3-5t) & pearl millet husks (6t) to holes	103
Applying pearl millet husks and biochar to rip-line	103

Source: Author's design.

The challenges related to the empirical assessment of labour-needs for CA have been presented in chapter 1.5.6. Here, only the corrected values are reported. Yet even with the corrected numbers used in Tab. 1.36, the CA approach in Mashare is still considerably more labour intensive than the highest approach reported in literature. This can partly be explained by the very high amount of time used for gathering and applying mulch material. For this task, no alternative value could be found in literature. However, the reported labour-needs can still be expected to be quite realistic, because finding sufficient mulch remains an important bottleneck for the full adoption of conservation agriculture in Mashare.

Potential bottlenecks for the adoption of CA in Mashare

The previous paragraphs presented the labour-demand of CA in Mashare, and naturally this high labour-demand may present a bottleneck for the adoption of CA for some smallholders.
However, there are a few other potential bottlenecks, which will be presented below:
At current levels of production, mulch stemming from planted sun-hemp and crop residues needs to be complemented by collected biomass to reach a sufficiently high level of soil cover. However, the vegetation around Mashare is overgrazed, and if a larger number of local farmers started to collect the remaining biomass it would be realistic to assume that amassing sufficient mulch cover became a time-consuming task. If we ignored the time needed for gathering mulch material, the labour-needs for manual CA would fall to 1966 hours/ha and lie much closer to the findings from literature (yet still be 1.6 times higher than the highest reported value).
Another potential bottle-neck for the adoption of CA in Mashare is the limited availability of animal manure. The current livestock management system in the study site is very unlikely to provide sufficient cattle manure should all households aim at adopting CA. Research is needed to determine whether appropriate new livestock grazing plans could mitigate this problem and thus be a pre-requisite for the wide-spread adoption of conservation agriculture in the study site.
Thirdly, the financial capital needed for purchasing the inorganic field inputs presents another bottleneck for many households. While most field inputs, such as biochar or mulch, can be created by the household free-of-cash out of natural resources, chemical fertilizers may force the household to re-invest relatively large sums of their income into agricultural production (160 US-$/ha for fertilizer alone).

The adoption of new farming systems and technologies always entails the potential of social change and this change can have positive as well as negative effects, e.g. lead to a new division of labour that disadvantages women or replace an older system that is very well adapted to local growing conditions. However, it is unlikely that these potentially negative aspects of adoption will occur in Mashare. First, the currently dominating smallholder farming system clearly does not represent a sophisticated and long-term adaptation to local growing conditions but rather a degraded form of farming that is better suited to land abundant regions such as southern Angola. Second, the CA approach forces households to organize their labour force even more centrally to cope with the increase in total labour demand. At the moment, all tasks are carried out to equal parts by male and female household members. It has to be kept in mind, though, that households taking part in the experimental trials are still adapting to this new technology. Although they currently follow the concept of equal labour, there is the possibility that they may come up with their own adaptations over time. Another important aspect for the adoption of CA is related to farmers' mindsets. Even if households in Mashare managed to cope with the increased total labour-burden and cash-needs of CA, the required change in mindset may take a long time. An example for this change is that farmers have to abandon the idea of owning "clean", crop-residue free fields and embrace the benefits of "dirty", i.e. mulch-covered fields. The case of Brazil (Evers & Agostini 2001) showed that it took high levels of land degradation and intensive cooperation between extension workers, researchers, the private sector and participating farmers to actually achieve a transition to CA farming. Also in Mashare, some form of continued external assistance may be needed to help farmers to achieve this agricultural transition. At the same time, the improved management of communal resources, e.g. of pastures and livestock herds for the provision of sufficient manure, may be a pre-requisite of the long-term success of this transition.

1.6.4.3 The potential role of CA for sustainable intensification in Mashare

This analysis revealed that CA in Mashare, despite its very high total labour-demand, offers several advantages to the dominant traditional farming system: First, it is characterized by an improved seasonal distribution of labour-demand for field preparation. Second, it allows both for water harvesting (via the planting basins and use of organic field inputs) as well as soil rehabilitation. These advantages address some of the main bottlenecks of traditional farming in Mashare, i.e. low and erratic rainfalls, very low levels of soil fertility and lack of animal-draught power which regularly leads to late ploughing. A detailed comparison of conservation agriculture with all other traditional farming systems will be presented in chapter 1.6.5.9, at the end of the first part of this study. The second part of this study will apply mathematical programming to examine in how far conservation agriculture presents a viable alternative for households in the Okavango catchment.

1.6.5 Synthesis and discussion of results

1.6.5.1 Repetition of Study Site Results

This first part of this dissertation presented the farming system analyses of the three study sites *Cusseque* in Angola, *Mashare* in Namibia, and *Seronga* in Botswana. The goal was to identify the main characteristics and constraints of arable smallholder agriculture in the Okavango catchment. To achieve it, a theoretical framework based on Boserup (1965) and Ruthenberg (1971) was applied. This allowed for analysing the respective smallholder communities at both the societal and the farm level. The observations made in the individual study sites could be explained well with the chosen theoretical framework. In fact, the study sites could be classified as typical stages of agrarian societies (and their respective farming systems), which can be encountered all over the tropical world.

In the following synthesis chapter, the results of the farming system analyses will be used to derive initial recommendations for future policy intervention. Moreover, it will form the basis for the bio-economic modelling exercise of part II of this dissertation.

Shifting cultivation in Cusseque, Angola

The study site *Cusseque* in Angola represents a system of shifting cultivation under long-term forest fallow in the African woodland savanna. The farming system can be regarded as ecologically sustainable because it is characterized by a balanced exploitation of the soil, i.e. a mining of soil nutrients during times of cultivation and their replenishment during an ensuing fallow period. As long as land availability allows long-term fallow periods, this system will remain in this balanced state and provide sufficient yields for both subsistence purposes and the sale of a small harvest surplus.

However, a recently built tar road and growing urban centers are driving Cusseque’s integration into the cash-based regional and national economy and are already causing a rise in commercial charcoal production (Holden 2015). This trend coincides with high population growth and urban entrepreneurs seeking to invest in agriculture. It is likely that these trends will result in the spatial expansion of agriculture as well as an increase in (commercial) natural resource use activities, e.g. for charcoal making. Therefore, declining land availability can be expected in the near future. If this development is not compensated for by adopting alternative farming systems, this is bound to initiate a process of soil degradation.

Semi-permanent cultivation in Seronga, Botswana

The study site *Seronga* in Botswana, represents a system of semi-permanent cultivation in the semi-arid drylands of Sub-Saharan Africa. Overall land availability appears high and irregular field expansion or clearing of new fields are the main means of managing soil fertility. However, the majority of the local population is clustered in settlements along the Okavango River and within Seronga Town. In Seronga Town, this population concentration is especially causing relative land scarcity and thus the failing of traditional means of soil fertility management.

Currently, Seronga is characterized by a diversity of different livelihood strategies. To a certain degree, this may be explained by some farmers’ frustration with arable agriculture, which is related to both erratic rainfall and high crop losses due to wildlife and livestock

damage. Farmers indicated that this frustration causes them to diversify into alternative livelihood sources rather than specialize in crop production.
Seronga Town access to the national cash-based economy is growing. However for the majority of farmers, market access remains too low to allow for commercial production. They continue to depend on subsistence production, and their farming systems will continue to be affected by the dynamics of subsistence agriculture described by Boserup (1965). In the long run, the farmers' unwillingness to invest into cropping makes it unlikely that current population growth will be compensated for by the adoption of improved farming methods. Instead, ongoing soil nutrient mining on fields of declining size appears to be a more likely trend around Seronga Town.

Semi-permanent to permanent rain-fed cultivation in Mashare, Namibia
Lastly, the study site *Mashare* in Namibia represents a transitional stage between a system of semi-permanent cultivation and permanent, rain-fed cultivation. In Mashare, fallowing has not yet been replaced by an alternative means of soil fertility management. At the same time, many farmers are affected by the scarcity of arable land. Decades of inadequate soil fertility management have depleted soil nutrient stocks and led to a dominance of pearl millet - the last cereal crop to provide a relatively reliable yield on local soils and under local rainfall conditions. Poor access to regional or national markets results in the dominance of subsistence production. Yet many farmers would not even benefit from improved market access because the majority are not even able to produce any marketable crop surplus. Instead, they rely on alternative livelihood sources or on government intervention (disaster aid such as *drought relief*) for their survival.
Over the last 10 to 15 years, the cattle economy in Mashare experienced a breakdown. It was most likely caused by inadequate pasture management (i.e. overgrazing) and resulted in a much skewed distribution of cattle ownership. In the past, almost all households owned at least a few animals, and they played an important role for rural livelihoods – as a sign of wealth and prestige, as a quasi-bank account or as a provider of animal traction. Nowadays, mainly the wealthy households manage to sustain their herds, because they are able to purchase medicine or additional fodder. Nowadays, the poorer farmers tend to invest their scarce cash resources into hiring oxen for ploughing from their more wealthy neighbours.
As in the other study sites, population growth in Mashare is ongoing and causing increased problems of land scarcity, soil mining, and thus impoverishment. Some households in Mashare are already in danger of falling into a poverty trap, from which they will be unable to free themselves without external intervention.

1.6.5.2 Applicability and limitations of the theoretical framework

The use of the Boserup-Ruthenberg framework allowed for an in-depth analysis of the agrarian societies (and their farming systems) in the study sites. Perhaps the most important benefit of using this framework was that it allows comparison of all three study sites, even though they were affected by fundamentally different events in time, are characterized by different ecosystems, and consist of different people that specialize in different livelihoods.

The analyses revealed the importance that *land availability* and *market access* have on farm management in each study site. Therefore, the results are in line with Boserup's (1965) assumptions on main drivers of change. All three study sites could be linked by the same main drivers and the same dynamics resulting from these drivers (soil degradation, declining labour efficiency, and the danger of household impoverishment). At the same time, the framework also allowed the identification and interpretation of site-specific drivers of change such as wildlife conflicts in Seronga or charcoal production in Cusseque.

The study sites were analysed in terms of i) R-values, ii) the labour needs of typical agricultural tasks, iii) the role of oxen, and iv) approaches to soil fertility management. By doing so, striking resemblances were found between what theory predicted and what was observed in the field. There were no contradictions to the theoretical framework, and all site-specific peculiarities could be explained[34]. This is not surprising, as the general applicability of the Boserup-Ruthenberg framework has been repeatedly proven, most recently for Sub-Saharan Africa in Jayne et al. (2014a).

Furthermore, some of the criticism on the Boserup-Ruthenberg framework (from Fischer-Kowalski et al. 2011) could be refuted for the three study sites. It was proven that the smallholder farming systems in all three sites still rely on manual labour and/or animal traction as their main energy sources; fossil fuel plays only a minor role, if at all. Fischer-Kowalski et al.'s (2011) finding that *Boserupian* intensification is unlikely in cases where fossil fuels provide the main energy source therefore does not apply to the research area. On the other hand, one may wonder what use Boserup's (1965) theory has in a world where fossil fuels play an increasingly important role and where external interventions, e.g. from governments or NGOs, lead to a blurring of the subsistence mode of production. Both assumptions are central for Boserup (1965). Fischer-Kowalski et al. (2011) may be right in their assessment that *Boserupian* intensification is less likely today than in the past.

However, when combined with Ruthenberg (1971), the framework still allows an understanding of potential development pathways of subsistence smallholders, even if they do not intensify production. Nowadays, *agricultural involution* (Geertz 1974) may be more likely than in the past, and many rural societies may follow a trajectory from an initially sustainable shifting cultivation system down a path of gradual resource degradation towards a system of permanent rain-fed agriculture, ending at Ruthenberg's (1971) "*low-level equilibrium trap*" (Ruthenberg 1971, 125). For instance, this appears to be the case for Mashare. On the other hand, Boserup (1965) convincingly argues that under subsistence production, these rising scarcities ultimately induce farmers to adopt new, intensified farming practices; it can be argued that these rising challenges may actually present a prerequisite for the sustainable intensification of subsistence agriculture in the research area.

In summary, the Boserup-Ruthenberg framework helps to identify likely developments in subsistence smallholder farming and the causes behind them. It furthermore gives testimony to smallholders' historical ability to innovate and successfully adapt their farming systems to changing challenges. Smallholder agriculture is not something backwards, but it has a high potential for sustainable intensification. By clarifying which trends hinder and which benefit

[34] The high labour needs for field preparation in Cusseque present a good example of this. They lie above those of most shifting cultivation systems in the tropics but are in fact typical for those rarer systems found in the African woodland savannas.

smallholder intensification, the framework provides insights that facilitate the formulation of policy recommendations.

However, there is a certain danger of misinterpreting the Boserup-Ruthenberg framework, i.e. when postulating a fixed sequence of agricultural stages. In reality, agrarian societies do not always follow a predetermined evolution through a set of societal stages, nor should these stages be regarded as truly discrete. Instead, they may skip a certain stage or – under declining population density – even move backwards to a less land-constrained stage. These *typical stages* represent nothing more than collective terms that try to capture several phenomena that usually appear jointly and develop interdependently along typical trajectories of change.

1.6.5.3 Non-agricultural means of smallholder adaptation to land scarcity

The following overview complements the previous analysis by looking at the main determinants of and responses to land scarcity in Sub-Saharan Africa, which were identified by Jayne et al. (2014) and presented in Chapter 1.2.5. Furthermore, the following conclusions are based on certain underlying assumptions:

1) *Land allocation policies & institutions* remain fixed throughout the period of analysis.
2) Following Ruthenberg (1971), *land quality* is regarded here as a function of farm management and as generally declining under the land-constrained systems of semi-permanent cultivation and permanent rain-fed cultivation; it is assumed to remain stable under systems of shifting cultivation, which are characterized by sufficient land availability to allow for the regeneration of soil fertility.
3) Therefore, local population density and market access conditions will be considered the main determinants of land scarcity in the research area.

The livelihood analyses in Chapters 1.6.1 – 1.6.3 revealed that a diversification of farm households into the non-farm sector can be observed in all study sites. However, it appears as if only a minority of relatively wealthy and/or more educated households successfully diversified into the non-farm sector in either study site.
Migration movements are strong within the Okavango catchment and are characterized by i) migration to local and national urban centres as well as to a more limited degree by ii) re-migration of refugees to rural areas of Angola. In the study sites, these migrations appear to not mitigate the effects of rising land scarcity; farmers report that most rural migrants are unable to find formal employment in the urban centres. Many return therefore to their rural homelands after a certain amount of time. This is in line with Gollin et al.'s (2013) finding that cities in Sub-Saharan Africa cannot offer large-scale employment opportunities.
The reduction of fertility rates by increasing *demand for contraception* was not empirically assessed in the study sites, yet high expected rates of population growth indicate that, even if there is demand, it is met only to a minor degree.

In summary, most non-agricultural means of responding to rising land scarcity have been observed in the study sites, yet they appear unable to effectively mitigate its negative effects. It can therefore be expected that subsistence agriculture will remain the main livelihood source for a majority of smallholders in the foreseeable future and agricultural intensification a pre-requisite for stable rural livelihoods.

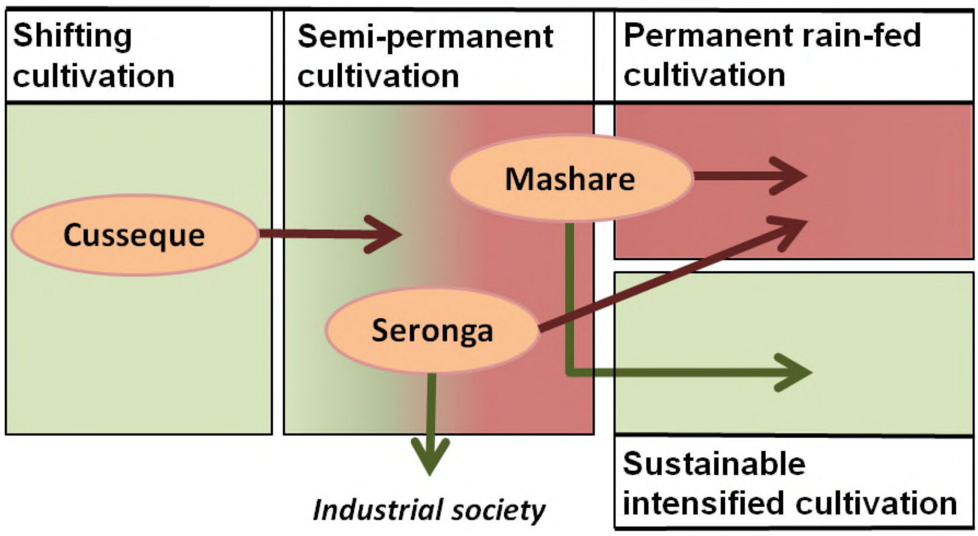
1.6.5.4 The role of the Okavango catchment's economic transition

The assumption of an on-going importance of smallholder farming is reaffirmed if one considers the findings of Barbier (2014). The majority of Okavango catchment must be considered marginal land[35], especially the mid and lower Okavango catchment, which is characterized by Kalahari sands of low fertility and erratic rainfalls. Barbier (2014) found that in these so-called frontier economies, any economic boom driven by natural resource use is usually short lived (see Chapter 1.4.4.2). This may be of special importance for the research area, especially for Namibia and Angola, which promote the establishment of large-scale commercial agricultural projects. Even if the planned development succeeds, according to Barbier (2014) it is likely to result in only temporary benefits for the smallholder sector. In the long run, however, it is more likely to result in the coexistence of a well-developed commercial sector with a relatively poor smallholder sector that survives mainly on marginal lands and continues to convert available land for subsistence production. This indicates that in the long term, even more successful and diversified households may not truly benefit from the economic transition of the Okavango basin. Instead, they may be forced to revert to traditional, natural resource-based livelihoods. At the same time, marginal lands are especially vulnerable to degradation processes. Any economic boom relying on natural resources can be expected to increase the speed of degradation processes and thus threaten the livelihood base of the smallholder sector. Barbier's (2014) findings are important as they show that it is not guaranteed that large-scale commercial agriculture projects in the research area offer sustained benefits to rural farm households via a trickle-down effect. This is an important argument towards smallholder-led development strategies.

1.6.5.5 Future trends of smallholder farming in the study sites

The findings presented so far allow a tentative prediction of the most likely future development trajectories of the three study sites.

Fig. 1.12: Likely and possible development trajectories in the three study sites



Source: Author's data. Note: Red arrows represent the most likely trends if no policy intervention takes place while green arrows represent those developments that have the relatively highest likelihood of success or voluntary adoption.

[35] See Chapter 1.4.3.

The red arrows in Fig 1.12 indicate a likely future where no pro-smallholder policy intervention takes place. The green arrows indicate a situation where conservation agriculture is promoted in Mashare and where Seronga is connected to the national economy via a reliable tar road and transport infrastructure (green arrows in Fig. 1.12).

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The reasoning behind Fig. 1.12 is as follows: In Cusseque, rising degrees of land scarcity are likely to turn this ecologically sustainable system into a system of semi-permanent cultivation. As long as subsistence production dominates, it is unlikely that farmers in Cusseque will voluntarily adopt intensification measures before their welfare is endangered (e.g. due to a certain level of soil degradation). Therefore, the dominance of subsistence production is likely to force the farming system of Cusseque into semi-permanent cultivation. Only then will the likelihood of a voluntarily adopted of sustainable intensification measures increase. Commercial production may present a way towards sustainable intensification in Cusseque, yet no research could be carried out to assess its chances and challenges. It was therefore not included in this analysis.

In Seronga, farmers' frustration with arable farming is likely to combine with rising population densities to cause a gradual shift to permanent rain-fed farming – at least for the majority of farmers living around Seronga Town or the bigger cattle posts. Due to the adverse climatic conditions for arable agriculture, Seronga's future may not lie in sustainable intensification, but in a transition towards an industrial society (i.e. a society based on fossil fuels instead of manual labour and biomass – see Sieferle 1997). However, if this transition remains impossible, e.g. because the region is not connected to the national economy via a reliable tar road, sustainable intensification may be the next best option.

Mashare in Namibia represents a transitional stage between semi-permanent and permanent rain-fed cultivation. Over the short to medium term, Mashare's farming system may transition fully to a permanent mode of cultivation and ultimately reach a "*low-level equilibrium trap*" (Ruthenberg 1971, 125). However, the transitional nature of Mashare also provides farmers with a high incentive for intensification – and therefore the highest likelihood of all study sites for a voluntary and successful adoption of a sustainably intensified system such as conservation agriculture.

1.6.5.6 From study sites to ORB – generalization of results

Here, an attempt will be made to upscale the results obtained for the local level of the study sites to the regional level of the research area, i.e. the ORB. To do so, it is helpful to recall the main insights gained so far. A comparison of all three study sites revealed that *natural resource degradation* and *social stratification*[36] are positively correlated with *population density*, while *cash availability* appears to be positively correlated with only *social*

[36] Seen here as inequality in household wealth and diversity of livelihood strategies.

stratification. This is in line with the assumptions of the Boserup-Ruthenberg framework, the applicability of which has been proven above. It is therefore assumed that the basic assumptions of this framework hold and that the evolution of many smallholder farming systems in the ORB can to a large extent be explained by their adaptation efforts to changing degrees of land scarcity and market access.

The issue of soil fertility management lies at the heart of the future agricultural development in the research area. Even nowadays, traditional farming systems rely mainly on land availability for the regeneration of soil fertility. However, scarcity of arable land in the ORB is likely to increase in the future. Current farming practices will then result in soil nutrient mining or achieve a low-level equilibrium. Furthermore, the case of Mashare illustrates the importance of land availability for livestock keeping. Here, overgrazing has resulted in an on-going breakdown of the cattle economy. Due to the multi-functionality of cattle keeping, especially as a provider of draught animals, this is harmful for rural livelihoods in the mid- and lower catchment. It can therefore be postulated that land scarcity degrades current natural-resource-based livelihood sources in the Okavango catchment. As has been shown, the majority of rural households depend on these livelihood sources.

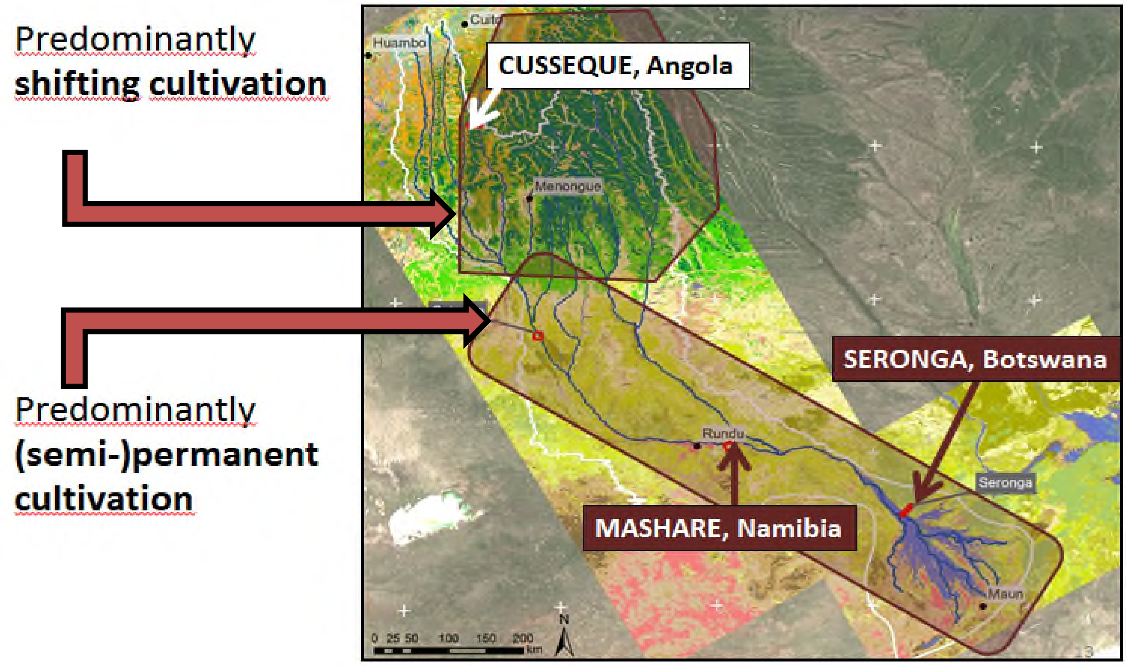
In the mid and low river areas of Namibia and Botswana, land scarcity is already a serious constraint to farming; it is caused mainly by the expansion of cropland due to a growing demand for food as well as by the rise of competing land uses, including conservation areas or the establishment of government-led large-scale irrigation projects.

Furthermore, land scarcity can be driven by the commercialization of natural resource use. Growing market access may induce a change in farmers’ mind-sets and decision making, e.g. by creating new needs or aspirations for commodities traded in international markets (see Pröpper et al. 2015). As a result of this changing mind-set, natural resource use or agricultural production may be intensified to generate cash income. This can already be observed in the study site Cusseque for charcoal production, which reduces the area of forest available for shifting cultivation. At the moment, subsistence-oriented production dominates in the basin, and important obstacles to market access include a lack of infrastructure for storage and transport of the harvest, access to electricity, finance markets as well as input markets. This may change in the future and increase the degree of commercialization of crop production, with far-reaching consequences on land use and smallholders’ decision-making.

Future land scarcity in the research area may be caused by two other important drivers of land use change. First, there is some indication that in Cusseque, medium-scale farmers may contribute to future land scarcity. They are already a dominant type of land user in Sub-Saharan Africa (see Jayne et al. 2014, Sitko & Jayne 2014). On the one hand, a roadside garden in Cusseque Village is tended for by locals yet owned by an unidentified urbanite. On the other hand, in 2013 an urbanite from nearby Chitembo was exploring the possibility of growing beans at the roadside for commercial purposes. Although these two observations are certainly no proof of a general land use trend, they indicate that the study site may be of interest to this emerging type of land user. It is therefore a reasonable assumption that in and around Cusseque, urban entrepreneurs will increasingly invest in agricultural production and drive competition for land. The rise of medium-scale farmers has not yet been observed in the other two study sites. A likely explanation for this could be favourable biophysical, infrastructural, and market conditions in the Angolan highlands, which turn agricultural production into a much less risky business than in the more arid lowlands of the Kalahari. Second, another driver of land use change that may soon affect the entire catchment is the establishment of large-scale commercial farms in Namibia and Angola. In the former, it has already resulted in the relocation of rural communities from the more fertile plots along the Okavango River to areas of lower soil fertility. Both trends combine to result in rising competition for land in the Okavango catchment, thus contributing to a rising degree of land scarcity for rural communities.

When combining the insights gained above with the three principal cropping areas of the Okavango basin (identified by OKACOM (2011, 83) and presented in Chapter H, Fig. 0.2), a tentative map can be created that hints at the likely distribution of the catchment's dominant farming systems (Fig. 1.13).

Fig. 1.13: Approximation of the spatial distribution of the dominant smallholder farming systems in the Okavango catchment.



Source: Author's design, based on a map by Stellmes et al. (2013).

While the land-abundant Angolan highlands are dominated by shifting cultivation practiced in *Miombo* woodlands, the (for smallholder cultivation) land-constrained mid and lower catchment is dominated by more permanent forms of smallholder agriculture that still rely on the basic management practices inherited from shifting cultivation. This distribution is based on the following assumptions: i) subsistence production dominates smallholder farming in the research area; ii) water availability and road infrastructure determine availability of arable land; and iii) the most fertile land in the Kalahari lowlands is found along the Okavango River, in the old floodplains and inter-dune valleys. These assumptions are backed up by Mendelsohn's (2009) finding that the majority of the rural population in the Namibian part of the catchment is concentrated within a 10 km-wide strip along the Okavango River.

1.6.5.9 A comparison of CA and dominant smallholder farming systems

The following chapter presents a comparison of the three traditional farming systems as well as the conservation agriculture approach promoted in Mashare (see Tab. 1.38). This comparison includes indicators of land, labour and energy efficiency. It reflects the trade-off decision a smallholder faces when choosing whether or not to adopt a sustainable intensified practice. Therefore, it helps illustrate why smallholders in the research area may be reluctant to adopt conservation agriculture.

However, any direct comparison between farming systems of the semi-humid highlands of Angola and the semi-arid Kalahari lowlands in Namibia and Botswana has to be treated with caution. As mentioned before, Angola has higher and less erratic levels of annual precipitation and offers more favourable cropping conditions. At the same time, the CA approach in Mashare was adapted to semi-arid conditions and aims to harvest water. It remains unclear whether this system, if applied in the Angolan highlands, would yield even higher yields than in Namibia or whether waterlogging would instead lead to reduced yields.

The comparison reveals that in regards to the mean per-hectare yields (i.e. *land efficiency*), both shifting cultivation in Angola and CA in Namibia dominate over the other systems. They provide higher and (as we know from the site-specific analyses) more stable yields than the other systems. Furthermore, in the traditional systems, land efficiency is negatively correlated to increasing permanency of cropping – a trend that is only broken by CA, which represents an example of intensified permanent cropping. In fact, these empirical correlations are in line with the theoretical assumptions of the Boserup-Ruthenberg framework on land efficiency.

A similar result can be found for the *efficiency of labour and energy use* (which includes the energy content of labour hours, applied manure, and inorganic fertilizers): In order to produce sufficient food to feed one person for a year, the least labour and energy (kcal produced compared to kcal invested) needs to be invested in shifting cultivation and the most in CA. Presented in another way, under shifting cultivation, the investment of 1 kcal of human labour yields 22.7 kcal, while under CA each invested kcal yields only 4.7 kcal. The other traditional systems lie between these two extremes. In terms of kcal return per labour hour invested, all traditional systems surpass CA.

When the energy content of organic and inorganic fertilizers is included in the comparison of kcal output per kcal input, the input-based systems fare much worse. Now, the traditional systems yield about as much kcal as they require as inputs, while CA yields only a tenth (0.08 kcal per 1 kcal invested). This means that more energy is invested than extracted. This comparison excludes the energy needed to produce and transport the inputs to the farm (which is especially high for inorganic fertilizer).

For an individual smallholder, this finding may be irrelevant. But for large-scale land use planning it raises the question whether CA and other systems based on (non-renewable) inputs can be regarded as sustainable. However, the apparently bad performance of CA can be put into perspective when considering CA targets both *food production* and *soil rehabilitation*. It seems logical that for improving soil fertility, more energy needs to be added to the soil than is extracted.

Tab.1.38: Comparison of the dominant farming systems of the study sites in terms of various efficiency indicators.

	Traditional Agriculture					Intensified Agriculture
	Shifting cultivation	Semi-permanent cultivation	Permanent rain-fed cultivation			Conservation agriculture
	Angola	Botswana	Namibia (no inputs)	Namibia (20 kg NPK fertilizer)	Namibia (5 t manure)	Namibia (0.5 t fertilizer & 15 t manure)
Mean kcal yield per ha (kcal/ha)	2,982,792	*859,275*	*709,635*	*1,559,217*	*1,353,435*	2,503,070
Mean yield in kcal per working hour *(kcal/hour of producer labour invested)*	3984	*1725*	*2031*	*3177*	*2716*	822
Mean producer labour hours needed to feed one person per year *(hours/year)*	168	*387*	*329*	*210*	*246*	813
kcal produced per 1 kcal invested as producer labour (incl. animal traction)	22.7	*7.2*	*8.3*	*9.2*	*8.0*	4.7
kcal produced per kcal invested as producer labour AND inputs	*no fertilizers applied*	*no fertilizers applied*	*no fertilizers applied*	*1.30*	*0.93*	0.08
Cultivated area needed to secure minimum kcal needs of one person *(ha/person)*	0.22	*0.61*	*0.71*	*0.37*	*0.42*	0.27
*including fallow area:**	1.6 - 5.5					

Source: Author's design based on empirical data, except for mean kcal yield/ha in Cusseque which is based on Holden (2015). Note that all italic values are based on empirically assessed cereal yields combined with the assumption that a typical (semi-)permanent field in Botswana and Namibia yields an additional 135 kg of cowpea per ha (this level was indicated by an initial yield assessment in 2012). * Derived by translating the estimated R-value of 4-14 into ha, i.e. assuming 0.22 ha to represent 4-14% of total area needed = 0.22/0.04 or 0.22/0.14

Moreover, the negative energy efficiencies of manure-based systems illustrate that for them, an appropriate livestock & rangeland management is of crucial importance. In these systems, energy is at least to some extent exported from rangelands in the form of animal fodder/grazing and transferred to the crop field in the form of animal manure. It has been indicated before that on the communal rangelands of Mashare, overgrazing is taking place. This may in the future result in a reduced availability of manure and reduced possibilities for widespread adoption of organic fertilization. Therefore, *sustainable rangeland management* may be another prerequisite for all farming systems relying on locally produced organic field inputs[37]. This specifically includes CA with its very high input needs of manure for fertilization and plant biomass for mulching (which in Mashare stems from communal rangelands and is therefore dependent on biomass regeneration on these rangelands).

Tab. 1.38 indicates an important advantage of CA over any of the traditional farming systems. Apart from its 1) soil rehabilitating characteristics, 2) its ability to harvest water, and 3) its reduced peaks in seasonal labour-demand, 4) it needs the least amount of land to produce sufficient food to sustain one person for one year. When comparing the kcal produced per unit of land with the minimum annual kcal needs of an adult smallholder in Sub-Saharan Africa (1830 kcal/day according FAO 2011), it becomes clear that CA is by far the most land efficient system of those that were analysed[38].

Comparison of seasonal labour demand

Tab. 1.39 presents an attempt to capture the peak in labour demand that was reported for the traditional farming systems in Botswana and Namibia. It compares the daily working hours needed to cultivate one hectare under each respective farming system.

The comparison is built on the assumption that field preparation in Mashare's traditional farming systems has to be carried out within a short time window. Farmer interviews revealed that its length is determined by the level of (erratic) precipitation. After first rainfalls, the soil can be ploughed for only one to two weeks. The comparison in Tab. 1.39 considers three scenarios: a time window of 1) seven, 2) fourteen, and a more favourable window of 3) twenty-one days for soil preparation and planting.

This comparison also builds on the fact that field preparation under CA can be carried out throughout the entire dry season, starting after harvesting at the beginning of June and ending with planting around the end of November; this indicates a field preparation period of six months or 183 days. Apart from soil preparation and planting, many other agricultural tasks such as preparing manure and other field input need to be carried out within this time period. All of them were considered in the amount of daily labour hours needed for field preparation under CA, thereby allowing a more realistic comparison of CA and the traditional farming

[37] It is assumed here that manure is produced only within the farm systems, i.e. the individual farm holdings, and not purchased from neighbours or on the local market. This is a realistic assumption for the research area. Further research would be needed to determine the impact of manure markets on the efficiency and ecological sustainability of these 'improved' farming systems.

[38] Only at first glance does shifting cultivation in the more favourable agro-ecological conditions of Angola require less land than CA, because in order to sustain its productivity, shifting cultivation requires a large area of fallow land that can be regularly cleared. The wide range of fallow area reported in Tab. 1.38 is based on the farming system's R-value as reported in Chapter 1.6.1.

system[39]. The CA system is represented twice in Tab. 1.39. This is due to the fact that the time needed for gathering mulch material in CA appears very high and may be subject to further debate. Therefore, one comparison includes and the other excludes the working hours needed to collect mulch material.

Tab. 1.39: Comparison of labour demand per day for field preparation between traditional farming systems in Mashare and CA in Mashare (Namibia).

Farming practice	Tasks included in comparison	**Labour-hours / ha**	Assumed max. time available for soil preparation in days	**Required labour hours / day**
Ox-based traditional farming in Mashare	*Ploughing*	*20*	7	**14**
	Planting	*80*	14	**7**
	TOTAL	**100**	21	**5**
Hoe-based traditional farming Mashare			7	**40**
	Hoe-based planting	*280*	14	**20**
	TOTAL	**280**	21	**13**
Basin tillage CA (*including* labour for gathering mulch)	*Gathering & making field inputs*	*1,260*	183	**12**
	Digging planting basins	*556*		
	Apply inputs to basins	*150*		
	Planting main crops	*96*		
	Planting sunhemp	*96*		
	TOTAL	**2,158**		
Basin tillage CA (*excluding* labour for gathering mulch)	*Gathering & making field inputs*	*180*	183	**6**
	Digging planting basins	*556*		
	Apply inputs to basins	*150*		
	Planting main crops	*96*		
	Planting sunhemp	*96*		
	TOTAL	**1,078**		

Source: Author's design based on personally gathered data.

The results reveal that compared to traditional *hoe-based* cultivation in Mashare, CA lessens the *peak* in labour demand for field preparation. When compared to traditional *ox-based* cultivation, the winner is determined by the actual length of the period for field preparation (as well as the labour needed for gathering mulch). Because the difference in the available data is too small, no conclusion can be made as to whether or not CA is characterized by lower seasonal peaks in labour demand than the traditional ox-based system. At the same time, the *total* labour demand of CA is much higher than in the traditional system. Under traditional ox-based field cultivation, 5 to 14 hours need to be invested per day to plough one hectare – but only over a time period of 7 to 21 days. Under CA, 12 labour hours need to be invested daily over a dry season of 6 months to prepare one hectare. Normally, the dry season is considered to be the "lazy" period during which less work is done and during which high temperatures turn any field work into an arduous business. Therefore, the adoption of CA has

[39] The labour needs of manuring under the traditional system are ignored here as this task is assumed to be carried out outside the time window for field preparation, i.e. the manure is assumed to be distributed on the field before the onset of rainfalls and incorporated into the soil via ploughing. The same holds for pre-planting, which also occurs independently of rainfalls.

significant physiological demands on farmers' bodies and requires a change of mind-set, i.e. an acceptance of continuous working days throughout the year. This concept may be widespread in the urbanized, so-called developed world, but is by no means widespread in traditional smallholder societies (see Boserup 1965).

This overview illustrated that a variety of indicators can be used to describe each farming systems performance or efficiency. Any evaluation has to be aware of the trade-offs between these indicators and their implications for the various stakeholders. Social planners, political decision makers or environmentalists may differ fundamentally from what a smallholder considers to be the most important indicators or trade-offs. Smallholders can be expected to be most interested in a system's labour and land efficiency, while environmentalists might focus on various forms of energy efficiency (see Fischer-Kowalski et al. 2011). Being aware of these differences may help improve the design of agricultural intervention policies and facilitate a general understanding of each stakeholder in all political arenas related to smallholder agriculture. It also showed that CA cannot be seen as the panacea for all smallholders of the Okavango basin or even just those of the study site. However, under progressing levels of land scarcity, soil degradation, and scarcity of draught animal power, CA in Mashare may very well represent smallholders' best available farming option.

1.6.5.10 Summary of the farming system analysis

The results presented above can be summarized into the following main points:

1) Rural societies in the study sites are in a transition from agrarian societies of rather homogeneous livelihoods towards societies that are better connected to regional markets, but which are also characterized by increasing economic inequality.
2) Smallholder subsistence forms of agriculture are the dominant farming systems in the Okavango basin. At least over the medium term, they will remain the main livelihood source for a majority of households. The farming systems are (to different degrees) affected by *declining land availability*, which is caused by two main drivers of change: i) increasing population density and ii) a growing integration into regional and international cash economies.
3) Under current cropping systems, a decline in land availability leads to a depletion of soil fertility. Therefore, traditional farming systems are currently on a pathway towards household impoverishment and natural resource degradation.
4) It appears likely that households will continue to follow traditional ways of farming rather than develop and adopt sustainable intensified farming systems. In other words: agricultural involution (Geertz 1974) appears more likely than Boserupian intensification (Boserup 1965).
5) Therefore, smallholders need external assistance (e.g. policy intervention) to achieve ecological and economic sustainability.
6) Applying the three indicators land, labour, and energy efficiency to evaluate the sustainability of cropping systems forms a basis to design successful measures towards sustainable intensification

7) For evaluating the *adoption likelihood of intensified sustainable cropping practices*, one needs to be aware that subsistence smallholders judge each practice both under the aspects of land and labour productivity and the trade-offs between them. Each location demands a locally adapted solution and there is no panacea for the entire basin.
8) The CA approach that is being tested in the Mashare study site may be the best available approach to break the vicious cycle of soil degradation and household impoverishment that affects some of the local farm households. However, it is unlikely that those subsistence farmers whose livelihoods are not yet directly endangered will voluntarily adopt labour-intensive CA.

At first glance, the future of smallholder societies in the research area appears to be a grim one; it is characterized either by resource degradation and household impoverishment or by the adoption of highly labour-intensive farming systems that require a “modern” mind-set of daily and regular working hours. However, this study remains optimistic about the role that smallholder farming may play for the improvement of rural livelihoods in the Okavango catchment. Smallholder farming systems have always shown great potential for innovation; in fact, sustainable intensification may provide the best available means for the stabilization of rural livelihoods. This stabilization may, in turn, be the precondition for allowing households to invest resources into education or alternative livelihood sources. For those farmers aspiring to join in the basin’s transition to a cash-based economy, sustainable intensification may serve as a stepping stone out of natural, resource-dependent agricultural livelihoods.

The following, second part of this dissertation applies bio-economic modelling to assess the role that CA may play in sustainable intensification of smallholder farming in the study sites Mashare and Seronga. Only in these two systems did smallholder farming reach levels of permanency and soil degradation that might induce Boserupian intensification. The model is based on the findings presented here, in the first part of the dissertation. It will assess the role of rising land scarcity and seasonal labour peaks for the adoption of CA and optimal farming strategies. Moreover, it will simulate the dynamic relationship between yield levels and soil fertility over time and thereby try to capture the long-term benefits of CA.

PART II: BIO-ECONOMIC MODELING

2.1 Introduction: goals and general modelling approach

This study seeks to identify optimal farming strategies for typical smallholder households in the lower Okavango River Basin (LORB). Especially, it aims to assess the role which *conservation agriculture* (CA) may play as a means for sustainable intensification.

To achieve these goals, a bio-economic household model (BEM) will be developed which is based on the analysis of part I of this dissertation. This model simulates the main constraints to agricultural production which were identified in the farming system analysis. These are *land scarcity* (which is the main consequence of *population growth* and *rise of competing land uses* on smallholder agriculture) and *seasonality of labour demand*. The model will optimize the use and management of important household resources; apart from *family labour*, this concerns *soil fertility,* which is treated here as a household's main resource which can be affected by households decisions (farm-management) and which affects agricultural output (yield/ha). The model simultaneously simulates farm-households' production and consumption decisions and allows for analyzing optimal solutions under five different scenarios. These scenarios reflect changes in the main constraints to agricultural production, such as land scarcity, the time available for traditional field preparation (seasonality) and the price of field inputs for CA. This will complement the more qualitative assessment of part I of this study with quantitative results. Specifically, it will assess which frame conditions are likely to induce smallholders' adoption of CA (which is seen as a method towards Sustainable Intensification).

Introduction to bio-economic modelling

Over the last decades, bio-economic modelling has often been used as a tool for the identification of sustainable and optimal resource allocation (see Holden et al. 2005, Ruben & van Ruijven 2000, Domptail 2011). Its advantages lie in the fact that it allows for the long-term simulation of ecological-economic systems and the dynamics occurring within them (Krusemann 2000). Bio-economic models therefore help in identifying optimal resource use rates and illustrate, which benefits land users might gain by conserving a resource today (Domptail 2011). Also, they are well suited for assessing technology adoption (Singh et al. 1986, Kuyvenhoven et al. 1998). They thus help in assessing the role of CA for smallholders in the research area. Proponents of bio-economic modelling also value the method for being able to go beyond the possibilities of pure qualitative or pure quantitative analysis tools (Domptail 2011) and for being applicable even under limited data availability (Sterman 1991). Bio-economic models have been defined as:

"*a quantitative methodology that adequately accounts for biophysical and socioeconomic processes and combines knowledge in such a way that results are relevant to both social and biophysical sciences* (Krusemann 2000, 16)"

More specifically, they usually take the form of:
"*numerical computer models simulating both economic or decision-making processes and biological or ecological processes, between which there is a least on path of dependency (and possibly a reciprocal impact)* (Domptail 2011, 13)".

These definitions imply that there are many ways to differentiate between BEMs. Nevertheless, they share some common characteristics and generally need to accomplish three main requirements (Börner 2006):

1. First, BEMs need to integrate biophysical and socioeconomic data and processes.
2. Second, BEMs need to account for the intertemporal aspects of decision-making related to resource allocation.
3. Third, BEMs need to represent a predictive tool that allows for the evaluation of the success of technology proliferation measures or policy interventions.

The first of these issue, the integration of two scientific disciplines and the simulation of a highly-complex system of possibly non-linear relationships, requires a reduction in model complexity (Buß 2006). This reduction goes beyond typical models, which are already characterized by a certain simplification of reality. It holds especially true for dynamic bio-economic models, where the number of variables to be computed multiplies with time horizon (Janssen et al. 2004). As uncertainty about assumption may undermine model relevance, only properly understood dynamics and the main driving forces should enter the model (Buß 2006). Another implication is that (because economic and ecological processes occur over different time scales) the analysis and optimization of natural resource management requires an appropriate time frame (Domptail 2011). Together, these issues require reflection on the relationship between the research question and the chosen modelling approach - according to Brown (2000), this includes the choice whether a model should be: farm-based vs. community-based, static vs. dynamic, stochastic or not; it also includes the degree to which both socioeconomic and ecological processes are simulated or whether uncertainty is considered. The second issue, i.e. intertemporal aspects of decision-making, can be included by formulating a dynamic model and by explicitly modelling the relationships between different model components over time. While in many linear models the ecological processes are included as fixed constraints only, in a BEM they need to be represented by a system of equations which are linked across discrete time-periods (Buß 2006). This may mean that management decisions in one period affect the state of the ecosystem or natural resource stock in the following period. Inter-temporality also implies that it is necessary to simulate the impact of land users' time preferences on decision-making (Domptail 2011): for instance, it is possible that land users (because they are forced to secure their short-term survival or income) are not able to value future benefits arising from conservation efforts. The third requirement, i.e. that BEMs need to provide a predictive tool, results to a large degree from finding appropriate answers to the issues mentioned above. However, the third requirement leads to the question of for whom and what will the BEM developed here be a predictive tool?

Main decision-making unit

This study considers the *unitary farm-household* as the relevant decision-making unit for the research question (because technology adoption and farm-management lie at the heart of this study, and both are seen as individual decisions). However, when simulating the farm-household level, a modeler may either construct typical, but not real farms (Holden et al. 2005), or create a skeleton model that can later be adapted to simulate the existing farms in a research area (Domptail 2011). While the latter case may be characterized by higher relevance for a specific research context, it also requires more data (ibid.). On the other hand, the typical-farm-household model may suffer under aggregation bias, which can be reduced by formulating the model for various typical farm-types (Börner 2006). Other approaches tried to extend these typical farm-household models to take into account interaction between households (e.g. Berger 2000, Hecht 2011). Yet despite increasing computer capacities, model size and complexity continue to be limiting factors in model formulation. Therefore, the modeler has to once again make a trade-off decision between his research goal vs. model complexity, spatial aggregation & household interactions (Börner 2006).

The implications for this study are as follows: Considering the limited data base and the research goals (on-farm optimization and assessment of technology adoption), this study will create a model of *typical farm-household categories* and the dynamics occurring *within* these typical households (between the ecological system *soil* and the socioeconomic *systems farm-household*), but NOT the interactions *between* different farm-household categories.

This leads to the question on how best to distinguish these typical categories. According to Krusemann (2006), farm-household decisions for resource allocation and farm-production are affected by its resource endowment, its objectives and external factors (both biophysical and socioeconomic). Therefore, it appears logical to use these factors for categorization. Typically, the stratification of a cross-sectional data-set is based on pre-determined criteria, which according to theory are expected to make a difference in regards to the research goal – such as household demographic features, degree of intensification or total value of production (Börner 2006). This is often combined with multivariate methods such as principal component analysis and cluster analysis, which aim at reducing the subjectivity involved in all categorization attempts (ibid.). However, in some cases a justified assumption on the main differentiated variable may be sufficient. For instance, Krusemann (2000) assessed technology adoption and issues of sustainable land use by differentiating household categories in regard to their initial asset endowment and discount rate. Holden et al. (2005) created three relatively homogenous household groups for their BEM in the Ethiopian smallholder context, which were based on ox-ownership as the most vital privately owned asset and because its ownership was more skewed.

As part I of this study has shown, ox-ownership plays an equally important role in the Lower Okavango River Basin. Therefore, this study created two household categories, one of relatively wealthier ox-owning farm-households and one of relatively poorer, non-ox-owning farm-households. This categorization was achieved via applying two-step hierarchical cluster analysis in SPSS (see chapter 1.5.3). It allows to compare a group of households that has limited access to productive assets (oxen) and capital with a group of households that has secure access to own oxen (and other cattle) and a higher mean income from non-agricultural livelihoods.

The following second part of this dissertation will begin with a review of farm-household modelling (chapter 2.2) and then present both a schematic and mathematical overview of the bio-economic model developed for the LORB (chapter 2.3). Chapter 2.4 will introduce the starting levels of important modelling variables as well as parameter levels. Chapter 2.5 presents the modelling results as well as a sensitivity analysis. Chapter 2.6 synthesizes the findings of both part I and II of this dissertation and concludes with a discussion of these results.

2.2 Review of farm-household models

2.2.1 Farm-household models, non-separability and basic model assumptions

In the context of peasant economies in developing countries, imperfect market environments are a common phenomenon (Sadoulet & de Janvry 1995, Taylor & Adelman 2003). Generally, farm-households operating in this environment may face imperfect markets for some (though rarely all) of their products or factors of production (Sadoulet & de Janvry 1995, Taylor & Adelman 2003). Common market failures include non-existent land or credit markets, as well as imperfect labour markets (Krusemann 2006, Holden et al. 2005). Under a market failure, the good or the factor that corresponds to that market becomes a non-tradable, the price of which is determined internally within the household, by a so-called shadow price, which serves as the decision price for the household (Sadoulet & de Janvry 1995). Thus the economic decision-making of a household under a market failure is based on shadow prices and not on market prices. When the household's decision making occurs under a market failure, there is no longer separability between production and consumptions decisions. Both decisions depend upon each other and must be made simultaneously (Sadoulet & de Janvry 1995). This interdependency between consumption and production decisions is called non-separability.

Farming systems and farm-households in lower Okavango River Basin (LORB) are affected by various market imperfections, ranging from lacking finance and insurance markets to high transaction costs, which restrain farm households from market participation. This results in the dominance of subsistence-oriented livelihood strategies, where non-separability can be assumed and where decision-making is more likely to be affected by the levels of shadow prices rather than by levels of market prices. Therefore, a *non-separable* farm-household model was chosen as the basis for bio-economic modelling in this thesis.

The following paragraphs present a review of (mainly non-separable) farm-household models developed over the last century. This review will afterwards be summarized to present the main assumptions underlying the farm-household model developed within this study:

One of the first attempts of creating a model of non-separable farm-households was made by A.W. Chayanov at the beginning of the 20th century (today only available in English as: Chayanov 1966). He followed basic utility-maximization theory but incorporated two opposing objectives within a farm-households utility function, i.e. income and leisure (Ellis 1988, 106). These goals conflicted as for the generation of income, agricultural work was required which reduced the amount of time available for consuming leisure. To be able to combine both utility maximization from consumer theory and production theory, Chayanov incorporated a production function as a constraint to utility maximization in his model, which depended on varying levels of labour input and market prices of outputs (Hecht 2010). Furthermore, while access to land was assumed to be flexible, labour markets were considered absent, thus leading to a constraint in the time available for production depending on the number of household producers. Chayanov also included a safety-first criterion as an additional constraint, i.e. a minimum level of production which the household had to achieve depending on its size. The incorporation of this variable constraint leads to the phenomenon that in Chayanov's model, after basic consumption needs have been met, the marginal utility

of additional farm income is relatively low compared to the marginal utility of an additional unit of leisure (Ellis 1988). A last core assumption of Chayanov's model was that agricultural produce is valued at market prices and either consumed domestically, i.e. within the households, or sold. Chayanov's model was a powerful tool for analyzing the effect of changes in a farm-households size and composition on a household's optimal behaviour, also in the African context (Ellis 1988). However, it was weak in predicting a household's response to changes which affect its production function, e.g. in terms of exogenous variables such as market prices (ibid.). For the sake of this study, the assumption of flexible access to land is unrealistic for the Lower Okavango River Basin. Thus, Chayanov's basic model may predict the agricultural extensification of farm-households (by relocating farm-household members from tasks such as daily maintenance to farming and by at the same time acquiring new land), but its limited potential to predict changes in cultivation pattern can be seen as an important drawback (see Hecht 2010 for a more detailed review of Chayanov's model).
The next important contribution to farm-household economics was the field of New Home Economics (Becker 1965[40]). Becker (1965) argued that goods themselves are not direct sources of utility. Instead, they are associated with characteristics relevant to a consumer (Ellis 1988). These characteristics cannot be purchased but need to be produced within the household. E.g. via combining the purchased food items with household labour and the energy of an oven to produce a meal, it delivers the desired utility. These products are called Z-Goods. Becker's (1965) approach was advanced by Barnum & Squire (1979), who developed the full version of the neoclassical farm household model (Sadoulet & de Janvry 1995). This model was then elaborated in a book edited by Singh, Squire, and Strass (1986) (ibid.). In Barnum & Squire's (1979) basic model, farm-households derive utility from the consumption of four different elements: i) Z-Goods, ii) leisure, iii) own agricultural produce, and iv) market-purchased goods (Barnum & Squire 1979). The strength of New Home Economics is that, by postulating Z-Goods, it allows to apply neoclassical economic theory also on the non-market sector (Low 1986). Also, it is suited to make predictions about household behavior under changing household variables (size or composition) as well as changing market variables (prices, wage rates, technologies) (Ellis 1988). Its weaknesses are neglect of risk and uncertainty (Chen & Dunn 1996) as well as its lower suitability for the analysis of food-deficit households (Low 1986).
In order to make up for the latter (and to be able to analyze rural farm households in Africa) Low (1986) developed an extension of the neoclassical model by combining insights from both New Home Economics and Chayanov (Hecht 2010). He assumed that produced crops can either be considered as consumable Z-Goods or be sold on the market, while farm-households also have the possibility to purchase subsistence goods directly from the market. Another important assumption is that (for food-deficit households) the amount of labour allocated to subsistence production does not depend on farm-gate prices of output but rather on the ratio of wages to the retail price of purchased food (Ellis 1988).

In sum, the early model of Chayanov considered only income and leisure, while Barnum and Squire (1979) extended it to include Z-Goods, leisure and the consumption of both own produced food or market-purchased goods. Low (1986) adapted the latter model to the

[40] The important contribution made by Becker (1965) to the analysis of labour within models of farm-households will be presented in more detail in Chapter 2.2.3.

situation of African smallholders (Hecht 2010). In terms of cash income, Chayanov considers only the sale of household production as a potential income source, while Low and New Home Economics also allow for the possibility of engaging in off-farm labour to generate cash (ibid.). All of these models have certain limitations, depending on their basic assumptions. What is shared by all is that utility is aggregated over all household members and the entire agricultural production cycle, thus not taking into account effects such as seasonally limited employment opportunities or different perceptions of utility by different household members (Chen & Dunn 1996). Based on the review of farm household theory, following assumptions will be applied to the farm-household model developed within this study:

1. The utility-function consists of the i) consumption of own agricultural output, ii) the consumption of market-purchased subsistence food and iii) the consumption of leisure.
2. A household has flexible access to land up to a certain point, at which no further land can be obtained due to a general scarcity of arable land.
3. A market for casual off-farm labour exists; labour can be hired in and hired out.
4. Farm output is either consumed domestically or sold on the local market.
5. Farm-gate prices of food for consumption differ from retail prices.
6. The safety-first criterion is implemented by introducing a minimum food production constraint.
7. The effects of seasonally limited employment opportunities are reflected by dividing each modelled sub-period (year) into two seasons, the dry and the rainy season, for which then different wage rates will be defined as well as a maximum time limit than can be invested in off-farm labour.
8. Due to lack of biophysical data on forest- and rangeland dynamics, livestock keeping and natural resource use are not modelled. Instead, they are included as fixed activities (yielding a fixed annual cash or food income but requiring a fixed annual labour input – see chapter 2.4.2). The model will therefore not simulate the entire household economy, but focus on agricultural production, leisure and casual labour. This simplification is a reason for excluding the Z-Good concept from the utility function.
9. Due to the gradual blurring of division of labour by gender in the research area and the modelling of casual labour (which, contrary to formal employment, is rarely gender specific in the research area), wage rates do not differ between household members. Instead, household labour is modelled with respect to available producer labour, which is considered to be equal between the genders in terms of productivity and wage.
10. As the focus of this study is on assessing a farm household's potential to improve its farming strategy and adopt CA as a new, labour-intensive technology, utility is aggregated over the entire household and intra-household differences are neglected.

The innovation of this approach lies in the specific combination of assumptions (e.g. on seasonality and access to land), which follows Börner's (2006) call for simplification, yet at the same time is expected to allow for assessing optimal farming strategies and technology adoption for non-separable, often food-deficit farm-households in the LORB.

2.2.2. The valuation of working time and leisure

The following chapter provides an overview of the treatment of time in (neo-classical) household theory. This is a very important topic for this dissertation, because (as will be shown in chapter 2.3.1), household labour is assumed to be the basic resource that is needed to activate most other household resources, such as cash income or even land. Furthermore, the consumption of leisure is included as an argument of the farm-households' utility-function. Thus, farm-households in the model have to make a trade-off decision between time invested in productive activities (labour) vs. time invested in the consumption of leisure. Reflecting on the value of working time vs. the value of leisure is crucial for a correct representation of this trade-off decision within the model.

2.2.2.1 The valuation of time in farm-household modelling

Work-time has always been at the focus of economists and in neo-classical theory it was commonly valued by using the gross wage rate of the specific work categories (Gonzalez 1997). As will be shown below, this may not be appropriate for the case of non-separable farm-household models. It was Becker (1965) who developed a household model that emphasized the importance of time used for consumption of goods and services (Gronau 1977). Becker (1965) did not regard goods, services and time as agents which carry utility of their own, but as inputs in a process that generated commodities which yielded utility (Gronau 1977) – the so-called Z-Goods. An example for this is consumption of a meal, which is valued by combining both food expenditures and the time spent for preparing a meal. A basic idea of Becker (1965) was that there was an opportunity cost in engaging in leisure, and this opportunity cost is the foregone earning the individual would have made while being engaged in a work-activity (Shaw 1992). Labour and recreation demand analyses used different approaches to measure opportunity costs of leisure time in order to derive its subjective time value, e.g., an individual's wage rate, or a fraction of the wage rate or the value of zero (ibid.). The reason for this is that "static optimization implies that the marginal rate of substitution between labour and leisure is equal to the wage rate" (Shaw 1992, 107).

An important criticism of this view is that a high marginal utility of income results in a low value of time on other activities and that, if you earn no wage, you have a zero value of time (Shaw 1992). Instead, the opportunity cost of an individual's time should be regarded as separate from his or her wage rate (ibid). Earlier, Gronau (1976) also argued that instead of the average wage rate it is the marginal wage rate that determines the value of time. The reason behind this is that the opportunity cost of time equally depends on wage rate, available alternative activities and the activity an individual is currently engaged in. Also, as the decision to switch from one activity to the other is made at the margin, the timing of the time allocation decision is of high importance, too (Concas & Kolpakov 2009). Hence time values do not only differ between individuals, but also for the same individual between different points in time.

Over the years, these criticisms led to several extensions of Becker's (1965) framework allowing for a more realistic simulation of time allocation within a household. De Serpa (1971) addressed Becker's (1965) basic assumption that time and goods are converted into commodities. Due to this assumption, Becker's (1965) model was only applicable to those cases where an individual could freely assign working hours to different activities and where working hours were not an argument of the utility-function (Gonzalez 1997). De Serpa (1971) overcame the latter limitation and proposed a model where time spent in activities enters the utility-function and acts as a direct source of utility. He furthermore postulated that the consumption of goods requires the allocation of a minimum amount of time. The implication of this view is that the allocation of time to the consumption of any commodity is partly a matter of necessity and partly a matter of choice (De Serpa 1971). This allowed the value of time to differ from the uniform wage rate in Becker's (1965) model and led to the distinction between the value of time as a resource, the value of time as a commodity and the value of saving time (Jara-Diaz et al. 2008). These three manifestations and values of time can be characterized as follows:

1) Time as a resource has a ***scarcity value*** equal to the value one attaches to gaining additional units of it (Cesario 1976), i.e. its opportunity cost (De Serpa 1971).
2) Time has a ***commodity value,*** if it is included in the utility function (Shaw 1992). It is the value of assigning time to an activity and it is valued as the ratio between the shadow price of time and shadow price of cash income (De Serpa 1971). In other words, it is valued at the margin, where the pleasure from freely assigning time to leisure equals the reward from work plus the (dis-)pleasure of working (Jara-Diaz et al. 2008).
3) The ***value of saving time*** in a constrained activity, which is the willingness-to-pay to reduce the (constrained) time assigned to an activity (Jara-Diaz et al. 2008).

De Serpa (1971) showed that the value of saving time in an activity is only positive, when there is a binding constraint on consumption time, i.e. an individual would like to allocate less time than is required (Gonzalez 1997). On the other hand, the value of saving time in an activity can be regarded as zero for all activities that are voluntarily assigned more time than required – i.e. leisure activities *in sensu* De Serpa (1971). These leisure activities can be characterized as having the same value assigned at the margin, because otherwise time would be relocated from the less to the more valuable activities (Jara-Díaz et al. 2008). As this value represents the value of time as a resource, i.e. its scarcity value, it is also known as the value of leisure (ibid.). This means the opportunity costs of e.g. one household's working hour can be used to value one hour of leisure. Under non-separability, the shadow price of family time should be used as an approximation of a household's opportunity costs – they thus become an endogenous variable (Skoufias 1994).

2.2.2.2 The distinction between working time, leisure & home production

Traditionally, economists defined leisure as the residual of work (De Serpa 1971). However, this can be criticized as an incomplete view, as this residual non-work time is also spent on tasks such as maintenance of the body (which cannot be regarded as leisure - Tipping 1968). Therefore, Tipping (1968) regarded leisure as a consumption activity that combines time and goods or services, e.g. in the case of "doing nothing" goods such as the seat of one's trousers or the soles of ones shoes. He therefore called for a category of *intermediate consumption* (Tipping 1968), to differentiate between leisure activities and those activities that allow one to enjoy leisure, such as going to a theatre. De Serpa (1971) included this distinction in his general model and defined leisure as:

"*… free time which may be used for rest, recreation, etc. This definition suggests a freedom from responsibility, a specific case of which is freedom from work (hence, the traditional economic definition of leisure as non-work)* (De Serpa 1971, 834)".

Leisure activities were those consumption activities which did not include any mandatory input of time. However, which activity was to be regarded as leisure or intermediate consumption would differ strongly between individuals and different occasions. This study tries to overcome this challenge by relying on Boserup's (1965) theory (which combines economic with anthropological insights); for instance, she indicates that agrarian societies usually "*consider both hunting, fishing and food collection as pleasurable activities, while food production is resorted to only to the extent that other and more agreeable activities fail to provide sufficient food* (Boserup 1965, 45)". As will be shown later, this study models only casual labour (on a neighbouring farmer's field) and crop production as productive activities – and following Boserup, both can be assumed to not provide any leisure. However, if natural resource use was modelled, this activity might have to be considered as leisure-providing activity as well.

A contribution equally important to DeSerpa (1971) came from Gronau (1977). According to him, household time should be assigned to the three main categories i) work, ii) home production and iii) leisure. He rejected the fact that home-production, i.e. non-leisure time that household members spend working within the household or for intermediate consumption, disappeared in Becker's (1965) general household model (Gørtz 2006). Gronau (1977) enhanced De Serpas (1971) definition of leisure and differentiated it clearly from home production:

"An intuitive distinction between work at home (i.e., home production time) and leisure (i.e., home consumption time) is that work at home (like work in the market) is something one would rather have somebody else do for one (if the cost were low enough), while it would be almost impossible to enjoy leisure through a surrogate. Thus, one regards work at home as a time use that generates services which have a close substitute in the market, while leisure has only poor market substitutes (Gronau 1977, 1104)".

The main critique of this approach was the assumption of perfect substitutability of market goods and home produced goods (Gørtz 2006). To come to a more realistic model of household decision making, later extensions of the classical household production model, such as in Graham & Greene (1984) or Kooreman & Kerkhofs (2003), included the idea that home production can be considered as an activity that also provides leisure – a concept known as *joint production* (Graham & Greene 1984); Examples for this include garden-work, taking care of children or (as indicated by Boserup 1965) fishing and food collection. The implication of including joint production in a household model is that the commodity shadow prices of a household are determined not only by the household resources and technology, but also by its members' preferences (Pollak 2002).
This study avoids the issue of joint production and home production by including these activities as *fixed* (i.e. non variable in input and output) in the model.

2.2.2.3 Implications for the treatment of time within this study

The correct way of determining the value of time depends on the way the time allocation problem is modelled (Concas & Kolpakov 2009). Theoretical assumptions about the relevant variables, about which are fixed and which are not, as well as about the nature of the binding constraints, all affect the result (Gonzalez 1997). Shaw (1992, 111) showed that what is put in the utility function is of central importance and there is "*no a priori reason to model the time allocation problem in any particular manner*". Therefore, the best approach for an empirical researcher may be to consider the different models and their assumptions on leisure one by one and then chose those which best reflect the specific activities that are to be valued (Shaw 1992). The following paragraphs will state the assumptions that this study makes on the role of leisure and working-time within its farm-household model:

For the valuation of family time, i.e. for both leisure and working time, this study will use the shadow price of family time as an approximation of its opportunity costs (Skoufias 1994). This shadow price will be derived via a first model run, which is based on the market wage rate. For subsequent model analysis, the newly derived shadow price will replace the wage rate as a means for valuing time spent on leisure.

Working time included in the model refers mainly to agricultural work, both on the farm-household's own fields and as casual labour (which usually takes the form of farm-labour on a neighbour's field). As has been shown by Boserup (1965, see part I of this study), this kind of work is usually regarded as drudgery by most smallholders and carried out only to the minimal amount necessary for securing a households minimum food needs. It does not provide any leisure in the sense of *joint production*.

This study treats the concept of *leisure* slightly different than the definitions above. On the one hand, leisure in this study includes time spent by household members for the purpose of relaxation, thus following the definition of leisure presented above. On the other hand, leisure in this study also includes the time invested in fulfilling social obligations, such as meeting friends, relatives or other members of the society as well as attending funerals, weddings or religious services. In the latter case, it can also be seen as a means to an end – e.g. for maintaining social status within the community. Thus, leisure in this model has the characteristic of being not only a utility providing activity, but also of having a productive attribute. Within the model developed here it is therefore treated as an activity characterized by *joint production* (albeit different to Graham & Greene 1984, who normally considered productive activities as providing utility as a side-effect). The reasons for treating leisure in this form are related to practical considerations of empirical data gathering. For the purpose of this study, it is not important to differentiate between the time used for relaxing or the time meeting social obligations. What is important, is that time invested in these activities is unavailable for agricultural production. This study will assess the issue of joint production for the activity *leisure* via its method for the empirical assessment of smallholders' preferences (Chapter 2.3.1.2). Lastly, this study will only simulate time allocation during the day, i.e. when productive activities compete for time with leisure. This time period is assumed to last 10 hours. This focus allows for a more realistic simulation of trade-off decisions between productive activities and leisure. Time used for sleeping, eating or body hygiene was therefore excluded from the analysis. The mathematical formulation of both utility function and time-constraint is presented in chapter 2.4.4.2.

2.3 A bio-economic farm-household model for the Lower Okavango River Basin (LORB)

This study aims to assess optimal farming strategies in the LORB and to analyze the potential role of conservation agriculture (CA) for overcoming the main agricultural constraints identified by the farming system analysis in chapter 1.6 (*land scarcity* and *seasonality of labour demand*).

Chapter 1.6 also showed that in the LORB (i.e. study sites *Mashare* and *Seronga*), farm-households are affected by low and erratic yields and soil degradation. Combined with population growth, climate change and the rise of competing land uses (all of which contribute to land scarcity), these characteristics may make it necessary to achieve a sustainable intensification of smallholder agriculture in the near future. Thus, the ultimate goal of this study is to identify possible pathways towards the sustainable intensification of smallholder production in the LORB.

It is assumed here that CA can make an important contribution to this goal, because its proponents expect it to overcome the main agricultural constraints mentioned above and to rehabilitate soil fertility. It is a system which is characterized by very high input needs for manure, inorganic fertilizers and labour, but it also results in dramatically increased per-hectare-yields (see chapter 1.6.4). Investments into CA may thus provide the best available means for sustainable intensification.

In order to reach this goal, this study developed a recursive multi-annual optimization model for two non-separable, typical farm-household categories (wealthier ox-owners and poorer non-ox-owners) in the two study sites *Mashare*, Namibia and *Seronga*, Botswana. Households are assumed to be unitary, i.e. to make joint decisions of resource allocation and maximize a joint utility-function. Neither intra- nor inter-household interactions have been simulated. The model's focus lies on the socioeconomic discipline (the *farm-household*), while the biophysical aspect (the level of *soil fertility* of the household's fields) is included as a dynamic constraint to production. This means that the level of soil fertility is dynamically modelled over discrete time periods and assumed to be affected by management decisions on production technology, farm inputs and amount of harvest. The model is dynamic and optimizes over a multi-annual time period of 15 years. This allows for considering the long-time period necessary for capturing ecological changes, e.g. in regards to soil fertility, but is short enough to assume that the life cycle of household members does not lead to changes in important household characteristics. Additional to this multi-annual approach, each year was separated into two sub-periods, the dry and the rainy season. The main goal was to capture the seasonal labour demands of the different management options for identifying optimal farming strategies. The analysis of the current situation (baseline scenario) will be complemented by four additional scenarios, which simulate changing levels of main agricultural constraints.

The following schematic model description explains the model qualitatively, and focusses on its systemic nature, important underlying assumptions as well as the inter-linkages between the different model components. Only afterwards, in chapter 2.3.2, will the mathematical model structure be presented. The different model scenarios that were mentioned above will be introduced even later, i.e. jointly with the scenario specific results (chapter 2.5).

2.3.1 Schematic model overview

Normative dynamic optimization

This study follows a *normative modelling approach* which identifies “the best possible behaviour” of smallholders in the research area (and not a positivistic approach, which would be appropriate if the goal was to generate a deeper system-understanding). Obviously, normative approaches need to be based on a variety of assumptions for being able to claim to have found a “best”, or optimal, solution. These assumptions will be presented below.

Furthermore, the study applies a *dynamic optimization approach*, which optimizes decision-making over both the entire planning horizon and for each sub-period. It thus follows the rather strong assumption that a decision-maker is fully aware of the long-term consequences of his decisions (Keusch 2001). The benefit of this approach is that the model yields normative information on how a decision-maker would have to act to adapt in an optimal way to changing frame conditions (ibid.) – such as changing levels of soil fertility.

Household activities and interactions

This model developed here focusses on simulating the productive activity “arable agriculture”, i.e. the relationship between farm-management, yields and soil fertility. This allows for capturing the complex interdependencies between management and soil fertility, but also for comparing the traditional farming systems with conservation agriculture (CA). Additional important activities are *participation in casual (off-farm) labour*, which is included as a potential cash income source; and *time spent as leisure*, which is regarded as a utility-increasing activity (see Fig. 2.1).

In order to simplify the model to answer the core research question[41], household activities such as livestock keeping and rangeland management, natural resource use or formal wage labour were not included in the model. Instead, mean annual labour needs and mean cash or food income from these activities (based on focus group results) were calculated for the typical household categories and either deducted or added to modelled households’ resource bases. Furthermore, this approach makes it unnecessary to include household interaction at the village level into the model.

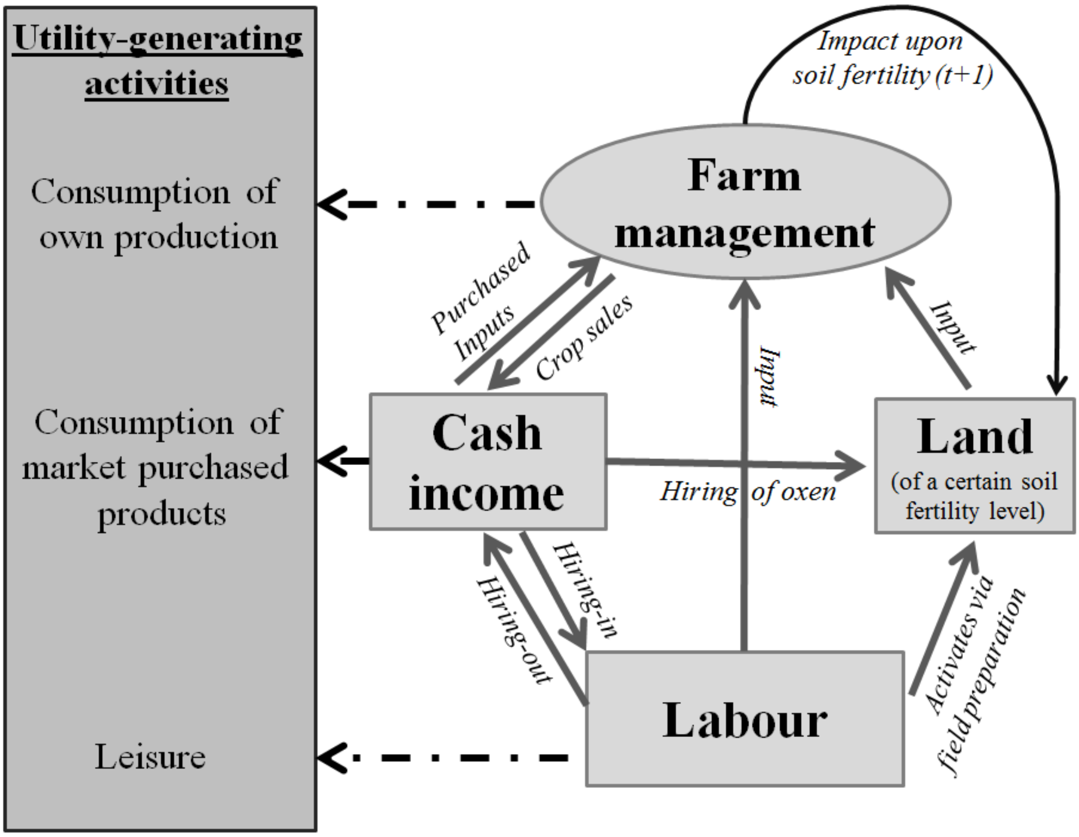
The model simulates five main production methods, which differ in terms of input, output and effect on soil fertility. These are traditional agriculture without input application (*TR None*), traditional agriculture with the application of 5t of cattle manure (*TR Manure*), traditional agriculture with the application of 20kg of NPK fertilizer (*TR Fertilizer*), traditional agriculture with the application of both 5t manure and 20kg NPK fertilizer (*TR Both*) as well as conservation agriculture (15t manure and 0.5 t inorganic fertilizer; chapter 1.6.5 presented a comparison of these practices). Special attention is given to amount and timing of inputs required by each of these practices, especially in regards to labour; the respective yield level of each method can be influenced by the smallholder via the level of the decision variable *soil fertility* (see below).

[41] This choice is also based on the fact that there are no empirical bio-physical data on the relationship between management and state of surrounding forest ecosystems or rangeland quality. These are available only for soil fertility and farm management.

Additional to agricultural production and the option to engage in leisure or casual labour, households can apply soil-fertility improving management options; i.e. fallow periods or clearing of new land. These management options require either labour inputs or a reduction in cultivated land, but increase soil fertility levels (and thus yields) in subsequent simulation periods.

The dynamic feedbacks between farm management (choice of farming practices and management options) and soil fertility will be simulated via a soil fertility function, representing the model's biophysical component. This function calculates the level of soil fertility based on the *chosen farming practices*, *management options (fallow, clearing)* and *achieved yield levels* of the previous simulation period. This introduces a dynamic element into the model. The relationship between *soil fertility*, *farming practice* and *yield* will be simulated via econometrically estimated production functions (for each farming practice). In general, increasing levels of soil fertility result in increasing yield levels.

Fig. 2.1: Functional relationships between household resources (squares), farm management and the arguments of the utility function.



Source: Author's design based. Note: Farm management decisions in simulation period (or year) *t* influence the level of soil fertility of the resource land in simulation period t+1 (i.e. the following year).

All mentioned activities compete for household-labour. Actually (apart from soil fertility), family-labour is a household's basic resource which needs to be used before other resources can be accessed (see Fig. 2.1): For instance, family-labour first needs to be invested into casual labour to generate cash-income (which cannot be saved and needs to be invested in the same period) before food or field inputs can be purchased. Alternatively, cash-income can be derived from selling production surplus, which is again generated by investing labour into farming[42].

Cash-income earned in the first (i.e. rainy) season of a year can be re-invested in same or in the following dry season, e.g. to hire-in external labour to increase the labour pool. It can also be used to purchase food of field inputs (note: ox-owning households are assumed to have free and unlimited access to animal manure from their own holding while the poor have to purchase all manure at the market, where it is assumed to be available in unlimited amounts). Credit is currently not available to smallholders in the research area and will not be modelled.

Another innovation of the model is the way that the resource *land* is modelled:
First, access to land differs from previous models: the farming system analysis in part I revealed that many non-ox-owning households do not manage to cultivate all of their land; the reason for this is lack of draught animals and a short time window for (traditional) field preparation. Therefore, the resource *land* needs to be *activated* in the model by investing labour into field preparation (which has to occur over a limited time window – for instance 7 days in the baseline scenario). Thus, labour is a basic household resource. The "activation" of land can be carried out manually (and thus with a very high labour demand) or by using draught-animal power (see chapter 1.6.2 and 1.6.3 for a review of agricultural labour needs). For following the latter approach, the poorer non-ox-owning households need to hire oxen for cash. The wealthy can choose freely whether they conduct manual of draught-animal-based field preparation. To reflect the fact that the poorer normally have to wait until the wealthy households finish with ploughing, the time period for field preparation by *rented* oxen is reduced by 50% (i.e. to 3.5 days in the baseline run).

Second, *land* is not seen as a static resource, but as a resource with a qualitative dynamic aspect: i.e., its level of *soil fertility* (which is dynamic, because it can be affected by management decisions). As mentioned before, the level of soil fertility is determined by a soil fertility function. Specifically, the relationship between *land* & *soil fertility* is simulated as follows: Instead of modelling various, individual plots and their respective soil fertility levels, all available land of a household has one common soil fertility level. This soil fertility level represents the holding's total pool of soil macro-nutrients, which can be used as inputs in crop production (chapter 2.3.1.2 presents this in more detail). This avoids the need to model farm management in a spatially explicit way. Instead, management options increase the household's total nutrient pool by a certain, fixed amount of nutrients per area. This implies that the main decision variable (which affects soil fertility) is the amount of land allocated to the various management options and production practices. Input-based practices (e.g. *TR Both*) deduct much less soil nutrients per ha than no-input agriculture (*TR None*) – under low yield levels (each kg harvested deducts nutrients), these practices may even increase the soil nutrient pool (and thus the lands *soil fertility level*), because the inputs manure and inorganic fertilizer contain nutrients themselves.
The model implicitly assumes that households regularly shift the location of their plots to areas that have been in fallow in the previous period(s) to harvest the restored nutrients. It is thus assumed that households follow a spatially optimal farm management approach. This

[42] As will be shown later, the wealthy households earn fixed seasonal cash income from non-modelled activities. For them, family-labour is therefore not so central as for the poorer household category.

approach is possible because this study considers only the macro-nutrients N P and K as determining the soil fertility, which allows assuming is a linear relationship between soil fertility and agricultural yields[43] (chapter 2.4.1.3 gives detailed information on the soil fertility index used in this study).
For the scenario analysis in chapter 2.5, the one-field & one-soil-fertility-pool assumption will be modified to analyze a situation where a household has two-fields and thus two independent soil fertility pools. This complementary analysis allows for a more realistic simulation of CA, which should not be rotated on the same field with traditional agricultural (see chapter 2.5).

2.3.1.2 Household objectives and decision variables

Utility function
The existence of non-separability supports the use of a direct, i.e. a postulated utility function. In this study, this function is based on a typical Cobb-Douglas function as presented e.g. by Rasmussen (2011) (Equation 2.01). The reasons behind this choice are the favorable mathematical and theoretical properties of this function, such as a marginal rate of substitution of 1 or a declining marginal propensity to consume. Moreover, it allows for estimating utility based on the levels of its arguments (here for the case of two inputs).

$$U(X_1, X_2) = A * X_1^{b1} * X_2^{b2} \quad (2.01)$$

with

U (X,Y)	: Utility U derived from the arguments X_1 and X_2
X_1 & X_2	: the two inputs (or arguments) of the function
b1 & b2	: the weights of the arguments
A	: a predetermined parameter (0 in the utility function of this study)

Equation (2.01) gives the non-linear formulation of the Cobb-Douglas function. This form has certain advantages in terms of model accuracy and higher level of detail. However, from a modelling point of view, it can be advisable to follow the assumption of linearity. Considering that the model presented here includes a non-linear production constraint, a linear relationship between the arguments of the utility function is assumed. Following Hecht (2010), the chosen function form will be the first derivate of a Cobb-Douglas utility function, such that:

$$U'(X_1, X_2) = b1 * X_1 + b2 * X_2 \quad (2.02)$$

Arguments of the utility function
Due to non-separability, households' decision-making will be represented by maximizing a utility-function of various arguments and not by maximizing a profit-function (see chapter 2.2.2). The utility function presented here will maximize the discounted utility of two typical farm-household categories in the LORB (Mashare & Seronga). Utility is approximated by the two arguments of the utility function which are introduced below. Their weights have been

[43] Extending this definition of soil fertility, e.g. by including C-content or water retention capacity, might have required to model distinct fields to be able to carry any ecological threshold effects or to consider non-linear relationships. However, data on these aspects was not available.

empirically estimated, and chapter 2.4.3 will describe the method used for this estimation. Utility is maximized over a time horizon of 16 years. This modelling period is deemed sufficiently long to capture long-term biophysical dynamics of soil management, but not so long as to include questions of lifecycles of household members (e.g. the effect of age and changing preferences on decision-making over time).

In general, smallholder farm-households in the Lower Okavango River Basin produce for subsistence purposes and only rarely manage achieve crop surpluses (which can be sold on local or regional markets) (see part I of this study). Therefore, a major objective of farm-households is the secure their basic nutrition needs by producing and consuming a sufficient amount of food. This is reflected in the utility function by the argument "*Acquisition and consumption of staple food*"[44]. Note that this argument consists of two parts, namely:

i) food produced within a household for domestic consumption and

ii) food purchased on a nearby market for consumption.

It is useful to combine these two aspects of food consumption into one argument, because both activities share the same basic attributes: On the one hand, farm-household production requires the input of household resources to produce a certain amount of staple food, which can then be consumed domestically. Usually, smallholders regard time spent in crop production as drudgery (Boserup 1965) and as one of the most arduous livelihood activities. On the other hand, in order to purchase staple food at the market, a household needs to invest cash resources. In the model, cash can come from only two *variable* sources[45], casual labour on a neighbour's field or from selling one's own crop production. Thus, just as staple food produced within the farm-household, market purchased staple food is derived mainly from arduous field work.

Although both food sources are united under the same argument of the utility-function, they are valued at different prices: the consumption of own-produced food is valued at the (relatively higher) farm-gate price of millet and the amount of market-purchased food at the (relatively lower) farm-gate price of maize (similar to Armington (1969), who distinguished demand for goods by kind and place of production). This approach was chosen because if the retail-price of market purchased staple food (usually maize flour) was used (which is higher than the farm-gate price of maize), purchased staple food would be valued higher than home-grown food. Interviews revealed that the opposite is true: farm-households prefer millet, which is perceived as tastier and which can also be used to make a traditional cereal-based drink called *shikondo*. The choice of the two farm-gate prices reflects this preference for home-grown food over market-purchased food (see chapter 2.4.4.2 for the mathematical formulation of the utility function).

Apart from productive activities in the narrow sense, households are assumed to aim at i) securing a certain amount of leisure time that can be spent with the family or be used for relaxation as well as ii) maintaining their social standing by meeting social obligations (e.g. visiting marriages, visiting friends or sick people, etc.). As introduced in chapter 2.2.2.3, this

[44] Note: only the consumption of staple food is considered here. Households may indeed have higher preferences for "modern" food items such as soft drinks or processed food than for traditional food items.

[45] The wealthy household category has a third cash source, a fixed annual cash income. The effect of this fixed income on whether or not food purchases are preferred over own production is not captured by this study.

study integrates both activities under the general term *leisure*. In essence, this definition captures most activities that compete with classical productive activities for time. In the utility function, this will be captured in the argument "*Consumption of leisure and meeting social & cultural obligations*". It is valued by the shadow price of family labour.

Justification for the arguments of the utility function and modelled activities

The reasons for postulating the arguments of the utility function as described above are rooted in the empirical assessment of smallholder preferences (see also chapter 2.4.3). Basically, the empirical assessment aimed to assess preferences for certain *activities* with a clearly specified *outcome*. Initially, preferences for five different household activities were assessed (*crop production, livestock keeping, natural resource use, off-farm labour, leisure*), each of which was attributed with a respective output (*direct utility* from consumption of leisure or *food & cash*, which can be used to achieve utility from the consumption of food). This allowed for including smallholders' perceptions on the role of family-labour in the various activities. Also, it helped to make farmers aware of the trade-offs involved in assigning different weights to these activities – by including the labour needed to carry out an activity, it forced them to think about the trade-offs involved when stating a high preference for one activity.

However, as mentioned before, *formal wage labour*, *natural resource use* and *livestock keeping* are neither included as variable activities nor as arguments in the utility function. Instead, they are included in the model as fixed activities, i.e. with fixed annual labour-input and food/cash output (which differs for both household categories). See the farming system analyses in chapters 1.6.2 and 1.6.3 for a calculation of the labour needs of these activities. These activities are included in the model as follows: each household category receives a fixed annual food and cash income from these activities, while its family labour-pool was reduced by the mean annual amount of labour needed for these activities.

The reason for excluding food obtained from natural resource use and livestock keeping from the utility function is partly related to this dissertation's focus on field-management, but more importantly to the lack of biophysical data on rangeland and forest dynamics (and the impact of management). In a marginal (and partly degrading) environment such as the LORB (the Kalahari), even the assumption of stable returns from these activities may be considered as optimistic. Thus, only those bio-economic relationships clearly understood by the researcher were included in the model.

Due to the minimal chances of smallholders in the LORB to engage in *formal* off-farm labour, this activity is not modelled, either. What is modelled is *casual* off-farm labour. Contrary to other studies (such as Hecht 2010), this dissertation argues that *casual* off-farm labour cannot be included in what smallholders perceive as *participation in off-farm labour*. During and after interviews, it became clear that smallholders related *participation of off-farm labour* rather to prestigious formal wage labour, i.e. formal employment, but not as arduous casual labour on a neighbour's holding. Casual labour can therefore not be seen as a utility-providing activity, but the purchases of staple food from cash income earned via casual labour as a perfect substitute of staple food produced within a farm-household.

General utility function used in this study

Based on the information given above, the general form of the utility-function used in this study can now be given. As presented above, the arguments of this function are *Acquisition and consumption of staple food (ConsStFd)* as well as *Consumption of leisure and meeting social & cultural obligations (ConsLeis)*. Their weights (i.e. the empirically assessed preferences) add up to 1, implying that there are constant returns to scale. Households are assumed to maximize Utility by maximizing the consumption of these arguments, such that:

$$Max\ U\ (CONS\_ST\_FD, CONS\_LEIS) = \alpha 1 * cons\_st\_fd + \alpha 2 * cons\_leis \qquad (2.03)$$

with

U (CONS_ST_FD,CONS_LEIS_OBL)	: the Utility U derived from the consumption of staple food and the consumption of leisure
α1	: the empirically assessed preference of the smallholder households for staple food consumption.
α2	: the empirically assessed preference of the smallholder households for leisure consumption.
cons_st_fd	: the level of consumption of staple food
cons_leis	: the level of consumption of leisure

The following paragraphs will introduce the various farming practices and management options in more detail. This includes the main decision-variables as well as important constraints.

Decision-variables and seasonality

According to Krusemann (2000), household decision-making on resource allocation and production structure is influenced by i) the farm-household's goals and aspirations , ii) its resource endowment as well as iii) biophysical and iv) socioeconomic frame conditions. The model will be based on study site and household category specific model formulations and thus allow for including all four aspects.

Household decisions are reflected within the model by the so-called decision-variables, all of which are accompanied by logical constraints (which either represent maximum or minimum values and/or equations simulating their structural relationships with other variables). The modelled decision-variables relate to:

1) the amount of labour invested in
    a. casual labour to generate cash income,
    b. crop production to produce staple food,
    c. land preparation to "activate" the resource land for crop production and
    d. the amount of family-labour invested into the activity "*Consuming leisure and meeting social & cultural obligations*", thus yielding direct utility.

e. the management of soil fertility, which occurs via the choice of farming practices (i.e. field inputs), yield levels and the management options *fallow* and *land clearing*.

2) the amount of cash income derived from crop sales or casual labour and the use of this cash income: i.e. for hiring workers and increasing the labour pool, for purchasing farm-inputs (such as fertilizer or seed) to increase crop production or for purchasing staple food and thus yielding direct utility.

The highest variety of management options exists for the activity *crop production*. Smallholders in the LORB have only a very limited access to industrial or mechanized technologies and field inputs. Therefore, the decision-variables on this activity cover only the following management options:

- Choice of farming practice, i.e. conservation agriculture (CA) vs. traditional farming (TR). While CA requires a fixed amount of inputs (15t/ha manure & 0.5t/ha fertilizer), traditional farming can be carried out in four different ways, i.e. by applying: 5t/ha of cattle manure (*TR Manure*), 20kg/ha inorganic fertilizer (*TR Fertilizer*), both 5t/ha of manure and 20kg/ha of fertilizer (*TR Both*) or no inputs (*TR None*)[46].
- The amount of land put under cultivation for each farming practice. This decision affects yields of the current period *directly* and (via the long-term effect on the level of soil fertility - see below) yields of the following periods *indirectly*.
- Arable land is indexed via its qualitative attribute *soil fertility* (a decision-variable), which describes the pool of macro-nutrients (NPK) available for crop production (see chapter 2.4.1.3). Soil fertility serves as a quasi-bank account that can be built-up (for increasing future production) or exploited (for increasing current production) via management choices (e.g. Van der Pol 1992). Soil fertility increasing activities include clearing of new land (if available), fallow periods and choice of CA or TR using field inputs - they thus rely on cash & labour inputs or the reduction of cultivated land (and thus possibly yield). Exploitative management options include lack of fallow periods and the choice of traditional farming practices without inputs on a larger area. Harvesting reduces soil fertility (each kg of produced food exports nutrients from the field).

An important constraint that applies to nearly all decision variables is the fact that each simulation period (= year) has been subdivided into two seasons, the dry season and the rainy season. The latter has been further subdivided into total season length and the time available for field preparation (determined by soil humidity and thus the amount of rainfalls). Therefore, the optimal level of the decision-variables differs not only between modelling periods, but also within these periods between the two seasons.

[46] As indicated, an important trade-off exists in resource allocation between the rainy and the dry season. Because field inputs need to be purchased in the dry season to be used at the beginning of the subsequent rainy season, also the cash for these inputs needs to be obtained in the dry season – either via crop sales or via casual labour. Choosing the soil fertility conserving and high-yielding Conservation Agriculture as a production technology requires substantial labour inputs for field preparation in the dry season. These may be so high that casual labour becomes impossible and households have to rely only on sales of crop surpluses from the last year to be able to obtain sufficient field inputs.

Crop production constraint

In the model presented here, crop production is simulated via a production function and complementary constraints (chapter 2.4.1 will explain the assumptions behind this constraint in detail).

The production function is based on an empirical yield assessment conducted in each study site (presented in chapter 1.5.7). It was estimated using OLS and takes the form of a linearized Cobb-Douglas function. It is specified for choice of technology (CA and the four traditional production practices *TR Manure, TR Fertilizer, TR None, TR Both*) and field size. As will be shown below, household resources (such as labour and cash) can be allocated to various activities that affect the availability of inputs in the crop production function. Note that the wealthy household category is supposed to have an unlimited supply of manure from their own farm, while the poor households have to purchase manure from neighbours (again, there is no upper bound on total manure availability)[47].

In each simulation period, a minimum consumption constraint has to be achieved that can only be covered by own crops. Also, a biophysical input called "soil fertility" is included as a continuous variable in the crop production function. A household's soil fertility describes the mean pool of macro-nutrients N, P and K of the household's entire land endowment and is defined as a ratio of available macro-nutrients vs. macro-nutrients theoretically required for producing a maize yield of 500 kg. This value is calculated in a soil fertility function which simulates the impact of farm-management decisions on a farm-household's soil fertility (see chapter 2.4.1.3). Together, crop production function and soil fertility function allow for a simplified simulation of the feedbacks between the ecological system and the socioeconomic system and to answer questions of optimal resource use rates over time. A detailed overview of these feedbacks will be given in chapter 2.4.1.

Biophysical constraint

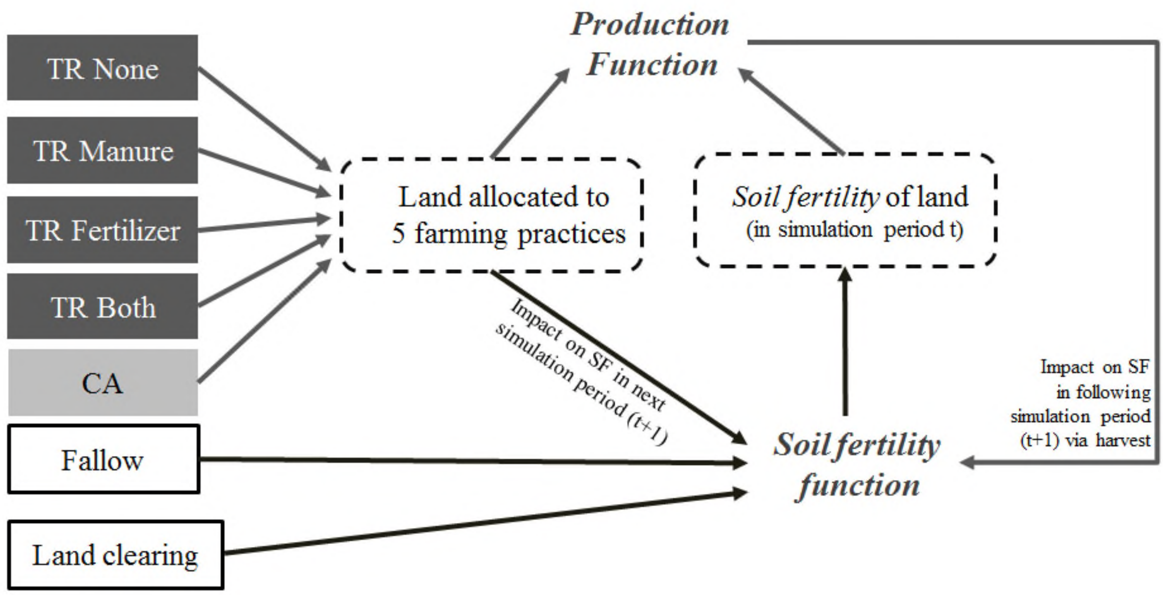
A major biophysical constraint of this model is the level of soil fertility of a household's land, and its interaction with farm-management (Fig. 2.2). Note that the soil fertility of a farm-household represents the mean soil fertility of all of its land. The level of soil fertility is represented as a numerical value related to a Soil Fertility Index, which was developed by soil scientists from the TFO project (see chapter 1.5.1, the involved scientists are the authors of Gröngröft et al. 2013b). This value approximates the total available pool of the macro-nutrients N, P and K in kg/ha in relation to the pool in kg/ha that is theoretically needed to produce a harvest of 500 kg of maize[48] (i.e. the nutrient content of the maize-biomass needed to yield this harvest). It is a ratio which can take values of above 100%, e.g. when sufficient nutrients are available to produce 1000 kg of maize. This study follows *Liebig's Law of the Minimum* (see Esslen 1905, Mitscherlich 1909); i.e. it assumes that the value of soil fertility is determined by the pool of that macro-nutrient which is available in the lowest amount, i.e. which restricts the maximum amount of crops that can be produced (example: as long as the pool of K is too low to produce more than 200 kg of maize, it does not matter whether the

[47] Currently, the total amount of manure in Mashare is so low that CA cannot be adopted to a large-scale. However, this study seeks to assess the potential role of CA in optimal farming systems. Its implementation would likely require complementary measures, such as an improved rangeland and manure management.

[48] Which according to a colleague from *soil sciences* Gröngröft (verbal communication) has similar nutrient requirements to the dominant crop *pearl millet*.

pools of N or P are big enough to produce more than 200 kg). It is assumed that 800% is the upper limit of the Soil Fertility Index, beyond which other factors such as micro-nutrients become limiting. This value would signify the availability of sufficient macro-nutrients to produce 4000 kg of maize, which is half of what is achieved on the irrigated agro-industrial *Green Schemes* (between 2009 and 2012, on average 7-9 t/ha[49]).

Fig. 2.2: Relationship between choice of farming practices, production and soil fertility



Source: Author's design. Note: *TR None* refers to traditional farming without of field inputs; *TR Manure* refers to traditional farming where on average 5t of manure are applied per ha; *TR Fertilizer* to traditional farming with 20 kg fertilizer per ha; *TR Both* to traditional farming with both 5t manure and 20 kg inorganic fertilizer; *CA* to conservation agriculture using 15 t of manure and 0.5t of fertilizer.

Empirical values of soil fertility were gathered for each of those fields on which the yield assessment was carried out. These empirically gathered soil fertility values (N = 54) were used to estimate the production function which will be presented in chapter 2.4.1. This function represents the effect that soil fertility as the biophysical component of the model has on farm output and ultimately farm-household's decision-making.

Due to a lack of data, the impact of the various management options on soil fertility cannot be based on empirical ground. Instead, the impact of management on soil fertility is reflected by theoretical values, which are based on literature review (which was conducted by TFO-colleagues from *soil sciences* – see chapter 1.5). This allowed determining a fixed effect of each farming practice and management option upon the three nutrient pools (presented in chapter 2.4.1.3, Tab. 2.3). They include the before-mentioned *CA, TR Manure, TR Fertilizer, TR Both* and *TR None* as well as the use of fallow and land clearing (see Barbier & Carpentier 2000). Furthermore, the difference is made between the amount of crops harvested under traditional agriculture (where crop residues (and their nutrients) are grazed and thus exported from field) vs. CA (where crop residues remain on a field, protected by fences, and where their nutrients gradually return to the soil). Thus, harvesting under CA has a less pronounced impact on soil fertility than harvesting under traditional agriculture. The effect of the above-

[49] Based on an interview with a Green Scheme manager

mentioned options on soil fertility was assessed on a per hectare basis. Thus, the effect of management on soil fertility can be calculated by multiplying the area under the different management options with their fixed effect on soil fertility (e.g. Tab. 2.3 in chapter 2.4.1.3 will show that a year of fallow increases the soil fertility by 10.8%, multiplied with the land allocated to fallowing in ha). Afterwards, the effect of each of the individual options (positive and negative) can be added up to derive the mean impact of farm-management on mean soil fertility. Thus, only the net effect of soil depleting and soil rehabilitating practices is considered within the model.

Next, a soil fertility function following Krusemann (2000) is used to simulate the effect of management on soil fertility (chapter 2.4.4.2 gives its mathematical formulation). In combination with the production function (where soil fertility is an input) this allows for simulating the dynamic feedbacks between farm management and soil fertility.

In assessing the effect of management on soil fertility, this study's approach is partly based on the results of Schlecht et al. (2004), who showed that in Niger, under biophysical conditions similar to the lower Okavango basin, manure as well as the combined application of both manure and inorganic N & P fertilizer resulted in a significant and linear increase in millet yields relative to input application (between levels of 2 and 21 t for manure application). They also showed that there is an aggregated effect over at least three to four years after input application, over which yields benefit from the initial input application. This is reflected in the model by allowing nutrients to be stored in the nutrient pool of the respective field, allowing for higher crop yields even a few years (or simulation periods) after input application. However, the effect of nutrient leaching is not captured by the model. Instead, the assumption is made that nutrient losses occur only in the form of harvesting and crop residue use (with crop residues being completely extracted due to grazing under traditional farming and being completely preserved as mulch under conservation agriculture).

Furthermore, Brouwer & Powell (1998) found that the most efficient use of manure in terms of yield increases and minimized leaching occur at around three tons of manure (dry matter). In the model, traditional farming using manure assumes an application rate of 5t, which is close to this optimal rate. However, even the 15t of manure assumed to be needed for conservation agriculture are within the application range of 12.7 – 15.5 t/ha analyzed by Schlecht et al. (2004).

The empirical findings and theoretical approaches presented here allow for a simulation of the relationship between farm management and soil fertility. The mathematical formulation of the soil fertility function and the impact of the management options upon soil fertility levels will be presented in chapter 2.4.

Land, cash and labour constraints

Land-, cash- and labour-use is constrained by total land, time, cash and soil fertility levels as well as crop production.

The land constraint refers to a household's initial and maximum land- or field size, the level of soil fertility of this land and the fact that the "inactive" resource *land* needs to first be activated (by investing labour into field preparation, which turns it into *cultivated land*). This

link between *labour* and *land* allows for modelling *seasonal peaks in labour demand* (and thus a main bottleneck of traditional farming identified in chapter 1.6.5).
It also allows for the non-spatially explicit modelling of fallow periods. If a household does not cultivate all of his land area, the non-cultivated land is left in fallow. Fallow is considered to have a soil-nutrient regenerating property and contributes positively to the land's total soil fertility level[50]. At the same time, households have the ability to extend their fields by clearing the remaining patches of bushland next to their fields. This does not only increase total available area of land (until an upper limit), but also adds soil nutrients to the lands nutrient pool, measured as its level of soil fertility.

The time constraint refers to a household's *producer labour-pool*, which is derived by multiplying the mean number of producers per household category with the season length and the average daily working time of eight hours (see chapter 2.4). Additional labour can be hired in to increase the labour pool and family labour can be hired out to generate cash income. As the dry season is traditionally characterized by low labour demand, the wage rate in the dry season and the maximum time that can be invested in this activity are drastically reduced to the wage obtainable in the rainy season, where demand for casual labour is high. Traditional field preparation can be carried out via manual labour or via draught-animal-power, i.e. using ox-drawn ploughs. If the household is an ox-owner, the daily labour time of its draught animal is assumed to be eight hours as well and the entire period available for field preparation can be used for ploughing and planting. If the household does not own any ox, he needs to hire it or refrain to manual field preparation. In case of hiring an ox, it is assumed that these draught animals become available only after half of the period available for field preparation has passed, i.e. when the first ox-owning households have finished preparing their own fields. Normally, an ox is hired jointly with its owner and, in order to preserve the health of the animal, does not work for more than five hours per day, usually in the morning. Therefore, non-ox-owning households can only use half the days available for animal-based field preparation, and instead of eight hours they can only work five hours per day.

The cash constraint describes the balance between the household's cash income sources (fixed income, income from crop sales and income from engaging in casual labour) versus its cash expenditures (for hiring in labour and/or oxen, purchasing food or field inputs). All prices are assumed to remain fixed over the entire modelling period. As credit-markets are missing (Pröpper 2009), purchases are only possible if sufficient cash is available in the respective season and period. Furthermore, purchased products (be it food or labour) cannot be re-sold. Cash cannot be saved from one period to the next, not even from one season to the next. Instead, farm-inputs purchased in the dry season can be used in the sub-sequent rainy season for crop production, which yields short-term returns via farm-income and affects the level of Soil Fertility in the following period. Investments in Soil Fertility are therefore the only option that represents a variable quasi-bank account and allows for long-term savings. Labour from external workers and family members are considered perfect substitutes, with the exception that hired labour cannot be invested in leisure.

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[50] While in fact only that part of the field left in fallow would regenerate its soil nutrients, it is assumed here that in the next year of cultivation the farmer will shift the location of his plots to these regenerated areas to reap the benefits of fallow. This assumption allows for a non-spatially explicit modelling of the fields entire pool of soil nutrients, or soil fertility.

2.3.1.3 Incorporating risk, discounting and intergenerational equity

Risk

As shown in part I, the semi-arid ecosystem of the lower Okavango River Basin (LORB) is a risky environment for smallholder farming; farmers have to adapt to an erratic distribution and level of precipitation and market failures. To accommodate that, this study incorporates risk by following Chayanov's approach to include a *safety first criterion*. It requires the model to produce sufficient food for ensuring the survival of the household. While this study does not simulate stochastic events leading to crop losses or variations in food prices, it is relatively conservative in its approach to farm-household modelling: First, as mentioned before, natural resource use, livestock keeping and formal wage labour are incorporated as fixed activities. While this approach does not allow for depicting the effect of external shocks on the entire livelihood strategy of a household, it ensures that the model can never abandon a generally diversified livelihood strategy and allocate most farm-household resources to agriculture. It can thus be seen as an extension of the safety-first criterion that relates to livelihood diversification.

Second, the weights of the utility-function's arguments have been empirically assessed as smallholder's preferences for the consumption of staple foods vs. leisure, yet always connected to the activity needed to achieve this consumption level. Smallholders' relatively low preference for leisure as compared to crop production (see chapter 2.4.3.3) can be assumed to reflect (among other factors) a part of their risk-management strategy.

Furthermore, yield-data used to estimate the production function stem from a drought year and can be expected to be slightly below average yield levels. The strategies modelled here may with the same amount of inputs be assumed to achieve slightly higher yields in reality than in the model.

Discounting

There is considerable scientific debate on the role of discount rates for sustainable natural resource management. They are complex tools that may represent a land user's time preferences and/or intergenerational equity, thus touching the fine line between economics and ethics (Domptail 2011). While recommendation on appropriate discount rates vary (Winkler 2006), for issues related to natural resource use it is generally suggested to use rates that are low (Evans 2008), decreasing with time (Weitzman 1994) or to omit them completely (Domptail 2011). Authors such as Hecht (2010) argue that in developing country contexts the use of discounting is imperative, as current revenues may be crucial for farm-household's survival.

The research objective may guide in the choice of the appropriate discount rate. In order to simulate the land-use strategies of smallholders it is important to use a rate that reflects their actual decision making. Domptail (2011, following Pearce et al. 1993) assumes that in these cases, discount rates primarily reflect opportunity costs and time preference (i.e. smallholders prefer consumption now over consumption in the future), while intergenerational equity can be dealt with in additional modelling constraints.

Intergenerational equity

The question of intergenerational equity is of special interest for the farm-household, which in contrast to a generic company is a family business that is transferred to the next generation via inheritance. Therefore, the farm-household cannot be expected to come to an end at the end of the modelling period. Instead, in order to be able to pass a functional holding to the next generation, the resource values at the end of the modelling period are considerations that influence farming strategies (Buß 2006). However, if not told otherwise, a computer model would assume a farm-household to come to an end after the last period and therefore it will empty all resource stocks in this period to maximize utility. This peculiarity of models can be overcome by introducing a transversality condition in the utility-function which represents the discounted returns to the resource stock of the last period by assuming that the resource is sustained forever (Hecht 2010, Buß 2006). Our term considers cash income of the last year directly in the utility-function and multiplies it with an "*eternal*" (Hecht 2010, 170) interest rate, thus avoiding the phenomenon of depletion in the last modelling period.

2.3.1.4 Limitations of the model

General limitations to the chosen approach relate to the theoretical assumptions underlying neo-classical farm-household optimization and that a smallholder's decision-making can be represented by the assumptions underlying the concept of a *homo oeconomicus*. These will not be dealt-with at this place. Instead, the focus will lie on the specific limitations of the model developed here. These are mainly related to limited data availability and the simplification needed for the simulation of a complex and dynamic socio-ecological system.

First, the model places emphasis on the feedbacks between crop yields and the state of the soil, which are represented via the soil fertility index and a soil fertility function. Both are based on the rather strong assumption of linearity and consider only changes in the pools of the three macro-nutrients N, P and K. In reality, however, soil improving management methods (and especially soil rehabilitating technologies such as CA) are likely to also cause changes in the soil organic matter content, thus benefiting water retention capacity, soil fauna and other factors. This may lead to more complex, non-linear feedbacks and the occurrence of ecological threshold effects. However, lack of biophysical data forced this study to follow the presented linear approach. In fact, this approach greatly facilitates interpretation of model results. Furthermore, due to the beneficial side-effects presented above, it can be assumed that soil fertility improving management options have an even more pronounced, positive effect on crop growth than presented here and even reduce crop losses due to drought. The beneficial effect of soil fertility on farm productivity can therefore be expected to be a conservative approximation.

Second, the model does not consider inter-household nor intra-household interactions. Inter-household interaction may become very important over the long run, especially if a growing number of household adopts soil improving farming methods that rely at least partly on animal manure. In this case, a minority of ox- and cattle-owning households would need to produce the amount required by relatively poorer, non-ox nor cattle-owning households. Trade between these typical household categories may then become a central bottleneck of

farm production. At the moment, manure can be purchased relatively easily from cattle-owners, as the general demand for it is so low that it is not yet a scarce resource. In Seronga, manure may even be obtained free-of-charge, i.e. if a cattle-owner allows for kraaling his herd within a neighbour's field for a few nights. However, as soon as the use of animal manure becomes widespread within the research area, this model would need to be extended and also consider inter-household interactions.
Intra-household decision making is excluded from the analysis for the sake of model simplification. The research objective was to assess the potential of farming system optimization and the adoption potential of CA, relying on the assumption that all household resources could be used to maximize a joint, unitary utility-function.

The task of system simplification for modelling demanded various trade-off decisions. The focus of this model on seasonal labour use and the role of soil fertility necessitated to consider most other household activities as exogenous. This makes a holistic analysis of the farm-households impossible. However, it allows for the in-depth consideration of the issues mentioned above and yields thus more detailed insights about the research objective than a holistic model might achieve.

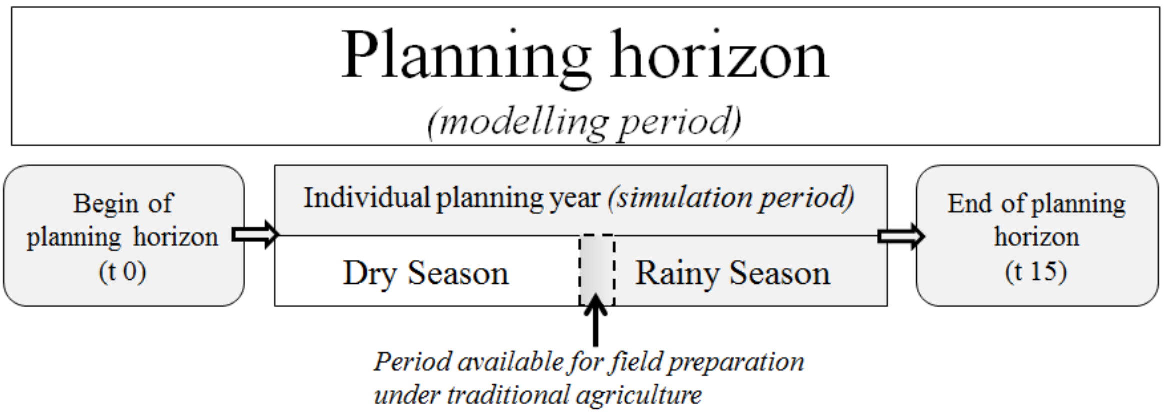
2.3.2 Mathematical model formulation

2.3.2.1 Computer-based optimization using the GAMS software-tool

This study developed a dynamic bio-economic model of farm-households in the LORB which includes a high number of decision-variables. It is formulated as non-linear-programming (NLP) problem. As this kind of problem is hard to solve manually, computer-based modelling was applied. In Economics, the most widespread software-tool for solving these non-linear problems is GAMS, the General Algebraic Modelling System (Buß 2006). This study uses GAMS for solving a bio-economic farm-household model. The advantage of GAMS is that although numerical solutions of non-linear problems remain a challenge, it solves for global optima. However, non-linearity is always connected with the danger of creating a too-large and too-difficult-to-solve model. To overcome this challenge, it is advisable to linearize all constraints to the greatest extent possible (Buß 2006). Furthermore, for internal calculations GAMS translates the non-linear formulations into linear approximations. Thus, appropriate modelling results may depend on a correct definition of variable "bounds" and "starting values" (ibid.).

The following chapter will present important equations from the model, all of which have been kept as linear as possible while still allowing for simulating the complex reality to a sufficient degree. The GAMS software-tool allows for representing exogenous variables (= parameters), endogenous variables (= decision variables) and the equations linking them in a clear and organized manner. Variables are denoted by a **V_**... (such as in $V\_FieldSize_{hh,t}$) and Parameters by a **P_**... (such as in $P\_WagePerHourCasualLabour_{seas}$).
To improve reader-friendliness, some of these variables and equations have been simplified in the following model overview and thus differ slightly from their original formulation in the GAMS code. Most variables are furthermore defined for various dimensions or sets, what is here called indices. Tab. 2.1 gives an overview of all indices used in the model. In the equations they will be characterized by lower script.

Fig. 2.3: The relationship between the planning horizon (= modelling period) and planning year (= simulation periods *t*)



Source: Author's design.

Tab. 2.1: Relevant indices used in the model

Index description	Index symbol	Index elements	Index element description
Time periods	t	*0, 1, ..., 15*	*tfirst* = first time period (0) *tlast* = last time period (15)
Household categories	hh	*hho, hhno*	*hho* = wealthier ox-owners *hhno* = poorer non-ox-owners
Season	seas	*DrySeason, RainySeason*	*DrySeason* = Dry & cold season *RainySeason* = Rainy & warm season
Nutrient pools	nut	*N, P, K*	*N* = Nitrogen pool *P* = Phosphorus pool *K* = Potassium pool
Technology choice	ac	*TR, CA*	*TR* = traditional smallholder farming *CA* = conservation agriculture
Field input choice	InputUse	*Fertilizer, Manure, BothInputs, None*	*Fertilizer* = inorganic NPK (2:3:2) fertilizer *Manure* = cattle manure *BothInputs* = use of both manure & fertilizer *None* = no use of inputs
Choice of energy source for field work	implement	*Manual* *DAP*	*Manual* = manual labour *DAP* = Draught animal power (i.e. animal traction)

Source: Author's design. Note: Field input choice can be varied only for TR; for CA it is fixed as *BothInputs*.

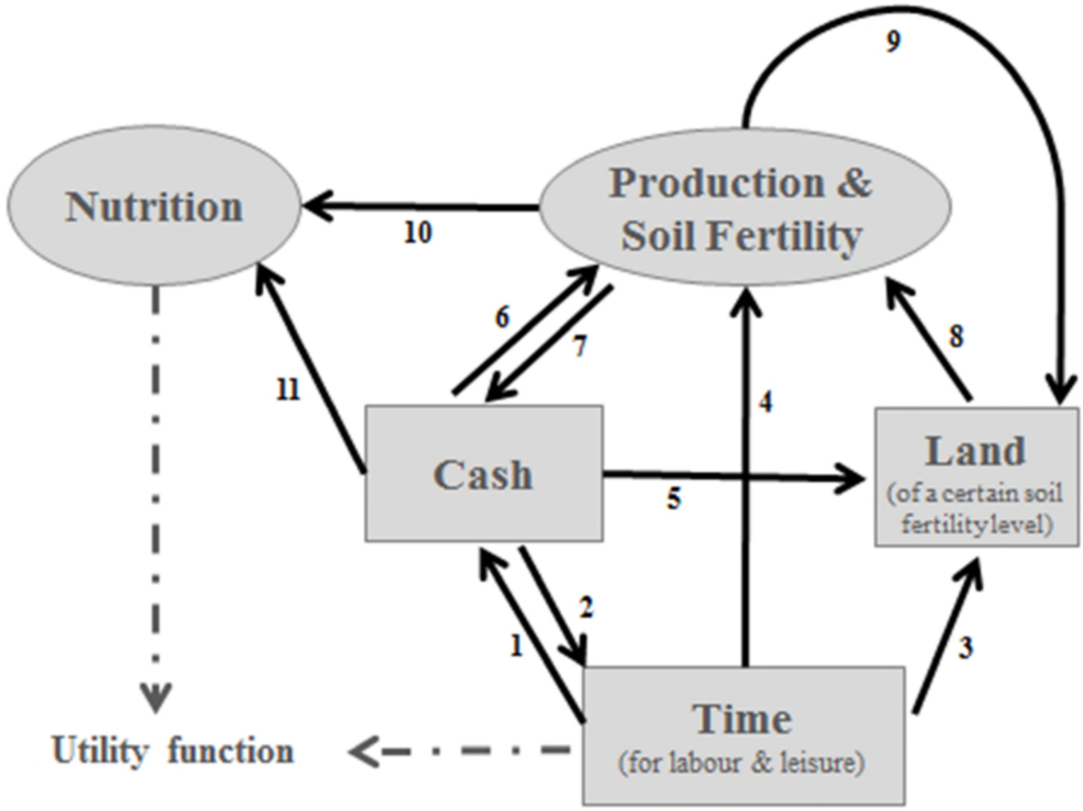
2.3.2.2 Mathematical model formulation – the modules

For the following overview, the model has been separated into 5 distinct units, i.e. the so-called modules. These modules represent the central equations of the GAMS code and have been arranged into groups based on their purpose in the model. An example for such a module is the Cash Module, which describes those equations responsible for calculating the cash income and cash expenditures of a given household category in a given simulation period and season. Thus, the modules do not represent self-contained mini-models – they just serve to structure the model for the reader. The following overview shows central equations of each module and the links between the different modules (Fig. 2.4).

1) The labour- and land-use modules

Due to the main agricultural constraints identified in part I of this study (i.e. seasonality of labour demand & land scarcity, which may induce an agricultural intensification based on labour-intensive CA), labour lies at the heart of the model. Thus, the labour module has to be characterized by a variety of links to other modules. Arrows 1 and 2 in Fig. 2.4 indicate that family labour can be invested into casual labour (hired-out) to generate cash income or that casual labour can be hired-in for cash to increase the household's labour pool. Labour is also a direct input into the production process and this amount of cultivation labour is determined by the choice of technology (ac) and inputs allocated to a certain area. Labour not used for any productive activity, i.e. labour invested in the consumption of leisure and for meeting social and cultural obligations, does directly enter the utility function. Fig. 2.4 helps to illustrate on the important link between the labour- (or time) and the land module, a main bottleneck of agricultural production in the model.

Fig. 2.4: Schematic overview of the modules of the bio-economic model and their feedbacks



Source: Author's design. Note: these modules can be understood as "categories of constraints", which sometimes include only one equation for a constraint and in other cases a set of equations for each constraint. The feedbacks are indicated with numbered arrows, which serve as references for their more detailed description in the following paragraphs. The sub-modules "seed-use" (included in cash constraint) and "land preparation" (included in labour constraint) were excluded for sake of simplicity.

As mentioned before, a farm-household in the model has a maximum area of land that can be cultivated, which is determined by the variable "$V\_FieldSize_{hh,t}$" in a given year. This variable can be increased to a limited degree by clearing vegetation from uncultivated land, i.e. by field extensions. A starting value of 1.0 ha and an upper bound of 2.0 ha describe the extreme values that the variable can take in the baseline scenario. For a specific year or simulation period, its value is determined by equation (1):

$$V\_FieldSize_{hh,t} = V\_FieldSize_{hh,t-1} + V\_ClearedLand_{hh,t} \tag{2.1}$$

with

$V\_FieldSize_{hh,t}$: Field size or maximum cultivatable area (in hectare) per hh in t.
$V\_ClearedLand_{hh,t}$: Land (in hectare) that is cleared from natural vegetation and added to the total field area of a hh in t.

The amount of cleared land is determined by:

$$V\_ClearedLand_{hh,t} = (V\_HiredLabourInvestedFieldClearing_{hh,t} + V\_FamilyLabourInvestedFieldClearing_{hh,t}) / P\_LabourneedsLandClearing \tag{2.2}$$

with

$V\_HiredLabourInvestedFieldClearing_{hh,t}$: Amount of labour-hours hired-in for clearing land per hh in t.

$V\_FamilyLabourInvestedFieldClearing_{hh,t}$: Amount of family-labour-hours invested in clearing land per hh in t.

$P\_LabourneedsLandClearing$: Parameter describing how many labour-hours are needed for clearing one hectare of natural vegetation.

The variable field size is *inactive* and needs to be *activated* for agricultural production by investing labour. Thus, a household may decide to use not more than a certain amount of labour and thus activate (i.e. plough, plant and cultivate) only a fraction of its field, leaving the uncultivated part in fallow; or it may choose to invest a larger amount of labour to make the entire field available for cultivation. The labour needed for i) preparing and ii) cultivating a hectare has been set as fixed for each combination of technology and input use (see chapter 2.4.2 on parameter levels). The following equations determine the amount of land activated for each technology, i.e. traditional agriculture or conservation agriculture. Labour needs include requirements for both land preparation and cultivation.

$$V\_AREA_{hh,ac,t} \leq \sum_{implement} (V\_FamilyLabourInvestedCultivation_{hh,ac,implement,t,seas} + V\_HiredLabourInvestedCultivation_{hh,ac,implement,t,seas}) / P\_LabourneedsCultivation_{seas,implement,ac} \qquad (2.3)$$

with

$V\_FamilyLabourInvestedCultivation_{hh,ac,implement,t,seas}$: Amount of family-labour in hours invested in field cultivation per hh, per ac, using implement in t in seas.

$V\_HiredLabourInvestedCultivation_{hh,ac,implement,t,seas}$: Amount of hired labour in hours invested in cultivating land per hh, per ac, using implement in t in seas.

$P\_LabourneedsCultivation_{seas,implement,ac}$: Parameter describing how many labour-hours are needed for cultivating one hectare per seas using implement per technology ac.

$$V\_AREA_{hh,ac,t} = \sum_{implement} V\_LabourInvestedFieldPreparation_{hh,ac,implement,t,seas} / P\_LabourneedsLandPrep_{seas,implement,ac} \qquad (2.4)$$

with

$P\_LabourneedsLandPrep_{seas,implement,ac}$: Parameter describing how many labour-hours are needed for preparing (ploughing and planting) one hectare of land per seas using implement per technology ac.

As the time available for field preparation (ploughing & planting) is constrained for traditional smallholder production, the task of field preparation is treated as separate from field cultivation, which includes all tasks carried out after planting to harvesting. A separate sub-module was created for determining the amount of labour invested in field preparation per technology.

The variable $V\_AM_{hh,ac,InputUse,t}$ represents the link between the land-, labor- and production modules. It shows the land size allocated and a combination of inputs used per technology. The choice of inputs is fixed for CA (both fertilizer and manure are needed), yet for traditional agriculture the household can decide whether to apply both inputs, only one type of input or none at all. $V\_AM_{hh,ac,InputUse,t}$ is constrained by the land activated for each technology, $V\_AREA_{hh,ac,t}$, such that:

$$V\_AREA_{hh,ac,t} = \sum_{InputUse} V\_AM_{hh,ac,InputUse,t} \tag{2.5}$$

with

$V\_AM_{hh,ac,InputUse,t}$: Amount of land allocated to the farming practices, i.e. either CA or TR and choice of inputs in into traditional farming (*TR: Manure,Fertilizer,Both,None*).

Apart from this upper bound, $V\_AM_{hh,ac,InputUse,t}$ requires additional investments in terms of labour and cash, i.e. labour for distributing respective inputs on the field and cash for purchasing these inputs, e.g. fertilizer. The fixed (per-hectare) labour- and cash needs of the production options will be presented in the chapter on parameter levels (chapter 2.4). The following equation on the area under traditional agriculture treated with inorganic fertilizer exemplifies how these fixed labour-needs per hectare are included in the computation of $V\_AM_{hh,ac,InputUse,t}$:

$$V\_AM_{hh,"TR","Fertilizer",t} \leq \sum_{implement} \Big(V\_FamilyLabourInvestedFertilizerApplication_{hh,"TR",implement,t,seas} + V\_HiredLabourInvestedFertilizerApplication_{hh,"TR",implement,t,seas} \Big) / P\_LabourneedsFertilizer_{seas,implement,"TR"} \tag{2.6}$$

with

$V\_FamilyLabourInvestedFertilizerApplication_{hh,"TR",implement,t,seas}$: Family-labour in hours invested in fertilizer application per hh, for “traditional agriculture (TR)” using implement in t in seas.

$V\_HiredLabourInvestedFertilizerApplication_{hh,"TR",implement,t,seas}$:Hired labour invested in fertilizer application per hh, for “traditional agriculture (TR)” using implement in t in seas in hours.

$P\_LabourneedsFertilizer_{seas,implement,"TR"}$: Parameter describing labour needs (in hours) for applying inorganic fertilizer per ha under TR, per seas using implement.

2) Production Function and Soil Fertility Module

Equations defining the production- and the soil fertility constraint are central to the model. Their mathematical formulation will be introduced here, while more details on the assumptions behind these equations will be given in a subsequent chapter (2.4.1).

The econometrically estimated production function is a linearized, logarithmic Cobb-Douglas function with only one variable input (soil fertility), while fertilizer & manure application take the form of dummy variables:

$$\begin{aligned} V\_LnYield_{hh,ac,InputUse,t} \leq\ & P\_EFF \\ & + P\_COEFF1 * V\_LnSFlevel_{hh,t} \\ & + P\_COEFF2_{"D-Fertilizer"} * V\_DummyFertilizer_{hh,ac,InputUse,t} \\ & + P\_COEFF2_{"D-Manure"} * V\_DummyManure_{hh,ac,InputUse,t} \end{aligned} \tag{2.7}$$

with

$V\_LnYield_{hh,ac,InputUse,t}$	:logarithmic yield of hh derived from ac using InputUse in t.
P_EFF	:technical coefficient (constant) of production function.
P_COEFF1	:coefficient (elasticity) of logarithmic, continuous independent variable soil fertility of hh in t.
$P\_COEFF2_{dummy\_in\_factor}$	:coefficient of independent dummy variables “manure use” or “fertilizer use”.
$V\_LnSFlevel_{hh,t}$	:logarithmic, continuous independent variable soil fertility of hh in t.
$V\_DummyFertilizer_{hh,ac,InputUse,t}$	:independent dummy variable for use of input “Inorganic Fertilizer” of hh under ac using InputUse in t.
$V\_DummyFertilizer_{hh,ac,InputUse,t}$	:independent dummy variable for use of input “cattle manure” of hh under ac using InputUse in t.

The yield obtained from this per-hectare logarithmic production function per management option needs to be converted into kg and multiplied with the area assigned to the respective management option:

$$V\_Production_{hh,ac,t} \leq \sum_{InputUse} P\_EulersNr^{V\_LnYield} * V\_AM_{hh,ac,InputUse,t} \tag{2.8}$$

with

$V\_Production_{hh,ac,t}$: Total agricultural output per hh per technology choice ac in t in kg.

$P\_EulersNr$: Eulers number **e**.

$V\_AM_{hh,ac,InputUse,t}$: Area allocated to a certain agricultural management option per hh per ac per different input combination in t.

In a third and last step, the technology specific yields need to be multiplied with their technology-specific yield-correction factor, which takes into account secondary crops such as legumes. This was necessary because the relationships between management, soil fertility and yields are based on cereal crops only and do not reflect nutrient needs or crop responses of legumes.

$$V\_TotProduction_{hh,t} \leq V\_Production_{hh,"TR",t} * P\_TR\_Yield\_Correction\_Factor + V\_Production_{hh,"CA",t} * P\_CA\_Yield\_Correction\_Factor \tag{2.9}$$

with

$V\_TotProduction_{hh,t}$: Total production per kg of a hh in t.
$P\_TR\_Yield\_Correction\_Factor$: Yield correction factor for traditional smallholder farming (TR).
$P\_CA\_Yield\_Correction\_Factor$: Yield correction factor for conservation agriculture.

The dynamic character of the model is caused by a time-lagged feedback loop between the per-hectare production function and the soil fertility function. The latter has been formulated as:

$$V\_SF\ Level_{hh,t} \leq V\_Nutrientlevel_{nut,hh,t} * 100) \tag{2.10}$$

with

$V\_SF\ Level_{hh,t}$: Soil-fertility level in % per hh in t.
$V\_Nutrientlevel_{nut,hh,t}$: Level of nutrient-pool per nut per hh in t.

Equation (2.10) was created for each of the three nutrients (N, P and K), thus forcing *V_SF Level* to always take the lowest value of the three variables *V_Nutrientlevel*. The actual feedback between management and soil fertility is found in the equation determining the individual nutrient-pools:

$$\begin{aligned} V\_Nutrientlevel_{nut,hh,t} \leq\ & V\_Nutrientlevel_{nut,hh,t-1} \\ & + \textstyle\sum_{InputUse}\sum_{ac} P\_NutrientImpact_{ac,nut,InputUse} * V\_AM_{hh,ac,InputUse,t-1} \\ & + P\_NutrientImpactFALLOW_{nut} * V\_FallowArea_{hh,t-1} \\ & + P\_StartValueNutrientsOFP_{nut} * V\_ClearedLand_{hh,t} \\ & - \textstyle\sum_{ac} P\_NutrientLossHarvest_{nut,ac} * V\_Production_{hh,ac,t-1} \end{aligned} \tag{2.11}$$

with

$V\_Nutrientlevel_{nut,hh,t-1}$: Level of nutrient-pool per nut per hh in period t-1.

$P\_NutrientImpact_{ac,nut,InputUse}$: Parameter for the impact of InputUse on nut per ac.

$V\_FallowArea_{hh,t-1}$: Area allocated to fallow per hh in previous period t-1.

$P\_StartValueNutrientsLowF_{nut}$: Starting value of nut for land cleared from natural vegetation on land of low fertility (Kalahari sands).

$V\_ClearedLand_{hh,t}$: Area of land cleared from natural vegetation and turned into cultivated land per hh in current period t.

$P\_NutrientLossHarvest_{nut,ac}$: %-amount deducted from nutrient-pool per kg for each nut per ac.

Equation (2.9) represents arrow 9 in the schematic model overview of Fig. 2.4., whereas equations (2.10) and (2.11) refer to the arrow 10.

3) The cash module

The cash module balances the seasonal cash income and cash expenditures of a household. The sources of cash income include i) fixed seasonal cash income from non-modelled activities (a parameter), ii) income from investing family-labour into casual labour (arrow 1 in Fig. 2.4) and iii) income from food sales (arrow 7):

$$V\_TotalCashIncome_{hh,t,seas} \leq V\_IncomeCasual_{hh,t,seas} + V\_IncomeCropSales_{hh,t,seas} + V\_FixedCashInc_{hh,seas} \qquad (2.12)$$

with

$V\_TotalCashIncome_{hh,t,seas}$: Total cash income per hh in t per seas.
$V\_IncomeCasual_{hh,t,seas}$: Cash income from casual labour per hh in t per seas.
$V\_IncomeCropSales_{hh,t,seas}$: Cash income from crop sales per hh in t per seas.
$V\_FixedCashInc_{hh,seas}$: Fixed cash income per hh per seas.

Cash expenditures can be used to cover the costs of a) hiring external workers (arrow 2 in Fig. 2.4) or oxen (arrow 5), b) purchasing staple food at the market (arrow 11), c) purchasing field inputs such as manure or fertilizer (arrow 6), d) purchasing seed (arrow 6) as well as e) transport from and to town for purchasing/selling food/produce.

$$\begin{aligned} V\_TotalCashNeeds_{hh,t,seas} \geq\ & V\_CostsHiringInLabour_{hh,t,seas} + V\_CostsPurchasingFood_{hh,t,seas} \\ & + V\_CostsPurchasingInputs_{hh,t,seas} + V\_CostsPurchasingSeed_{hh,t,seas} \\ & + V\_TravelCostsFoodSales_{hh,t,seas} + V\_TravelCostsFoodPurch_{hh,t,seas} \end{aligned} \qquad (2.13)$$

with

$V\_TotalCashNeeds_{hh,t,seas}$: Total cash needs or expenditures of a hh in t per seas.

$V\_CostsHiringInLabour_{hh,t,seas}$: Cash needs of hiring workers per hh in t per seas.

$V\_CostsPurchasingFood_{hh,t,seas}$: Cash needs of purchasing food per hh in t per seas.

$V\_CostsPurchasingInputs_{hh,t,seas}$: Cash needs of purchasing inputs per hh in t per seas.

$V\_CostsPurchasingSeed_{hh,t,seas}$: Cash needs of purchasing seed per hh in t per seas.

$V\_TravelCostsFoodSales_{hh,t,seas}$: Cash needs of a bus-trip to town for selling produce per hh in t per seas.

$V\_TravelCostsFoodPurch_{hh,t,seas}$: Cash needs of a bus-trip to town for purchasing food from the market per hh in t per seas.

Cash expenses may never exceed cash income, which is achieved via equation 2.14:

$$V\_TotalCashIncome_{hh,t,seas} \geq V\_TotalCashNeeds_{hh,t,seas} \tag{2.14}$$

$$V\_TotalCashIncome_{hh,t,seas} = V\_TotalCashNeeds_{hh,t,seas} + V\_CashIncomeBal_{hh,t,seas} \tag{2.15}$$

with

$V\_CashIncomeBal_{hh,t,seas}$: Auxiliary variable that is needed for the Utility function in the last modelling period.

Equation (2.12) and (2.13) above imply that no money can be saved from one year or even one season to the next. However, the model formulation allows for accessing all cash income sources in both seasons. A year or time period t starts with the rainy season during which agricultural output is produced and ends with the dry season, where the household may start to use the agricultural output of the previous season – be it for sales, storage or domestic consumption. If the household decides to sell part of his output for generating cash income, these sales may happen during the dry season of the same year the output was produced. However, part of this output may also be sold only in the following rainy season, i.e. during the next time period t+1. Thus, crop sales are a potential income source even during the rainy season while the new harvest is still being cultivated.
Also, cash expenditures for field inputs need to be done in the dry season of the previous planning period (t-1), as they need to be available at the beginning of the rainy season. Thus, although no direct cash savings are possible, there is an intertemporal link between purchase of inputs and use of inputs. Cash income and expenditures are determined by multiplying the decision variables on amount or time invested or purchased by the respective prices. For casual labour this takes the form of:

$$V\_IncomeCasual_{hh,t,seas} \leq V\_FamilyLabourInvestedOfffarmLabour_{hh,t,seas} * P\_WagePerHourCasualLabour_{seas} \tag{2.16}$$

with

$V\_FamilyLabourInvestedOfffarmLabour_{hh,t,seas}$: Amount of family labour invested in casual labour (off-farm labour) per hh in t per seas.

$P\_WagePerHourCasualLabour_{seas}$: Wage rate per hour of casual labour per seas.

The income obtained by sale of own agricultural produce is determined by the amount of food sales multiplied with the farm-gate price of crops, which differs for maize (main crop of CA) and millet (main crop of TR):

$$V\_IncomeFoodSales_{hh,t,seas} \leq \sum_{ac} V\_AmountFoodSold_{hh,ac,t,seas} * P\_FGPRICE_{ac} \quad (2.17)$$

with

$V\_AmountFoodSold_{hh,ac,t,seas}$: Amount of own produce sold in kg per hh per ac in t per seas.
$P\_FGPRICE_{ac}$: Farm-gate price per kg per ac.

The costs of hiring external workers is calculated similarly to the income obtained from casual work:

$$V\_CostsHiringInLabour_{hh,t,seas} \geq V\_HiredInLabour_{hh,t,seas} * P\_WagePerHourCasualLabour_{seas} \quad (2.18)$$

with

$V\_HiredInLabour_{hh,t,seas}$: Amount of labour-hours hired per hh in t per seas.
$P\_WagePerHourCasualLabour_{seas}$: Wage rate per hour of casual labour per seas.

The cost of purchasing food are determined by multiplying the amount in kg with the retail-price of maize per kg:

$$V\_CostsPurchasingFood_{hh,t,seas} \geq V\_AmountFoodPurchased_{hh,t,seas} * P\_RPC \quad (2.19)$$

with

$V\_AmountFoodPurchased_{hh,t,seas}$: Amount of food purchased in kg per hh in t per seas
P_RPC : Retail-price per kg of maize.

The costs needed for purchasing food (as well as for selling food) at the urban market are based on the assumption that one household member can at maximum transport one bag of 50 kg to and from town. That means for every 50 kg of food purchased or sold, the price (and time) needed for a bus-trip to town needs to be added to the cash-expenditures. The same approach as for purchasing food is used for determining the expenditures needed or purchasing seed. However, seed is purchased during the dry season of time period t and can then be used only in the rainy season of the next time period t+1:

$$V\_CostsPurchasingSeed_{hh,t,\text{"DrySeason"}} \geq \sum_{ac} V\_AmountSeedPurchased_{hh,ac,t+1} * P\_RPSeed_{ac} \quad (2.20)$$

with

$V\_AmountSeedPurchased_{hh,ac,t+1}$: Amount of purchased seed in kg that can be used per hh per ac in t+1.

P_RPSeed_{ac} : Retail price of seed per ac.

The time lag between purchase and use of seed does also apply to field inputs. Exemplary for the other inputs, only the case of "fertilizer" is presented here:

$$V\_CostsFertilizer_{hh,t,\text{"DrySeason"}} \geq \sum_{ac} V\_AM_{hh,ac,\text{"Fertilizer"},t+1} * P\_COSTS_{hh,ac,\text{"Fertilizer"}} \tag{2.21}$$

with

$V\_AM_{hh,ac,\text{"Fertilizer"},t+1}$: Amount of land treated with fertilizer in ha per hh, per ac in t+1.

$P\_COSTS_{hh,ac,\text{"Fertilizer"}}$: Costs of purchasing sufficient fertilizer to treat 1 ha of land per hh per ac.

The parameter *P_COSTS* has the subscript *hh*, because it is assumed that the wealthier household category has free access to the input "cattle manure" while the poorer category needs to purchase this input from wealthier households.

4) The nutrition module

The nutrition module is responsible for securing a minimal standard of living for a household. It makes sure that the consumption of own output remains above the level of the necessary minimum calorie consumption calculated in chapter 2.4.2. The module also determines the level of *Total seasonal food consumption*, which consists of own produced food and market purchased food. This variable directly enters the utility function. Another task of the nutrition module is to balance the various sources and inter-temporal uses of own crop output:

$$\begin{aligned} V\_TotProduction_{hh,t} \geq & \sum_{seas} V\_AmountFoodOwnConsumption_{hh,t+1,seas} \\ & + V\_AmountFoodSold_{hh,t+1,seas} \\ & + V\_AmoundFoodStored_{hh,t+1,seas} \\ & + V\_AmountSeedStored_{hh,t+1} \end{aligned} \tag{2.22}$$

with

$V\_AmountFoodOwnConsumption_{hh,t+1,seas}$: Amount of own produce domestically consumed by hh in t+1 in seas.

$V\_AmountFoodSold_{hh,t+1,seas}$: Amount of own produce sold at the market by hh in t+1 in seas.

$V\_AmoundFoodStored_{hh,t+1,seas}$: Amount of own produce stored by hh for consumption in period t+1 in seas.

The food consumed per season can come from three sources, own production, purchases and food stored in the previous period t-1:

$$\begin{aligned} V\_FoodConsumption_{hh,t,seas} = & \; V\_AmountFoodPurchased_{hh,t,seas} \\ & + V\_AmountFoodOwnConsumption_{hh,t,seas} \\ & + \sum_{ac} V\_AmountFoodStored_{hh,ac,t,seas} \end{aligned} \tag{2.23}$$

with

$V\_AmountFoodPurchased_{hh,t,seas}$: Amount of food purchased in kg per hh in t per seas.

5) Utility function

All arguments of the utility function are indexed by the time period *t*, the season *seas* and the household category *hh*. Utility *U* is maximized over all time periods, i.e for the entire planning period. It is thus index-less.

The discount-rates have been introduced in chapter 2.3.1.3. Accordingly, the sum over all elements in the utility function is multiplied by $1/DiscountRate^t$. To reflect dependence on current revenues more realistically, a higher discount rate is assumed for the poorer household category and a relatively lower discount rate for the wealthier household category.

To avoid resource stocks depletion in the last modelling period, a "*farm-household activity continuing term*" (Hecht 2010) is introduced (see chapter 2.3.1.3). This term (HH-ACT) delivers returns to the stock of household resources in the last period by assuming that it is sustained forever (Hecht 2010, 170). This is achieved by considering cash income of the last year directly in the utility function and multiplying it with an "eternal" interest rate (ibid.):

$$V\_HH\text{-}ACT = \sum_{hh} \sum_{seas} \sum_{t\_last} (V\_income\_balance_{t\_last,hh,seas}) * (1/(1+P\_DR_{hh}{}^{t\_last})) \qquad (2.24)$$

with

V_HH-ACT	: the farm-household activity continuing term
$V\_income\_balance_{t\_last,hh,seas:}$	: The unused cash income of hh per seas in the last simulation period t_last
P_DR_{hh}	: Household-specific discount rate

The two arguments of the utility function are monetarized to make them comparable:

$$V\_cons\_st\_fd_{hh,t,seas} = V\_AmountFoodOwnConsumption(hh,t,seas) * P\_FGPrice(\text{"TR"}) + V\_AmountFoodPurchased(hh,t,seas) * P\_FGPrice(\text{"CA"}) \qquad (2.25)$$

with

V_AmountFoodOwnConsumption(hh,t,seas)	: Amount of consumed food in kg stemming from own production per hh in t per season.
V_AmountFoodPurchased(hh,t,seas)	: Amount of consumed food in kg purchased at the market per hh in t per season.
P_FGPrice("TR")	: Farm-gate price of millet.
P_FGPrice("CA")	: Farm-gate price of maize.

and

$$V\_cons\_leis_{hh,t,seas} = V\_Leisure(hh,t,seas) * P\_ShadowPriceFamilyLabour(hh,seas) \quad (2.26)$$

with

V_Leisure(hh,t,seas)	: Amount of family-labour in hours invested into leisure activities per hh in t per season.
P_ShadowPriceFamilyLabour(hh,seas)	: Household- and season-specific shadow price of one hour of family-labour.

Thus, the utility-function takes the form of:

$$V\_U = \sum_t \Big(\sum_{hh} \sum_{seas} (P\_\alpha 1 * V\_cons\_st\_fd_{hh,t,seas} + P\_\alpha 2 * V\_cons\_leis_{hh,t,seas}) * 1/P\_DR_{hh}{}^{t}\Big) + V\_HH\text{-}ACT \quad (2.27)$$

with

V_cons_st_fd	: Acquisition and consumption of staple food.
V_cons_leis	: Consumption of leisure and meeting social and cultural obligations.
P_DR_{hh}	: Household-specific discount rate.
V_HH-ACT	: Farm-household activity continuing term.
$P\_\alpha 1$	: Weight of the argument *consumption of staple food* (preference)
$P\_\alpha 2$	: Weight of the argument *consumption of leisure* (preference)

2.4 Empirical data gathering, computation and parameter levels

Most of the methods used for empirical data gathering have already been presented in part I of this study. The following chapter will therefore focus on how the empirical data was computed and prepared for use in the bio-economic farm-model. It will also present the literature relevant for these computations. As the model represents typical farm-household categories of two study sites Mashare, Namibia and Seronga, Botswana, it is based on mean data for a group of poorer households and a group of wealthier households.

The chapter starts with the production constraint of the model and includes theoretical considerations for the integration of production and the biophysical component, such as the link between yield, farm-management and soil fertility. Building on these considerations, the econometrically estimated production function will be presented as well as complementary production constraints that are based on mathematical programming. Afterwards, this chapter will present the approach applied for assessing smallholder preferences for various productive activities, two of which will be used as weights in the utility function. The end of the chapter will introduce the approach chosen for clustering the households of Seronga and Mashare into typical household categories and present descriptive statistics of these clusters. This will also include the values of all parameters, or exogenous variables, included in the model, such as: maximum and mean field size, input/output-prices, households' labour pools as well as mean cash and food income from non-modelled activities. Additionally, the theoretical values that describe the effect of farm management options on soil fertility will be presented.

2.4.1 Production constraint – theoretical considerations and econometric estimation

A central aspect of any BEM is the interface between the ecological system (or natural sciences) and the socioeconomic system (or social sciences). For farm-household models, the main relationships that need to be taken into account are i) the link between production factors (inputs such as land, labour but also soil fertility) and yield as well as ii) the link between choice of farm management options and soil fertility. This allows for regarding a decrease in the level of soil fertility as a cause of yield decline but also as a result of farm management (Krusemann 2000). Typically, the interface between social and natural sciences is represented as a production function and specified via this function's formulation (Krusemann 2000). A production function specifies the relationship between any combination of inputs and the levels of agricultural output that can be obtained by these inputs (Sadoulet & de Janvry 1995).

The production function specified in this study simulates the physical output obtained by farming, i.e. the consumable harvest in kg. Furthermore, the level of soil fertility is regarded as a secondary, or indirect, output of the production function and serves as a sustainability indicator in the model. Its value is obtained by connecting the production function to a soil fertility function, in which the amount of output produced as well as the choice of technology and field inputs applied affect the level of soil fertility. At the same time, the value of soil fertility of the previous modelling period (year) is regarded as an input into the production process. This closes the circle between the production function and the soil fertility function, which jointly represent the interface between both scientific disciplines involved in this study.

The following chapter will elaborate on the chosen approach to modelling the production constraint and its links to the soil fertility constraints. Therefore, some of the aspects of the soil fertility function will have to be revisited.

2.4.1.1 The role of production functions in sustainability analysis

In order to analyze sustainability issues in crop production, Krusemann (2000) argues that technology choice cannot be treated exogenously. I.e., in order to endogenize it, four important adaptations are required:

1) The production functions needs to consider changes in the biophysical component, e.g. soil fertility.
2) Changes of soil fertility need to be endogenized.
3) Choice of technology needs to be included.
4) The objective function needs to reflect farmers' considerations regarding soil degradation or -conservation.

This study incorporates these points as follows: 1) via including soil fertility as a continuous input into the production function, 2) by formulation a soil fertility function that makes the value of soil fertility dependent on choice of technology, inputs and production levels, 3) by considering both traditional farming practices as well as conservation agriculture as technology options in the model with different effects on yields and soil fertility and different input requirements as well as 4) by including a discount rate as an approximation of smallholders time preference.

Under rain-fed agriculture, water is the most limiting factor, if all other factors are abundant (Krusemann 2000), especially under dryland farming in Southern Africa. However, given the LORB's poor soils, severe shortages of macro-nutrients may be even more limiting than water (see Van Keulen & Breman 1990). This study takes this into account by using empirical yield data from a water-scarce area in a drought-year (and thus using lower-than-average yields) and by explicitly modelling soil fertility as an approximation of the macro-nutrient pools. Due to the complementarity of the three main macro nutrients, a balanced fertilization is required. This is achieved by applying Liebig's Law of the Minimum to the three nutrient pools which results in Soil Fertility being determined by the pool of the least available macro-nutrient[51]. Seasonal labour-availability has been identified as another main constraint to production in the research area. Therefore, this will be included in the model as a second main determinant of crop production.

Using the assumption of *Liebig's Law of the Minimum* has an important drawback; in reality, the relative abundance of one nutrient supplied by field inputs will lead to mining of other nutrients; this can only be avoided by supplying a sufficient amount of all required nutrients from external sources (Krusemann 2000). This is taken into account in so far as that in the model, CA can only be adopted as a "package of inputs" and not to varying degrees, e.g. just inorganic fertilizer or just manure. Thus, it can be assumed that the CA technology simulated

[51] As mentioned before, the pools are not defined as absolute amounts of nutrients, e.g. in g/kg of soil, but as values on an index, where a pool of 100 (%) means that sufficient nutrients are available for producing a maize harvest of 500kg. The three pools are thus directly comparable.

within this model is characterized by a balanced provision of nutrients and that it actually represents a technology for sustainable intensification.
At the same time, it has to be kept in mind that, in the short-run, the effects of soil mining are usually lost in the random variation of yields caused by weather patterns (Krusemann 2000). Moreover, they can also be affected by pest occurrences or differences in farm management. For capturing soil degradation via econometric analysis, very long and consistent time series data are required. For cross-sectional data on degradation, such as are available to this study, mathematical programming techniques are an appropriate alternative (ibid.). As said before, this study applies mathematical programming by developing a bio-economic optimization model. Within this model, the effect of the various management options, at the level of the three macro-nutrients N, P and K, will be captured via using fixed theoretical values. These values were compiled by a review of soil scientists of the TFO-project (no publication). They relate to the nutrient content per kg of output or input. For instance, they describe to how much percent a kg harvested under CA decreases the value of soil fertility in the next year and by how much it increases when applying certain input amounts or fallow periods. The approach also captures the effect of the amount of harvest (which is an export of soil nutrients) on soil fertility.

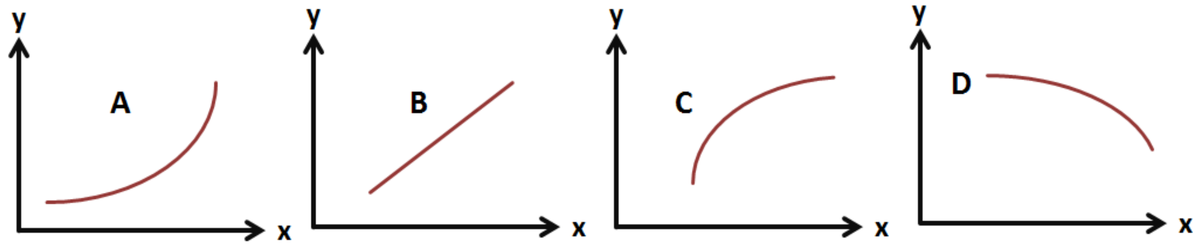
The per-hectare effect of the different farming practices on soil fertility is fixed. However, it can be varied within the model by the area assigned to a certain management practice (see Fig.2.2). This is plausible because soil fertility is modelled as a mean nutrient pool available to the farm-household and not spatially explicit for different plots. The per-hectare effects of the farming practices on soil fertility are included in the model as parameters. They enter the soil fertility function, where they are multiplied with the amount of land assigned to each farming practice. The *empirically* gathered soil data are included in the econometric estimation of the production function (see chapter 2.4.1.3).

2.4.1.2 Econometric estimation of input coefficients

Note: In this study, the term "*production constraint*" refers to all model equations which constrain production, i.e. particularly the (econometrically estimated) production function and the land allocated to the different farming practices; the term "*production function*", on the other hand, refers exclusively to the econometrically estimated equation (which relates the level of soil fertility and choice of farming practices to yields). This production function will be presented below in detail.

In the field of production economics, there is considerable debate on the relationship between inputs and yields and the importance of synergistic effects (De Wit 1992). While basically all models assume diminishing marginal returns to input use, there are many different views on the functional form of the production function. A detailed review on this issue can be found in Krusemann (2000). However, there is no given mathematical function form for a production function and historically all functions were based on more or less subjective choices (Rasmussen 2011). Instead, the choice of what constitutes an appropriate production function for a specific problem should depend on the area of functional form which is to be described (Keusch 2001, Rasmussen 2011). Assuming an S-shaped relation between inputs and outputs, four different areas of a production function can be differentiated (see Fig. 2.5).

Fig. 2.5: Alternative production function shapes.



Source: Author's design adapted from Rasmussen (2011).

This study assumes that the production function of smallholders in the LORB can best be approximated by shape C in Fig. 2.5, because the application of inputs in the study sites resulted in an immediate and pronounced effect of yields (which afterwards gradually declines). It is therefore assumed here that the soils in the LORB may react quickly to input applications and are to a large part not yet in such a degraded state that soil rehabilitation is needed before input application has an effect on yield (see chapter 1.4.3 on this issue).

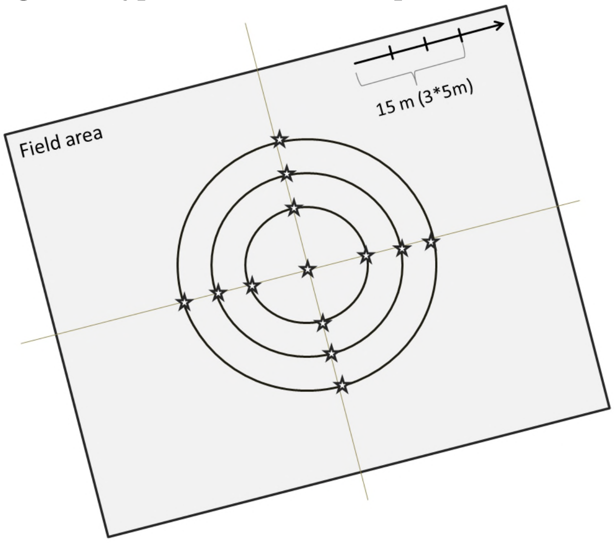
An important task of any production function is to capture the non-linear response of outputs to varying levels of input, i.e. the degree to which substitution is possible between inputs (Krusemann 2000). However, for a production function with only one continuous impact and two dummy-inputs, this question becomes less relevant[52].

Traditionally, production functions are based on empirical observations and derived via econometric techniques. Chapter 1.5 presented empirical data assessment (on yield and field management). Additionally, for each field included in the yield assessment, a top-soil sample was taken (i.e. the top-most 15 cm) and analyzed in regards to macro-nutrient content by the TFO project's soil scientists (see Chapter 1.5). Each sample consists of 13 sub-samples, taken in the center of each field and then of three samples (taken every five meters in four different directions from the field center: Fig. 2.6). The soil samples were taken at the end of the growing season to minimize the impact of any applied input on soil fertility.
Due to data limitations arising from this assessment method, a traditional approach to the econometric estimation of a production function could not be applied: only the value of soil fertility is a continuous variable which represents an input into the production process; all other inputs (labour, cattle manure and inorganic fertilizer) had to be included as non-variable (with fixed values per hectare).

[52] However, substitutability is reflected in the production constraint in a more general way, i.e. mainly in the choice of land allocated to each farming practice. As mentioned before, these practices are included in the model as two technologies (traditional agriculture TR and Conservation Agriculture CA). TR can be treated with varying amounts of inputs, but CA is a non-variable technology. Complementarity is partly reflected in the way land and labour are connected: Land is needed for any productive activity and it needs to be activated by labour. Labour-needs for activation reflect the labour-hours needed for field preparation, i.e. ploughing and planting. They differ for the different technologies (TR & CA) and the implements used (hoeing via manual labour or ploughing animal-traction). Furthermore, every hectare of land cultivated under a certain technology requires a basis amount of cultivation labour (weeding, harvesting). The additional labour-needs for input application under TR are added to these basic labour needs of cultivation.

Moreover, due to multi-collinearity between “choice of technology” and “field inputs” (i.e. all conservation agriculture plots were treated with cattle manure), this study decided to exclude technology from the econometric estimation and instead to focus on the impact of animal manure on yields. A reason for this is the fact that this study aims at improving farming strategies in the LORB, and a detailed comparison of the effects of various field inputs was considered as more relevant than a comparison of traditional farming practices and CA. As will be shown below, choice of technology as well as labour and land have instead been included in the production constraint via mathematical programming.

Fig. 2.6: Hypothetical field with pattern of soil sample assessment.



Source: Author’s design. The stars signify locations where samples were taken.

Our econometric estimation aimed at deriving coefficients for the variable input “soil fertility” as well as the dummy inputs “application of inorganic fertilizer” and “application of cattle manure”. The latter two had to be included as dummy variables, because no information could be obtained on the exact kg-amount of manure and fertilizer application per field. Instead, average per hectare values of these inputs were assessed via focus group interviews. For the estimation, it was assumed that each smallholder applies roughly the same amount of field inputs per hectare per technology (e.g. 5t cattle manure in TR Manure vs. 15 t of cattle manure under CA). By doing so, a production function could be estimated on a per hectare bas which depends on the level of soil fertility (a continuous variable) and manure/fertilizer input (dummy variables). In the model, these hectare figures are then multiplied with the area allocated to each farming practice (*CA, TR None, TR Manure, TR Fertilizer, TR Both*).

Special case I: The incorporation of land, labour and cash into the production constraint

The amount of labour needed for i) each of these activities as well as for ii) preparing the land for these practices is assumed as constant for any farming practice. The same holds true for the amount of cash needed per ha for the different inputs. As mentioned above, these inputs couldn’t be included in the econometric estimation of the production function due to data limitations. Therefore, they are stated via separate equations in the model and regarded as constraints to production. With inputs of cash and labour being fixed per hectare (but differing for each farming practice and technology), the *Area of land allocated to the different available farming practices* becomes a central decision-variable in the model.

Special case II: Incorporation of technology choice

Due to multi-collinearity, the impact of technology could not be captured econometrically. Thus, its coefficients were approximated in the following way: The yield data used in the econometric estimation refer to the yields of the main cereals. However, both traditional farming and conservation agriculture produce secondary crops such as beans and cowpeas.

To make their yield comparable to the yield of the main cereal crop, their mean annual harvest/ha/ technology was first translated into kcal and then into kg-equivalents of the main crop[53]. Thus, it was found that e.g. 1kg of cowpea correlates to 0.99 kg of maize or millet. The mean annual harvest of each technology's secondary crop was then multiplied with this ratio to get a total yield / ha. This value was then compared to the mean annual harvest of the main crop, which allowed for deriving a so-called *yield correction factor*, i.e. the amount by which the yield of the main crop has to be multiplied to also take into account the mean yield of the main secondary crop. For traditional farming, this factor is 1.15 while that for conservation agriculture is 1.96.

This factor allowed for including the mean effect of technology on yields. This was achieved via including it in the last step of the production constraint, i.e. after the per hectare production function was multiplied with the amount of land (in ha) dedicated to a certain farming practice and technology. Thus, the last step is the multiplication of the total yield per farm-households per technology with the technology's respective *yield correction factor*.

Production function specification

The appropriate functional form has been identified above (shape C in Fig. 2.5). For the purpose if this study, it is also important that the chosen (per-hectare) production function can be multiplied with the area allocated to a certain farming practice. This can be achieved by using a homothetic production function (Rasmussen 2011), where the ratio of inputs to each other always the same regardless of production levels. A Cobb-Douglas production function fulfills all of these requirements (ibid.). It was therefore chosen for the econometric estimation of this study's production function.

The estimated production function is characterized by having one output (yield), one continuous input (soil fertility) and two dummy inputs (*Application of Manure* & *Application of inorganic fertilizer*). For each of these three inputs, a coefficient was econometrically obtained. The nature of the three input variable furthermore implies that the general relationship between the single continuous input, i.e. soil fertility, and yield is represented by shape C in Fig. 2.5, while the application of manure or fertilizer (dummy-inputs) affect only the intercept but not the slope of the equation. As mentioned above, the amount of cash and labour needed for production is included in the variable *Land allocated to a certain production practice*. A linearized Cobb-Douglas function was estimated which takes the general form of:

$$LnY = \alpha + \beta_1 LnSoilFertility + \beta_2 Dummy\text{-}Manure + \beta_3 Dummy\text{-}Fertilizer \qquad (2.28)$$

[53] According to FAO (1953), 1kg of "Dry Beans and Peas, in shell" have 3450 kcal/kg while "Pearl millet" has 3480 kcal/kg; dividing them one obtains the ratio of 0.99, i.e. 1 kg beans correlates to 0.99 kg pearl millet.

where *LnY* represents the natural logarithm of yield of the main cereal crop in kg/ha and *LnSoilFertility* the natural logarithm of the 0 % - 100 % range of soil fertility assigned to a farm-household. Naturally, the Dummy-variables for the application of manure and inorganic fertilizer were not included with logarithmic values in the estimation. To depict their effect on yield/ha, their coefficients were transformed following Giles (2011) by using the formula:

$$\textit{Impact of Dummy-Variable j on Yield in \%} = 100 * (e^{(\textit{Coefficient j})} - 1) \qquad (2.29)$$

Tab 2.2 shows the results of the econometric estimation of the production function, which is based on empirical data for yields, soil fertility and input application and which was corrected for heteroscedasticity.

Tab. 2.2: Results of the production function estimation for Mashare & Seronga

Dependent variable: **Ln(Yield)** in kg/ha	**B**	**Std. Error**	Impact on Yield
c	**3.938*** **	0.621	
Ln (Soil Fertility) in %	**0.253***	0.136	
Dummy **Manure**	**0.594****	0.212	**+ 81 %**
Dummy **Fertilizer**	**0.643*** **	0.174	**+ 90 %**
Dummy **Study Site Seronga**	**- 0.452***	0.261	**- 36 %**
R^2 (*adjusted*)	0.367		
F	**6.769*** **		
N	53		

Source: Own data. Statistically significant at *= 0.1, ** = 0.05, *** = 0.001.

Adaptation of the production function to the GAMS software

Using dummy-variables within the GAMS software would turn the optimization problem into a mixed-integer-non-linear-programming (MINLP) problem, which can be hard to solve. In order to avoid this and create an easier to solve non-linear programming (NLP) model, the production function was reformulated. In the application of the model, four individual production functions where used, one for each choice of field inputs (none, inorganic fertilizer, organic manure, both fertilizer and manure). Together with technology choice (TR, CA), they represent the farming practices presented before (CA, TR None, TR Manure, etc.).

For each input or input combination, the value of the dummy value was added to the constant, leaving *Soil Fertility* as the only remaining variable in each of the four production functions. I.e. applying a certain choice of inputs to a certain area of the field automatically activates the corresponding production function. Its per-hectare output will then be multiplied with the respective area on which the inputs were applied.

2.4.1.3 Soil Fertility Constraint

The theoretical background of the soil fertility index and its mathematical representation were introduced in the previous chapters. The following paragraphs present the parameter levels that describe the effect of farm management on nutrient pools and thus soil fertility. They also give insights on data limitations and the chosen approach to overcome them.
The soil fertility function used to describe these relationships could not be based on empirical data, but had to be postulated based on theoretical values. It is based on the soil fertility function developed by Krusemann (2000). It allows for representing sustainability of farming by following Barbier & Carpentier's (2000) argument that: "*sustainable agriculture does not need to be sustainable now but can have a period of unsustainability and then of recuperation of the natural resources or even a period of substitution by a man made resource* (Barbier & Carpentier 2000, 2)". By adopting this view of sustainability, it is possible to use bio-economic models for analyzing under which condition a farming system becomes sustainable instead of analyzing whether or not it is sustainable (ibid.).

Before presenting the theoretical values, central equations of the soil fertility constraint will be re-introduced, albeit in a schematic form. This helps to remember how soil fertility is simulated in the model and the role of the farming practices in its calculation.

Schematic overview of the nutrientpool-equation

As mentioned before, the model represents soil fertility as an index (in %). Its level is determined by the pool of that nutrient (N, P or K), which is available to the lowest amount. The nutrient pools are calculated such that:

Nutrientpool (**N**) in year t =

Nutrientpool (**N**) of last year *(t-1)*			+	
Parameter X (**N**)	*	Area allocated to farming practice X *(t-1)*	+	
Parameter Y (**N**)	*	Area allocated to fallow *(t-1)*	+	(2.30)
Parameter Z (**N**)	*	Area of cleared land *(t)*	-	
Parameter-Harvest (**N**)	*	Harvest per technology *(t-1)* ;		

Nutrientpool (**P**) in year t = ... equivalent to **N** in 2.30 ...

Nutrientpool (**K**) in year t = ... equivalent to **N** in 2.30...

where the Parameters were provided by soil scientists from the TFO project, while harvest and area allocated to the farming practices & management options (fallow, land clearing) are decision-variables. N, P and K represent the three macro-nutrients and t the simulation period.
As can be seen, management has a time-lagged impact upon the nutrient pools and thus soil fertility. Therefore, these functions represent the central dynamic aspect of the model. This time-lag also avoids double counting of the effect of manure and fertilizer on yield, because both households have a direct effect on crop production (via their dummy-variables in the production function) as well as an indirect effect via their impact on soil fertility.

The effect of farm-management on soil fertility

As mentioned above, soil scientists of the TFO project provided theoretical values on the impact of management on soil fertility (see Tab. 2.3).

Tab. 2.3: The effect of farm-management on soil nutrients and starting values.

Management Option	N (%-change per ha)	P (%-change per ha)	K (%-change per ha)
Fallow period of one year	10.8	10.8	10.8
TR Fertilizer (20 kg inorganic NPK fertilizer)	2.1	29.2	3.6
TR Manure (5t of cattle manure)	159	421	184
TR Both (20kg fertilizer & 5t manure)	161	450	188
CA (0.5t fertilizer & 15t manure)	530	1993	641
Harvest of 1 kg (TR)	0.2	0.2	0.2
Harvest of 1 kg (CA)	0.033	0.059	0.006
Starting value more fertile soil *(Old floodplains/*mopane-*stands)*	212	143	396
Starting value less fertile soil *(Kalahari sands)*	222	58	99
Starting values in initial modelling period	82	145	330

Source: TFO's soil scientists (unpublished data).

The lower bound of soil fertility & the effect of fallow on soil fertility

Note: Data on the relationship between fallow and soil fertility is unavailable. Thus, it also needed to be based on theoretical values. These values were developed in cooperation with soil scientists and based on empirical measurements: The results of the farming system analysis of Mashare, Namibia, indicated that smallholder production may have stabilized at a very low equilibrium of soil fertility and yields (chapter 1.6.2). This finding is used here to approximate the effect of fallow on soil fertility as well as the lower bound of soil fertility: In order to conservatively estimate the lower bound of soil fertility, one Standard Deviation (i.e. 83 kg/ha) was subtracted from the mean yield level of 127 kg/ha for no-input agriculture (TR None) in Mashare - leading to 54 kg/ha. It was then assumed that natural mineralization over the dry season (where fields are left in seasonal fallow) provides sufficient nutrients to at least produce these 54 kg/ha. Building on the soil fertility index (where a value of 100% implies that 500 kg of maize can be produced), a minimum harvest of 54 kg/ha implies a lower bound of soil fertility of 10.8%.

In order to determine the impact of rainy season fallow, a second assumption was made: While dry season fallow maintains soil fertilities lower bound, it does not increase it. However, during the humid & warm rainy season, mineralization processes are assumed to increase considerably. Although it is likely that nutrients are partly leached, some will remain, e.g. bound in fallow vegetation (from where they are returned in the soil via de-bushing). Lacking empirical data, it is assumed that fallow (in the rainy season) increases soil fertility (i.e. all three nutrient pools) by 10.8 %. This assumption is of course an approximation and does not take into account non-linear effects between mineralization and fallow length (which might be caused e.g. by a gradual buildup of soil organic matter or increasing soil fauna activity). However, this value is a conservative and plausible estimation. Lacking empirical data, it was considered the best available option for modelling.

2.4.2 Determination of parameter levels for each household category

In both study sites (Seronga & Mashare), the model differentiates between two household wealth-categories. For each of them, different parameter levels on resource endowment are needed. The data source for determining these parameter levels are household surveys, farmer interviews and focus group interviews (described in chapter 1.5). As described in in the farming system analysis in part I of this study, the two farm-household categories were identified for each study site via cluster analysis – this analysis resulted in a group of relatively wealthy ox-owners and a group of relatively poor non-ox-owners (see below).
For each household category, individual parameter values on household resources and price levels were calculated. All price-parameters were then translated into US-Dollar for ease of comparison. The following chapter will re-introduce the descriptive statistics of each household category (Tab.2.4 and 2.5) and inform on how values for the non-modelled household activities were computed.

2.4.2.1 Family labour and land preparation

The pool of available family labour, i.e. the labour provided by household members only and not that of any hired external workers is based on the number of producers per household. Thus, the model considers only producer labour. The fact that some activities are partly carried out by dependents was taken into account in part I of this study, i.e. by reducing the demand for labour of an activity by the share or dependents involved in this task, usually either 33, 50 or 66 % (see the labour sections of chapters 1.6.1-1.6.3 for the rationale behind this calculation). The seasonal pool of family (producer) labour is calculated by multiplying the mean number of producers per household category with the mean number of days per season (based on smallholder statements on season length) and assumed ten labour hours per day (see also Hecht 2010).
The choice of considering only ten productive hours per day instead of all available daylight was based on the fact that neither personal hygiene nor the time needed for switching from one activity to the other (farming to leisure to casual labour) was included in the model. At the same time, a number of more than eight hours (which is often considered as a typical working day (e.g. Hecht 2010) per day was chosen as the activity of consuming leisure and meeting social and cultural obligations was included in the analysis of household resource allocation, which can be carried out in the low times during the day or in the evening. It has to be noted that it is highly unlikely that a household would actually allocate ten hours per day to agricultural activities, as working during under the hot midday sun is generally avoided.

However, field preparation was reported to sometimes take place early in the morning and late in the afternoon, thus theoretically allowing for a ten-hour labour day while still retaining a lengthy midday break.
From this seasonal pool of family labour, the mean labour demand of non-modelled activities such as natural resource use and animal husbandry has been deducted to calculate the amount of family labour available for allocating to leisure (& meeting social and cultural obligation), crop production and/or casual labour. The mean demand for labour from these activities has been reported in the site-specific analyses of part I of this study. By reducing the available labour poor by the mean demand per activity for Seronga, Botswana and Mashare, Namibia, the maximum amount of family labour included in the model is presented in Tab. 2.6.

Tab. 2.4: Mashare, Namibia - typical farm-household categories

		Wealthy Cluster	**Poorer Cluster**
Household size (Nr. of persons per HH)		7 (SD: 3.9)	6 (SD: 3.1)
Number of Producers (aged: 16 - 59)		3.1 (SD: 2.1)	2.7 (SD: 1.9)
Share of Producers on HH size		0.48	0.46
Gender of HH head (% of female HHs)		30	50
Average age of HH head		52	55
% of HH heads who finished sec. school or higher		11	9.5
% of HH heads who finished primary school		26	29
Sample size		99	156
Livestock ownership:			
Goats (average herd size of HHs)		9.6	2.0
Cattle (average herd size)		16	0.4
Cattle **(quartiles)**	25	2	0
	50	11	0
	75	20	0
	100	200	19
Ox-ownership (% of HHs owning the asset)		98	0
Use of Inputs (% of HHs using this at least sometimes):			
Fertilizer		3	0.6
Pesticides		1	0
Improved seeds		55	32
Manure		5	0.6
Mean annual cash-income (in US-$/HH/a)			
from Salary		1007	314
from Own Business		216	58
from Remittances		503	16
from Pensions		263	205
Mean annual cash income (US-$/HH/a)		**1,846**	**721**
Mean annual cash expenditures (US-$/HH/a)		**1,621**	**883**
Quartiles of annual cash income:	25	505	121
	50	868	535
	75	1,904	920
	100	15,848	3,396

Source: Author's design based on empirical data. Note: The two typical farm-households in Mashare, Namibia, resulting from a cluster analysis: a relatively wealthy cluster of ox-owners and a relatively poorer cluster of non-ox-owners. The fact that the poorer cluster has higher expenditures than cash income may be explained by high data variability or un-assessed cash income sources.

Tab. 2.5: Seronga, Botswana- typical farm-household categories

		Wealthy Cluster	Poorer Cluster
Household size (Nr. of persons per HH)		4.1 (SD: 2.3)	3.7 (SD: 2.1)
Number of Producers (aged: 16 - 59)		2.3 (SD: 1.6)	1.8 (SD: 1.3)
Share of Producers on HH size		0.6	0.53
Gender of HH head (% of female HHs)		34	73
Average age of HH head		54	48
% of HH heads who finished sec. school or higher		14	18
% of HH heads who finished primary school		42	36
Sample size		83	103
Livestock ownership:			
Goats (average herd size of HHs)		8	1.1
Cattle (average herd size)		21	1.1
Cattle **(quartiles)**	25	5	0
	50	12	0
	75	29	0
	100	200	12
Ox-ownership (% of HHs owning the asset)		98	0
Use of Inputs (% of HHs using this at least sometimes):			
Fertilizer		6	2.9
Pesticides		4.8	2.9
Improved seeds		77	77
Manure		7	1
Mean annual cash-income (in US-$/HH/a)			
from Salary		676	281
from Own Business		413	71
from Remittances		25	15
from Pensions		128	130
Mean annual cash income (US-$/HH/a)		**1,644**	**537**
Mean annual cash expenditures (US-$/HH/a)		**696**	**170**
Disposable annual cash income (quartiles):	25	235	0
	50	560	235
	75	1940	635
	100	1,4890	1,1224

Source: Author's design based on empirical data. Note: The two typical farm-households in Seronga, Botswana, are resulting from a cluster analysis: a relatively wealthy cluster of ox-owners and a relatively poorer cluster of non-ox-owners.

Tab. 2.6: Total family labour pool per household category of the LORB included in the model.

Family labour pool (in hours of producer labour)	**Dry Season**	**Rainy Season**
Mashare - Wealthy Households	2,916 hours	1,622 hours
Mashare - Poorer Households	2,842 hours	2,500 hours
Seronga - Wealthy Households	1,561 hours	1,654 hours
Seronga - Poorer Households	1,376 hours	1,371 hours

Source: Empirical data.

The issue of ox-ownership and land preparation

As presented in part I of this study, availability (or rather lack of) draught animal power (usually oxen) at the beginning of the rainy season is a main bottleneck for traditional agriculture in the LORB. To reflect this bottleneck, the time available for preparing a field under traditional agriculture is restricted to seven days in the model's baseline run. Afterwards, soil humidity is assumed to have decreased to such an extent that field preparation (ploughing & planting) cannot be carried out anymore.

The wealthier, ox-owning household categories in both study sites are assumed to have access to only one (1) oxen. Interviews revealed that family-owned oxen are not made to work more than eight hours per day. This means that for a period of seven days, the wealthy can invest a maximum of 56 hours into animal-traction based field preparation. Additionally, they can carry out manual field preparation labour (but not more than 7 days * 10 working hours per day * number of producers per household). This results in 129 hours in Seronga and 174 hours in Mashare. This concerns traditional agriculture. Under CA, field preparation is carried out in the dry season. It is thus not constrained by rainfalls and restricted to seven days. Alternatively, they can hire an additional draught animal (as described below for the poorer households).

The poorer households do not own draught-animals. They can choose to invest family-labour to prepare their land either under CA or under *manual* traditional agriculture. The maximum time of family labour they can invest is 101 hours in Seronga and 151 hours in Mashare. Alternatively, they can invest cash and hire draught-animals (including the animal owner, who carries out the work together with his animal). However, the amount of hired animal-based labour is drastically lower than that available from family-owned draught-animals. In reality, hiring oxen is possible only after the wealthier households have finished preparing their own fields. As household interaction is not modelled, it was assumed that hiring oxen is possible only after half of the period for field preparation has passed, i.e. only 3.5 days remain available. The mean daily working hours of hired oxen usually do not exceed five hours. Thus, even if an ox is hired, the poorer households can only invest 17.5 hours (3.5 days * 5 hours) into ox-based field preparation.

Labour for field preparation includes ploughing (carried out by the hired ox and ox-owner) and planting; both tasks are carried out at the same time, with one person following the oxen and planting directly in the fresh furrow. Thus, for every hour of hired ox-labour, both households need to invest a complementary hour of planting labour. This complementary labour can be carried out by both family and hired labour. Naturally, hired labour can also be used for manual field preparation, both under CA and TR. However, manual field preparation requires significantly more labour/ha than draught-animal based field preparation (see chapters 1.6.2 and 1.63).

2.4.2.2 *Casual labour, cash income and food income*

The issue of casual labour

Due to widespread market failures in labour markets, various constraints have been imposed on casual labour (both for hiring in and hiring out). First, casual labour in the model refers mainly to work carried out on someone else's field. Thus, demand for labour and employment opportunities are considerably lower in the dry season than in the rainy season, i.e. the growing period. This means that households can earn cash income from engaging in casual labour by invest a maximum of 100 hours of family labour in the dry season and a higher maximum of 350 hours in the rainy season. Both values have been arbitrarily chosen to reflect imperfections of the labour market. At the same time, the amount of labour that can be hired in has been constrained for the rainy season to 50 hours. This reflects higher demand for labour during this period and simulates a certain level of scarcity. Sensitivity analysis has been carried out for varying bounds on both variables.

Calculation of fixed cash income

The household survey provided data on regular monthly or annual expenditures as well as on the mean income of various cash income sources, such as "own business", "salary" (e.g. as bartender in a local bar) or "pension". Using mean stated values on income instead of observations naturally reduced the accuracy of the income variable. For example, by deducting the mean annual expenditures from the mean annual cash income, the poorer cluster in the Namibian study site was characterized by a negative amount of "annual disposable cash income" of -190 US-$, while the Botswanan study site had a slightly positive amount of 170 US-$. The finding of Namibia implies that either the stated values are incorrect or that households may rely on other income sources (sales of goats or poultry) for their survival. To facilitate the analysis of the model results, it was assumed that for the poorer household categories in both study sites, annual regular expenditures and income from non-modelled activities equaled out and that there was no fixed annual cash income. For the wealthier household categories the mean value of "Annual disposable cash income", i.e. 224 US-$ in Mashare and 696 US-$ in Seronga, equally divided on both seasons, could be used. It was calculated by subtracting "Mean annual regular expenditures" from "Mean annual cash income". Thus, the fixed seasonal cash income included in the model is 0 per season for the poorer household category and for the wealthier households 112 US-$ (Mashare) ad 348 US-$ (Seronga).

Calculation of fixed food income

The fixed food income of all household categories was calculated by translating the mean seasonal (dry- and rainy season) harvest of edible natural resources into kcal and by adding them up for each category in each study site. As yield-data on milk were missing in Seronga, those of Mashare were used as proxies for the milk-harvest of wealthier households.

The value for the mean harvest of natural resources per household category and season was derived by focus groups and thus represents a consensus of the mean value that all focus group participants could agree on. Furthermore, to facilitate the analysis of model results, it was assumed that all natural resources are consumed domestically and not sold on the local market. This assumption is justified because the amount and income derived from commercial use of natural resources (e.g. the few "thatching-grass entrepreneurs" of Mashare, Namibia) was excluded from this value and instead considered as part of the cash income source “own business”. The value for mean natural resource harvest (in the strict sense) relates to all households in each study site, i.e. it does not differentiate between wealthier and poorer households. However, to be able to take into account the wealth differences, the mean fixed food income of the wealthy category was extended for food income derived from cattle husbandry. Because cattle are rarely slaughtered, this includes only the mean harvest of milk derived from the activity “milking livestock”.

Tab. 2.7: Mean annual kcal-income obtained from milking by wealthy HHs *in Mashare*

Source of kcal	Seasonality	Total kcal-harvest	Dry Season (kcal)	Rainy Season (kcal)
Milking livestock	Rainy season mainly	646,600 kcal	49,142	597,458

Source: focus group data multiplied by mean energy content of 3.8% milk (USDA 2016).

Tab. 2.8: Mean annual kcal-income from natural resource use *in Mashare*

Source of kcal	Seasonality	Total kcal-harvest	Dry Season (kcal)	Rainy Season (kcal)
Fishing*	All year	18,240	9,120	9,120
Harvesting wild fruits/nuts/vegetables**	75 % dry season 25 % rainy season	1,179,744	884,808	294,936
Collecting *Mopane*-worms (insects)***	Dry season only	157,320	157,320	0
Sum			**1,051,248**	**304,056**

Sources: * focus group data multiplied with mean meat weight of 0.5 kg/fish & transformed into kcal via mean kcal content of *Tilapia* (the dominant fish species), taken from Mjoun & Rosentrate (2010); **focus group data multiplied with mean energy content reported by Murray et al. (2001); *** focus group data (per bucket) multiplied with mean mopane-weight-per bucket from Gondo et al. (2010) and mean kcal content per kg/*lepidoptera* in Schabel (2006).

Tab. 2.9: Mean annual kcal-income from natural resource use *in Seronga*

Source of kcal	Seasonality	Total kcal-harvest	Dry Season (kcal)	Rainy Season (kcal)
Fishing*	All year	48,000	24,000	24,000
Collecting wild fruits/nuts/vegetables**	All year	565,966	282,983	282,983
		Sum	306,983	306,983

Sources: *focus group data on fish multiplied with mean meat weight of 0.5 kg/fish and transformed into kcal via mean kcal content of *Tilapia* (dominant fish species), taken from Mjoun & Rosentrate (2010); **Harvest amount of 128 kg/a from Mmopelwa (2009), multiplied with energy content reported by McAdrle & Katch (2009) of 18.5 MJ/kg and transformed into kcal.

Tab. 2.10: Mean seasonal kcal-income from non-modelled activities in the LORB in the model

Mean seasonal kcal-income	Dry season	Rainy Season
Mashare - Poorer household category	1,051,248	304,056
Mashare - Wealthy household category	1,100,390	901,514
Seronga - Poorer household category	306,983	304,056
Seronga - Wealthy household category	364,986	1,012,180

Source: Author’s design, based on computed values

Thus, the difference in fixed seasonal food income between both household categories is caused only by the kcal delivered from milking livestock. Again, to facilitate analysis, it was assumed that milk was consumed domestically and not sold at the market. As reliable data on the amount of milk produced per household was only available for Mashare, Namibia, this value was used to approximate food income from milk for the wealthy household category in Seronga, Botswana (Tab. 2.10).

2.4.2.3 Additional parameters in the model

Calculation of minimum food needs

The minimum seasonal food needs per household category (= Chayanov's acceptable minimum standard of living) was calculated by first multiplying the total number of persons per household-category with the mean season length in days (for the dry season, 200 days in Mashare and 184 days in Seronga vs for the rainy season 165 days in Mashare and 181 days in Seronga) and the daily minimum kcal requirements of an adult human (1790 kcal in Namibia vs 1830 kcal in Botswana (between 2004 and 2006, taken from FAO 2011). In a second step, the seasonal fixed kcal-income per household category was deducted from this amount. In the third and last step, the resulting seasonal demand for kcal was divided by the mean kcal-content of a kg of maize. This equation yielded the minimum level of agricultural production in kg (of maize equivalents) that a household has to produce per season. The resulting seasonal and annual food requirements of each household category are reported in Tab. 2.11.

Tab. 2.11: Minimum food consumption needs per household category per year.

Minimum *seasonal* food consumption needed to avoid undernourishment		**Dry Season**	**Rainy Season**
Wealthy Households	- Mashare	411 kg	341 kg
	- Seronga	286 kg	98 kg
Poorer Households	- Mashare	322 kg	423 kg
	- Seronga	264 kg	259 kg
Minimum annual food production needed to avoid undernourishment			
Wealthy Households	- Mashare	752 kg	
	- Seronga	384 kg	
Poorer Households	- Mashare	745 kg	
	- Seronga	787 kg	

Source: Empirical data.

Initial and maximum field size

The initial field size in the first modelling period is slightly lower than the mean field sizes reported in part I of this study (1 ha as compared to 1.5 – 2.5 ha). In order to represent a certain degree of land scarcity, maximum field size was determined to lie at 2.5 ha. Thus, apart from fallow periods and applying field inputs, soil fertility can also be increased by clearing a maximum of 1.5 ha over the modelling period. Scenario analysis will be applied to determine the effect of various field sizes on the optimal farming strategy and resource allocation of both household categories.

Discount rate

Choosing an appropriate discount rate is of considerable importance, as it: "... *measures the impatience of consumers, in the sense that consumption in the future is given less weight than consumption now* (Sadoulet & de Janvry 1995, 22)". The choice of an appropriate discount rate does not only reflect the impatience of smallholders for consumption, but also the risky nature of production. Under drought-prone conditions such as in the LORB, where an adverse rainfall year may have a negative impact on household resources and thus counterbalance the benefits of long-term investments in soil fertility, consumption now may seem preferable to future consumption and result in less frustration. Following Krusemann (2000), different discount rates are assumed for both household categories. Poorer households are assumed to be more concerned with meeting their immediate needs while the wealthier households have the resources and relative livelihood security to also consider the long-term effects of any management decision. Therefore, Krusemann (2000) used discount rates of 8%, 12%, 18% and 25% for different smallholder household categories in southern Mali, with 8% describing the wealthiest and 25% the poorest household categories. This study uses the same values for the discount rate, assuming 8% for the wealthy cluster and 25% for the poorer cluster. These relatively high rates reflect decision-making under risky production conditions insofar as consumption in the future is always rated lower than it would be for commercial farmers which operate under perfect markets. For example, Domptail (2011) uses a lower discount rate of 4% for her model of commercial ranchers in Namibia.

Seed storage

It is assumed that on average, 20% of all stored seeds cannot be stored over the dry season. This is the value reported for the case when seeds are stored in a raised little container which is placed upon 4 wooden posts. Farmers indicated that only households with access to animal traction construct these storage containers, as the manual transport of wooden poles from the forest to the homestead is otherwise to arduous. Alternatively, households store the seeds directly on mats on the ground and protect them from rain via an easy cover of natural materials. However, due to rain pooling on the mattresses and vermin or rodents accessing the seed, losses of up to 80% have been reported for this type of storage. In the model, the optimistic assumption is used that both household categories have access to the raised containers and that thus for both categories seed losses amount to 20%. Alternatively, seed can be purchased on the market at the beginning of the growing season, thus avoiding seed losses due to rot and pests.

Prices, starting values and cultivation options

Tab. 2.12 presents labour needs for field preparation and clearing under various production choices. Tab 2.13 indicates the mean demand for cultivation labour/ha and gives an overview of the costs and inputs needed for the various agricultural cultivation options[54]. Tab. 2.14 presents the starting values of main household resources, while the mean prices per unit of important variables are given in Tab. 2.15.

[54] To avoid confusion, the term cultivation system is avoided here because the main difference between the four traditional cultivation options lies in the choice of field inputs. In a narrow sense, there are only two farming systems, the traditional rain-fed systems (which could be further differentiates into semi-permanent and permanent cultivation) and Conservation Agriculture.

Tab. 2.12: Mean labour-demand of land preparation and land clearing in hours/hectare

	Dry Season		Rainy Season	
	Ox-based	**Manual**	**Ox-based**	**Manual**
Land preparation *under traditional agriculture* (hours/ha)	157	157	77	186
Land preparation *under CA* (hours/ha)	1,760	2,286	96	96
Land clearing (hours/ha)	415		0	

Source: Own data.

Tab. 2.13: Comparison of the mean demand for cultivation labour, inputs and cash of the five main cultivation options included in the model, per study site.

Cultivation options	**Mean labour needs cultivation** (hours/ha)	**Mean amount of manure applied** (kg/ha)	**Mean amount of NPK fertilizer applied** (kg/ha)	**Mean amount of seed needed** (kg/ha)	**Total costs of inputs (*wealthier HHs*)** (US-$/ha)	**Total cost of inputs (*poorer HHs*)** (US-$/ha)
TR None	191	None	none	15	0	0
TR Manure[1]	311	5,000	none	15	free input	94
TR Fertilizer	291	none	20	15	6.4 (Mash.) 9.6 (Ser.)	6.4 (Mash.) 9.6 (Ser.)
TR Both[2]	411	5,000	20	15	6.4 (Mash.) 9.6 (Ser.)	100.4 (Ma.) 103.6 (Ser.)
CA	664	15,000	500	25	160 (Mash.) 240 (Ser.)	443 (Mash.) 523 (Ser.)

Note: In the model, these differ also by season. [1]Assuming ox-based transport of manure, otherwise 391 hours/ha. [2] Assuming ox-based transport of manure, otherwise 491 hours/ha.

Tab. 2.14: Starting levels of important variables.

Starting levels of variables in the initial modelling period (in both HH-categories and study sites)	
Field size	1 ha
Cash endowment (= fixed cash income)	0 US-$ for poorer HHs in both study sites Seronga: 348 US-$/season for wealthy HHs Mashare: 112 US-$/season for wealthy HHs
Stored food for consumption	700 kg (maize equivalents)
Stored seed	50 kg (millet, needed for traditional farming) & 30 kg (maize, needed for CA)
Level of macro-nutrient **N**	82 %
Level of macro-nutrient **P**	145 %
Level of macro-nutrient **K**	330 %
Level of Soil Fertility (resulting from min. levels of nutrient pools)	82 %

Source: Own data.

Tab. 2.15: Mean variable prices

Prices per unit of variables	Price in Mashare, Namibia	Price in Seronga, Botswana	Source
Inorganic NPK fertilizer (2:3:2)	0.32 US-$/kg	0.48 US-$/kg *(assumed 150% of Mashare)*	Focus group
Cattle manure	0.019 US-$/kg (free for wealthy HHs)	*(assumed same as Mashare)*	Focus group
Seed (millet)	0.3 US-$/kg	0.8 US-$/kg	Focus group and expert interview
Seed (maize)	0.28 US-$/kg	0.7 US-$/kg	Focus group and expert interview
Casual labour *Dry Season* (hiring in & out)	0.06 US-$/hour	0.45 US-$/hour	Assumed as a fraction of rainy season - wage
Casual labour *Rainy Season* (hiring in & out)	0.19 US-$/hour	1.11 US-$/hour	Focused interviews
Oxen labour (hiring in)	0.75 US-$/hour	1.78 US-$/hour	Focused interviews
Farm gate price millet (= traditional farming)	0.31 US-$/kg	0.8 US-$/kg	Focus group
Farm gate price maize (= CA)	0.28 US-$/kg	0.7 US-$/kg	Focus group
Retail price maize flour	0.36 US-$/kg	1.00 US-$/kg	Supermarket
Price of a bus-trip to town	1.00 US-$/trip	1.00 US-$/trip	Assumption

Source: Own data. *Note*: A travel time of seven hours and travel costs of 1 US-$ have been assumed as necessary for purchasing every 50 kg of maize (This constraint reflects that fact that one person rarely carries more than a 50 kg bag and needs one day in the bus to go to town and come back).

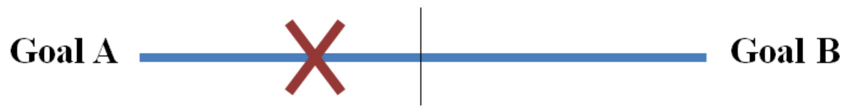
2.4.3 Fuzzy pair-wise comparisons for obtaining smallholders' preferences for various livelihood activities and leisure

An important side-goal of this study was to empirically assess the preferences of households for engaging in various productive activities or leisure as well as for achieving the respective outcomes related to these activities (i.e. consumption of food and leisure). These preferences will later be used in the bio-economic model for weighting the arguments of a household's utility-function. The empirical assessment is achieved via the method of Fuzzy Pair-Wise Comparisons as developed by Van Kooten et al. (1986). First, i) the theoretical foundations of this method, ii) the approach towards the computation of the empirical data as well as iii) the process of empirical data collection will be explained. Afterwards, the results of the fuzzy pair-wise comparisons will be presented.

2.4.3.1 Theoretical foundations

Van Kooten et al. (1986) contributed to the existing methodology on measuring farmer's goals and objectives by extending the traditional method of paired comparisons. In the traditional method, farmers were asked to compare various goal statements one pair at a time and to make a binary, "*all-or-nothing* (Van Kooten et al. 1986, 42)" choice between them, thus indicating absolute preference of one goal over the other. The authors extended this method by dropping the need to make a binary choice. Instead, they allowed respondents to indicate the degree of preference of one goal over the other and to even indicate indifference. Specifically, this means that respondents were confronted with two goals, e.g. A and B, which were located at the two extremes of a unit line, where the center of the line was clearly demarcated (Fig. 2.7). Respondents were then asked to make a mark on this line, with a mark on the center indicating indifference or equality of preference between the two goal and a mark closer to e.g. goal A indicating a preference of goal A over B. The closer this mark was placed towards the endpoint A of this line, the more was goal A preferred over B.

Fig. 2.7: A fuzzy approach for making pair-wise comparisons between goals A and B



Source: Author's design based on Van Kooten et al. (1986). Note: In this example, the red mark above indicate a slight preference of goal A over B.

A measure of the intensity of preference for goal A over B, $r_{AB,}$ is 1 minus the distance from the mark to the A, with total distance between A and B being 1 (Basarir & Gillespie 2007). Whenever $r_{AB} < 0.5$, B is preferred over A and whenever $r_{AB} > 0.5$, A is preferred over B. In case of $r_{AB} = 0.5$, the farmer is indifferent to both goals. Absolute preference for one of the goals, r_{AB} is characterised by a value of either 1 (B absolutely preferred over A) or 0 (A absolutely preferred over B) (Van Kooten et al. 1986, Basarir & Gillespie 2007).

For the identification of preference values, the following approach can then be applied: In case of *n* goal statements, there are *n**(*n*-1)/2 pair-wise comparisons. For each paired comparison, a measure r_{ij} can be obtained that indicates the degree by which a respondent prefers alternative i over alternative j. The degree to which j is preferred over i can be measured by $r_{ji} = 1 - r_{ij}$. For each respondent, an individual fuzzy preference matrix R can be constructed with elements as follows:

$$R_{ij} = \begin{cases} 0 \;\; if \;\; i = j \; \forall \;\; i, j = 1, \ldots.., n \\ r_{ij} \;\; if \;\; i \neq j \; \forall \;\; i, j = 1, \ldots.., n \end{cases} \tag{2.31}$$

Following Basarir & Gillespie (2007), the method of Van Kooten et al. (1986) can be more clearly illustrated by presenting the i * j fuzzy preference matrix (R) such that:

$$R = \begin{bmatrix} 0 & r_{12} & r_{13} & . & . & . & r_{1j} \\ r_{21} & 0 & r_{23} & . & . & . & r_{2j} \\ r_{31} & r_{32} & . & . & . & . & . \\ . & . & . & . & . & . & . \; . \\ . & . & . & . & . & . & . \\ . & . & . & . & . & 0 & r_{i-1j} \\ ri1 & r_{i2} & . & . & . & r_{ij-1} & 0 \end{bmatrix} \tag{2.32}$$

where each element of the matrix is a measure of how much alternative i is preferred to alternative j and takes on a value in the closed interval [0, 1]. From the individual preference matrices, it is possible to calculate a measure of preference, *m*, for each alternative. For alternative j, the intensity of preference measure has been defined by Van Kooten et al. (1986) as follows:

$$m_j = \;\; 1 - \;\; \left(\sum_{i=1}^{n} \; \frac{r_{ij}^2}{(n-1)} \right)^{1/2} \tag{2.33}$$

which has a range of 0 to 1 with larger values indicating a generally larger preference for the respective alternative. Via examining the various preference measures, the alternatives (or goals) can be ranked from the most to the least important one.

2.4.3.2 Empirical data gathering

In order to take into account the risky nature of crop and livestock production in the research area, the alternatives included in the fuzzy pair-wise comparisons carried out within this study were not presented as more or less abstract goals. Instead, the alternatives where presented as important livelihood activities, each of which were related to a clearly defined output or goal, as well as time devoted to meeting social obligations or leisure (see below). The five activities included in this study are:

1) **Crop production**, with the primary goal of producing and consuming sufficient food for nourishing the family regardless of any negative effect on soil fertility.
2) **Livestock keeping**, including not just the benefits of consuming or selling the livestock but importantly and specifically also the benefits of owning a large cattle herd (see Hecht 2010).

3) **Natural resource use**, including hunting, gathering or fishing of any resource from the non-cultivated land. This includes both the use for domestic purposes as well as for cash-income generation. If carried out as a main business that aims solely at earning money this was excluded from this alternative and regarded as off-farm labour.
4) **Off-farm labour**, originally describing all activities explicitly aiming at earning cash income, such as casual labour and formal employment (but not crop sales). During the interviews, it was found that farmers tended to relate this activity almost exclusively to formal, white-collar wage-labour and therefore expressed a strong preference for this prestigious livelihood activity (contrary to less prestigious casual labour).
5) **Leisure and meeting social obligations**. This activity covers all those activities that a household may need to do to sustain itself and its position within the society, but not those activities that produce a directly measurable output. This activity therefore includes leisure time for relaxation or meeting friends but also meeting social obligation such as attending funerals or weddings. It did not include *Going to church*, as farmers might then have felt forced to attribute a much higher value to this activity than what would be realistic.
6) **Maintain and conserve your land**. In the face of declining land productivity and field sizes, farmers were expected to feel the need to invest labour for conserving their arable land in order to pass it on to their children. This task includes theoretical efforts at improving soil fertility, such as applying manure or conservation agriculture (CA). As most farmers were not aware of CA or alternative means of soil fertility management, and despite a lengthy explanation, it seems unlikely that they clearly understood the change in labour-allocation that these practices would typically entail. Therefore, this theoretical activity generally received higher preference than what farmers might actually be willing to do.

The interviewers presented each of these activities by showing a cardboard with photos of typical aspects of this activity (see Fig.2.8 as an example for two activities). These cardboards were placed at both end of the unit line for each single comparison and not just during the introduction, thus making it possible for illiterates to be constantly aware of which activities were compared to each other.

Fig. 2.8: Two of the cardboards used for introducing the compared activities

Source: Author’s design. Note: Depicted cardboards show the two activities *Participation in off-farm labour* and *Natural resource use*.

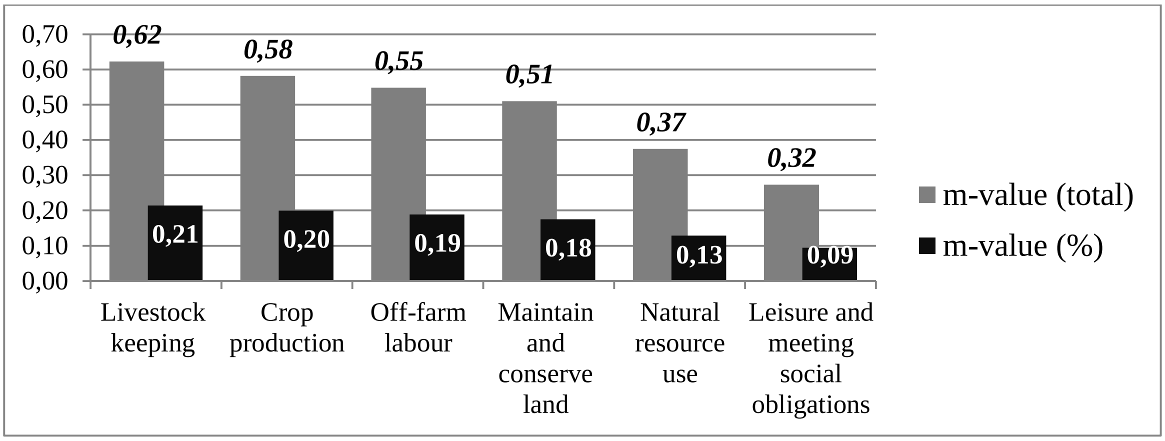
In each of the study sites, a preference-survey was carried out covering 67 households (47 in Mashare and 20 in Seronga[55]), randomly chosen and equally covering the two clusters of crop-producing households identified in part I of this study. A team of interviewers was trained for two days and one pre-test per interviewer were carried out in each of the core sites. The interviewers where trained to be able to explain the purpose of the research in general and of the preference-assessment in particular. An interview guide is available in Annex 2, yet interviewers were trained to use it mainly as a mental checklist and not follow it word by word. Like all other interview guides, it was translated into local language in each core site, yet the annex shows the English original version.
For the purpose of the interviews, smallholders were asked to imagine a year of nearly perfect rainfall, where crop and livestock production were performing as well as expected and hoped for and where smallholders would be able to reach most of their goals if they chose to invest resources and family labour into them. The rationale behind this was to ensure that throughout the exercise, smallholders would remain aware of production risk and thus formulate reasonable preferences that mirror their preferred but at the same time attainable livelihood strategies. After this introduction, the various activities and their related goals were presented to the respondents and they were asked to compare them with each other. As an introductory example, the interviewer presented a comparison of cooking and eating spaghetti bought in a shop versus cooking and eating pap, a local cereal-based food. This comparison made it easy to show farmers that they would not always want to carry out one activity, e.g. cooking spaghetti, but that it might actually be advantageous to consider both activities in a more differentiated way (and in this example to thus achieve a certain degree of food diversity). The same explanation was used for explaining to smallholders the meaning of their preference statements – the more time they would spend in an activity (represented by moving the mark closer to the activities end-point on the line), the less time they would be able to spend in the other activity and thus the less output this activity would generate.

2.4.3.3 Preferences of smallholders in the lower Okavango River Basin

Results of the fuzzy pair-wise comparisons are presented in Fig. 2.9 - 2.11. While the first two figures indicate the relative preference per study site for all activities mentioned above, the latter shows only the relative preferences for those activities which are included in the bio-economic model. Although this study will model only the activities *Crop production* and *Leisure*, these figures depict preference for all main household activities.
This helps to understand the relative importance of leisure and crop production in its livelihood strategy. Furthermore, it facilitates scenario analysis, e.g. in the case of assuming a household invests more of its labour into farming and less in other activities. In this case, the overview of all preferences allows to identify that activity of lowest preference and to assume that a household would reduce the labour invested in this activity (and thus also the output obtained by it) to increase his labour availability for farming or leisure. Therefore, both the complete preference list as well as that of only the modelled activities is presented here.

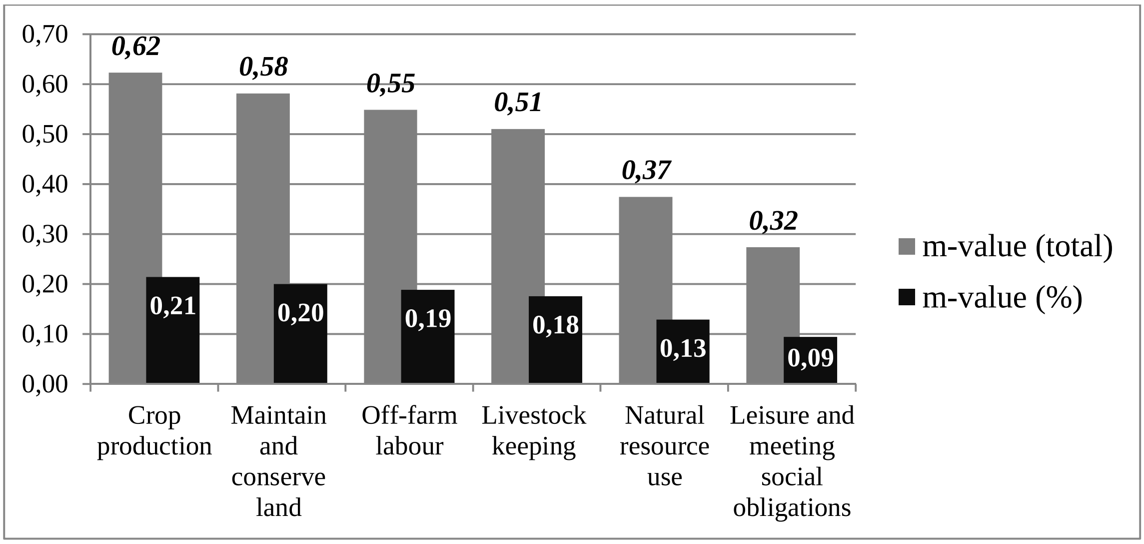
[55] Towards the end of the interview process in Seronga, serious doubts arose about the quality of the interviews conducted by one of the two field assistants. All of the interviews conducted by this assistant had to be excluded from the analysis. As there was no time to train an additional field assistant, only 20 preference-assessments are available for Seronga.

Fig. 2.9: Relative preferences of smallholders in Mashare for various HH activities



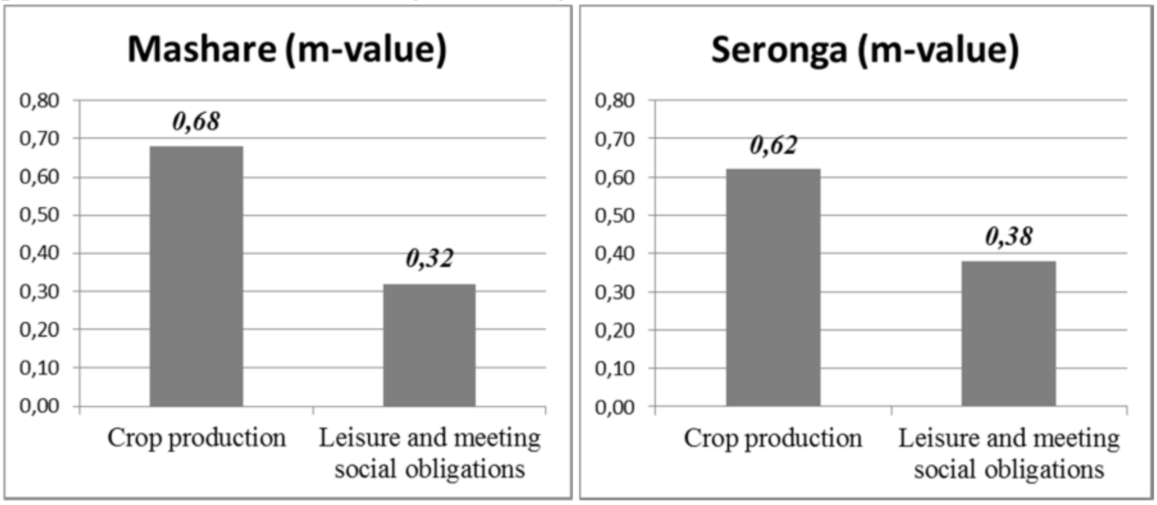
Source: Author's design based on empirical data. Note: ordered by decreasing preferences with the original m-value (grey column) and the m-value transformed into percentage for easier comparison (black column).

Fig. 2.10: Relative preferences of smallholders in Seronga for various household activities



Source: Author's design based on empirical data. Note: ordered by decreasing preferences with the original m-value (grey column) and the m-value transformed into percentage for easier comparison (black column).

Fig. 2.11: Preferences of smallholders in Mashare and Seronga for the modelled activities *Crop production* and *Leisure & Meeting social obligations*.



Source: Author's design based on empirical data.

2.4.4.3 Shadow wage rate as a proxy for the valuation of leisure

For an accurate valuation of time and leisure in the model, the opportunity costs (shadow price) of family working time need to be assessed. The model developed in this study is formulated as an optimization-model for a constrained objective-function which maximizes household's utility. For linear-programming (LP) problems, the GAMS-software would now automatically generate this shadow price and save it for each resource-variable under the label *marginal value*. However, this is not the case for NLP-problems. Here, no marginal value can be determined. Therefore, in order to derive a shadow price of family working time, the model had to be reformulated as a linear programming problem. In order to do so, the non-linear production constraint was reformulated as a choice between five discrete production practices with fixed yield-levels per ha.

- CA (yield of 921 kg/ha)
- TR None (yield of 158 kg/ha)
- TR Fertilizer (yield of 423 kg/ha)
- TR Manure (yield of 438 kg/ha)
- TR Both (yield of 459 kg/ha)

These yield levels are arithmetic means of per-hectare yields derived from combined yield data for both Mashare and Seronga. Therefore, they slightly differ from those presented in the site-specific analyses in part I of this study. With fixed yield levels per ha, the dynamic aspect of soil fertility management became obsolete and played no role in the linear model. Thus, the resulting marginal value only presents an approximation of the actual shadow price of family working time. The resulting shadow prices differ for each study site, each household category and each season. They are reported in Tab. 2.16. These values were generated in the linear formulation of the model and then used in the NLP-version of the model for the valuation of leisure in the objective function, i.e. the hours invested in leisure per household per study site per season were multiplied with the respective shadow price of family working time, or *shadow wage rate*.

Tab. 2.16: Shadow wage rate per study site, household category and season (in US-$)

		Mashare *(US-$ / hour)*	Seronga *(US-$ / hour)*
Wealthy HH	- Rainy Season	0.538	3.734
Poorer HH	- Rainy Season	0.236	1.640
Wealthy HH	- Dry Season	0.170	1.514
Poorer HH	- Dry Season	0.075	0.665

Source: Author's design based on model data.

2.5 Scenarios and Discussion

The following chapter presents the main results of an analysis based on models for five different scenarios in Mashare and Seronga (Tab. 2.17). In general, the model optimizes household strategies in regard to the decision variables presented before. For the sake of clarity, however, the results presented here will focus on the factors that induce or hinder sustainable intensification (which is seen here as synonymous to the adoption of CA).

Part I of the dissertation suggested that *Boserupian* intensification in the study sites occurs because of necessity, i.e. because traditional methods fail to provide for household needs. Therefore, the scenario analysis will either tighten or loosen important constraints on production (such as *land availability* or the *period available for traditional field preparation*) and analyse how this affects CA uptake by households. Because the various scenarios created a vast set of data, only most relevant results will be presented. Emphasis will be given to i) land allocation for production practices, ii) leisure and labour use and iii) achieved levels of soil fertility. Details on the use of cash are given only for the baseline run. In later scenarios, cash results are reported only in the case of drastic changes.

Scenario 1, the baseline run, will present the optimal solution for the current situation, i.e. under parameter levels described in chapter 2.4.2. **Scenario 2** analyses whether or not households are cash-constrained in their adoption of conservation agriculture (CA). It simulates the effects of a subsidy of 50% on the costs of CA. **Scenario 3** simulates a year of favourable rainfalls and simulates the effects of doubling the time for traditional field preparation. It also aims to analyse the role of CA under conditions that are more favourable for traditional farming. **Scenario 4** captures the effect that ongoing population growth has on individual households. It is assumed that, due to population growth, a part of each household's land has been given away to children and that no new land can be cleared anymore. This situation is captured in the model by setting initial *and* maximal land availability to 1 – 1.2 ha. **Scenario 5** analyses the role of CA in a situation that is assumed to be beneficial for its adoption. This scenario combines the subsidy for CA costs from scenario 2 (the pull-factor for sustainable intensification) with the reduced land availability from scenario 4 (the assumed push-factor for sustainable intensification).

Tab. 2.17: Tested scenarios

	Scenario description	**Short characterization**
Scenario 1	Baseline scenario	Includes parameter levels from chapter 2.4.2., run separately for a 1-field and 2-field version.
Scenario 2	Subsidizing the costs of CA	Input costs of CA reduced by 50%.
Scenario 3	Relaxing the time constraint on traditional field preparation	The time available for traditional field preparation is increased from 7 to 14 days.
Scenario 4	Increased land scarcity due to increasing population density	Sets the initial & maximum field size of Seronga to 1 ha and of Mashare to 1.2 ha & disables food purchases
Scenario 5	Combining Scenarios 2 & 4	A subsidy on CA costs is combined with the increased land constraint & disabled food purchases

Source: Author's design.

2.5.1 Baseline scenario

In the next paragraphs, the results of the baseline run of the model will be presented. This means that all parameters will be set to the parameter levels introduced in chapter 2.4.2. The main decision variables of the model household categories are i) the amount of time allocated to leisure vs. labour and ii) the choice of how much land is allocated to the five agricultural management options (traditional farming with various input combinations & conservation agriculture) and how much lies fallow. Before going into a deeper analysis of the optimal farming strategies and their main bottlenecks, the optimal levels of decision variables for each study site and household category will be presented.

Specification of the baseline scenario into two distinct analyses

It has to be noted, however, that the baseline scenario is separated into two distinct baseline runs and each of these two runs in analysed separately. The reasons for this will be presented below. These are the two model runs:

1) A first run where, in accordance with chapter 2.3, households are assumed to manage one single field and therefore one single pool of soil macro nutrients (i.e. what this study defines as *soil fertility*[56])
2) A second run where a household is assumed to have two fields and to therefore manage two distinct soil nutrient pools.

Both analyses provide useful insights into optimal household strategies: The first baseline run is the least constrained one. Here, management choices are kept flexible, and CA can be rotated with traditional agriculture on the same field. This is an important assumption because it allows households to use CA as a soil fertility management technique (The use of CA implies that HH always combine planting basins with 15 t of manure and 0.5 t fertilizer, it is a fixed technology package and no variation in inputs is possible). Thus, because CA is applied on the same field as traditional agriculture, both practices can benefit from the improvement of soil fertility.

This is a realistic assumption because the available data for CA allow only for modelling its positive short-term effects on soil fertility and yields in a linear way (which are caused by increased input use and improved water & crop residue management). Note: the experimental field plots are still too young to capture the long-term benefits of CA. Therefore, empirical data on these benefits is missing. It is therefore justified to use the existing data on CA in a first baseline run and regard CA as a proxy for any flexible and improved field management option. This allows for deducting first conclusions on constraints to farming and optimal farming strategies.

However, another goal is to model the actual role that CA can play in optimal farming strategies. In reality, CA cannot be easily rotated with traditional agriculture because this violates the CA principle of minimum tillage and negates its expected benefits for soils (such as increased soil organic matter or improved habitat for soil fauna – see chapter 1.6.4). Therefore, the second baseline run will be simulated. Here, the arable land of a household

[56] Reminder: Soil fertility is defined as an index where a level of 100% describes a nutrient pool sufficient to produce an equivalent of 500 kg maize yield. Accordingly, a soil fertility value of 300% would describe a nutrient pool sufficient to produce 1,500 kg of maize. The upper limit of soil fertility is assumed to be 800%, after which other factors (e.g. water, micro-nutrients) become more binding.

(and thus its soil fertility pool) was divided into two distinct fields: one field where only traditional agriculture[57] can be practiced and one field where only CA can be practiced. The implication of this is that CA cannot be used anymore to increase the soil fertility for traditional agriculture.
Both baseline runs have their merit, and together they provide valuable insights into constraints on farming and optimal farming strategies (they will for instance reveal that the option to combine traditional farming with CA as an improved method for soil fertility management can lead to very different optimal strategies than when kept on separate fields). Therefore, both versions will be presented here. However, in order to simulate the role of CA as realistically as possible, the following scenario analyses will be based on the two-field formulation of that model.

From a technical point of view, changing from the one-field to the two-field modification of the model was achieved by defining a new *set* called *field*. This set consists of the elements *CA_Field* (i.e. the field for conservation agriculture) and *TR_Field* (i.e. the field for traditional agriculture). Naturally, this set had to be added to all model variables for soil fertility, agricultural production, and land use. As an example, the variable *FieldSize(hh,t)* was changed into *FieldSize(hh,field,t)*. This implies that in the one-field baseline run, the field size was determined for each household *hh* and simulation period *t*. In the two-field baseline run, it is furthermore defined for each of the two fields *field*. This allows for a field-specific simulation of farm management and soil fertility. To ensure that land cannot be switched between the CA and non-CA field (which would turn CA again into a potential soil management practice for traditional agriculture), the area allocated to a field can only be increased, but never decreased. The impossibility to re-allocate land from one of the fields to the other is a simplification that of course does not hold in reality. In the model, it implies that any part of a field that is not cultivated in a specific simulation period is left fallow.

The next paragraphs will first present the *one-field* run for each study site and then show the main changes compared to the *two-field* run.

2.5.1.1 Study Site Mashare

Area allocated to the respective farming practices

Figs. 2.21 & 2.22 show the area allocated to the different farming practices by both household (HH) categories[58] as well as the achieved soil fertility levels. Additionally, Fig. 2.14 indicates the resulting total annual yield per category. The results show that the wealthy HHs manage to cultivate all available land in every simulation period and that fallows plays no role in their

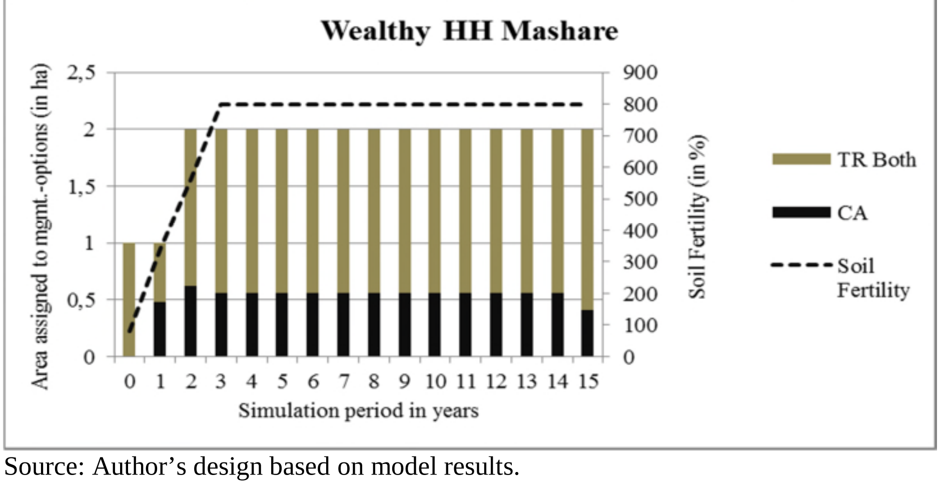
[57] Which includes the four input options i) traditional agriculture without input application (TR None), ii) traditional agriculture with inorganic fertilizer application (TR Fertilizer), iii) traditional agriculture with cattle manure application (TR Manure), and iv) traditional agriculture with application of both manure and fertilizer (TR Both).

[58] Reminder: A wealthy ox-owning category with a seasonal fixed cash income *vs.* a poorer category without fixed cash income and without ox ownership. In the model, it is not possible for the poor HH to purchase an ox and rise to the level of a wealthy HH. The wealthy have free and unlimited access to manure from their own holding, while the poor need to purchase it at the market. Manure is assumed to be always available; its production is not simulated.

optimal strategy. They rely on a stable ratio of 0.56 ha of CA and 1.44 ha of traditional agriculture using both manure and fertilizer (from now on called *TR both*). Before reaching this stable ratio, HHs boost their soil fertility level[59] by clearing all available land and increasing the area allocated to CA in the second simulation period. This results in a rapid increase in soil fertility up to its maximum level of 800%[60] in the third simulation period, upon which the stable ratio of CA to *TR Both* is achieved.

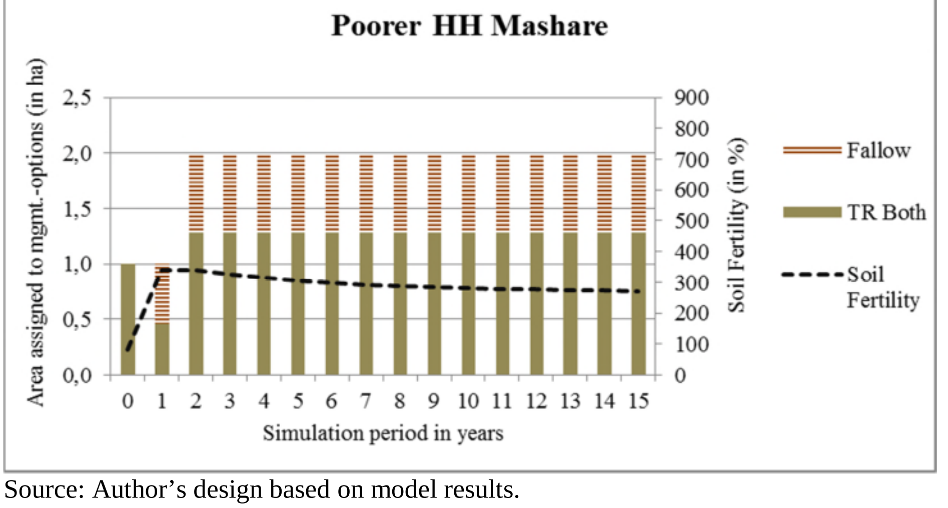
Contrary to the wealthy HHs, the poorer HHs rely exclusively on *TR Both*[61] (1.29 ha) and a relatively large fallow area (0.71 ha) (Fig. 2.13). A soil fertility peak is achieved in the third period, mainly via land clearing and low production levels in the previous, second simulation period. Afterwards, soil fertility gradually declines until the end of the modelling period.

Fig. 2.12: Area cultivated under different agricultural management options and soil fertility levels of the wealthy household category in Mashare, Namibia (1-field baseline scenario).



Source: Author's design based on model results.

Fig. 2.13: Area cultivated under different agricultural management options and soil fertility level of the poorer household category in Mashare, Namibia (1-field baseline scenario).



Source: Author's design based on model results.

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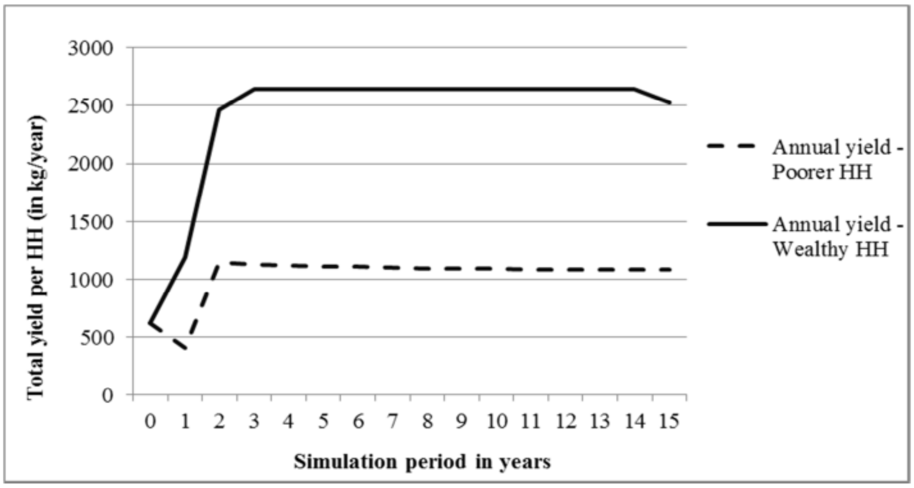
59 Reminder: Defined here as a household's nutrient pool of N, P, and K, which is increased by fallow, land clearing, and input application and decreased by harvesting.

60 Reminder: Beyond this level, it is assumed that other factors such as water or micro-nutrients become more limiting than the macro-nutrients N, P, and K. Following Liebig's *Law of the Minimum* (see Mitscherlich 1909), soil fertility increases are in this case no longer possible via the application of inputs.

61 Reminder: Defined as traditional agriculture using a fixed amount of organic manure (5 t) and inorganic fertilizer (20 kg) as inputs.

Fig. 2.14: Agricultural production levels of both household categories in Mashare.



Source: Author's design based on model results. Note: Output is measured in kg/year grain equivalents of *pennisetum glaucum* (pearl millet).

Leisure and labour use

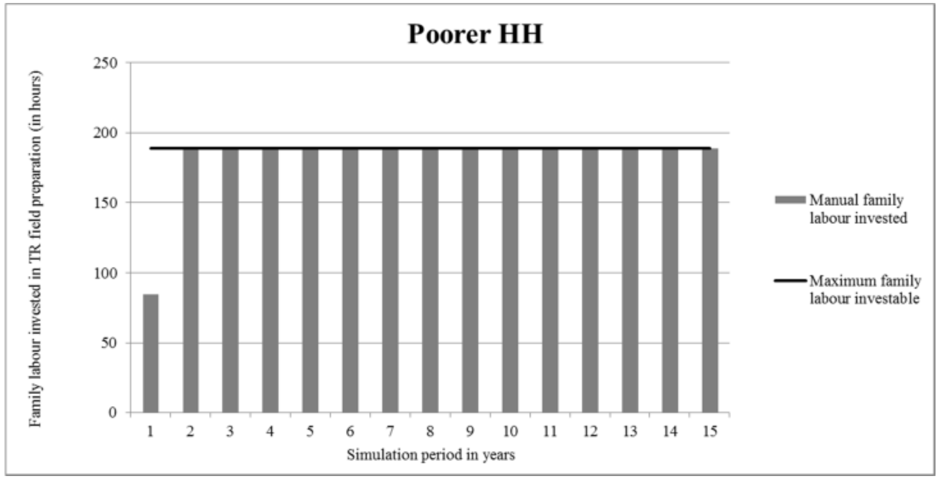
The poorer HHs use all available family labour and the maximum possible amount of hired labour for manual field preparation (Figs. 2.15 & 2.16). As they rely exclusively on traditional agriculture (Fig. 2.13), they are limited by the time available for traditional field preparation (i.e. seven days) and do not manage to cultivate more than 1.29 ha. As will be shown below, the poorer are constrained in cash income and rather invest it in inputs than ox-assisted field preparation, which allows for preparing more land in a limited time. However, it requires 66% more cash per hectare – 58 vs. 35 USD). This make it impossible for them to cultivate all available land (2 ha), and their level of agricultural production is constrained mainly by the time available for traditional field preparation. Their inability to cope with this seasonal peak in labour demand also results in a very high share of leisure on total available household time (Fig. 2.19): in most periods, it lies at 70% in the rainy season and 84% in the dry season.

The wealthy HHs use all available *ox-assisted* labour for traditional field preparation (56 hours of family labour and 35 hours of hired labour[62]) as well as some *manual* family labour (Figs. 2.17 & 2.18). Theoretically, they could invest even more manual labour into traditional field preparation, yet the remaining land is allocated to CA.

Interestingly, the wealthy invest almost no family labour into land preparation for CA. Instead, they delegate it to external workers (a total of 1,519 hours are hired, about 1,319 hours of which are invested in field preparation for CA during the dry season). This results in a situation where family labour contributes only 14% of the total labour invested in the dry season. In the rainy season, however, it contributes around 95% of all labour (although even here the maximum of 50 hours of hired labour is used). In comparison, for the poorer farmers, family labour contributes 100% in the dry season and also 95% in the rainy season. The main reason for this may lie in cash availability and the very low wage rate in the dry season, which makes it worthwhile for the wealthy to invest their regular cash income into CA and external workers. The poorer do not have a regular cash income and rely on traditional farming instead.

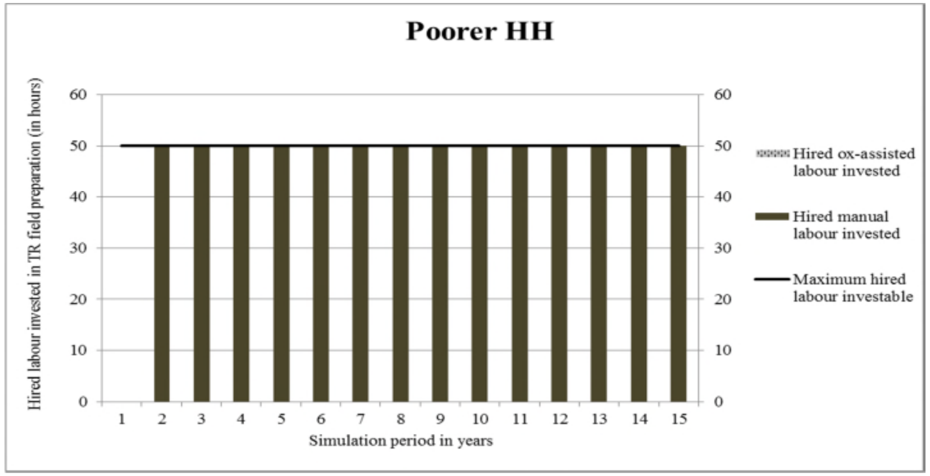
[62] This is the maximum time for ox-assisted hired labour. Together, ox-assisted and manual hired labour in the rainy season may not exceed 50 hours. This upper bound was chosen to reflect labour market imperfections.

Fig. 2.15: Family labour invested into field preparation under traditional agriculture by the poorer household category.



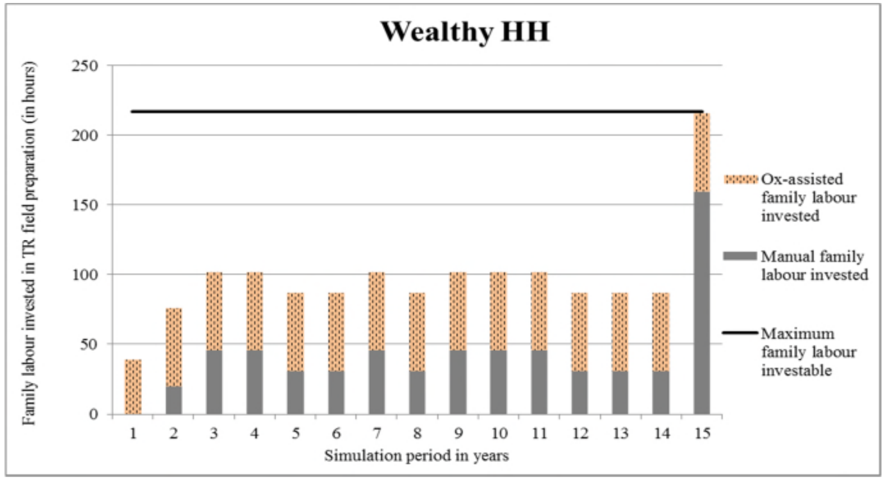
Source: Author's design based on model results.

Fig. 2.16: Hired labour invested into field preparation under traditional agriculture by the poorer household category.



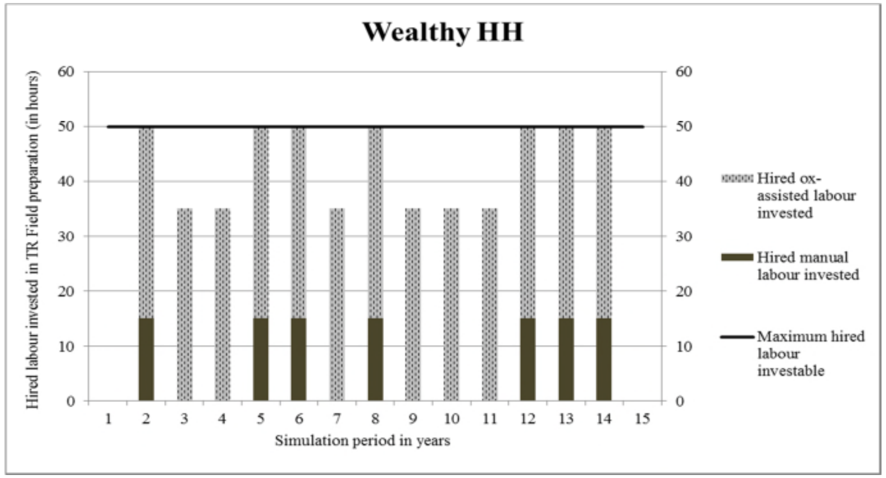
Source: Author's design based on model results.

Fig. 2.17: Family labour invested into field preparation under traditional agriculture by the wealthy household category.



Source: Author's design based on model results.

Fig. 2.18: Hired labour invested into field preparation under traditional agriculture by the wealthy household category.



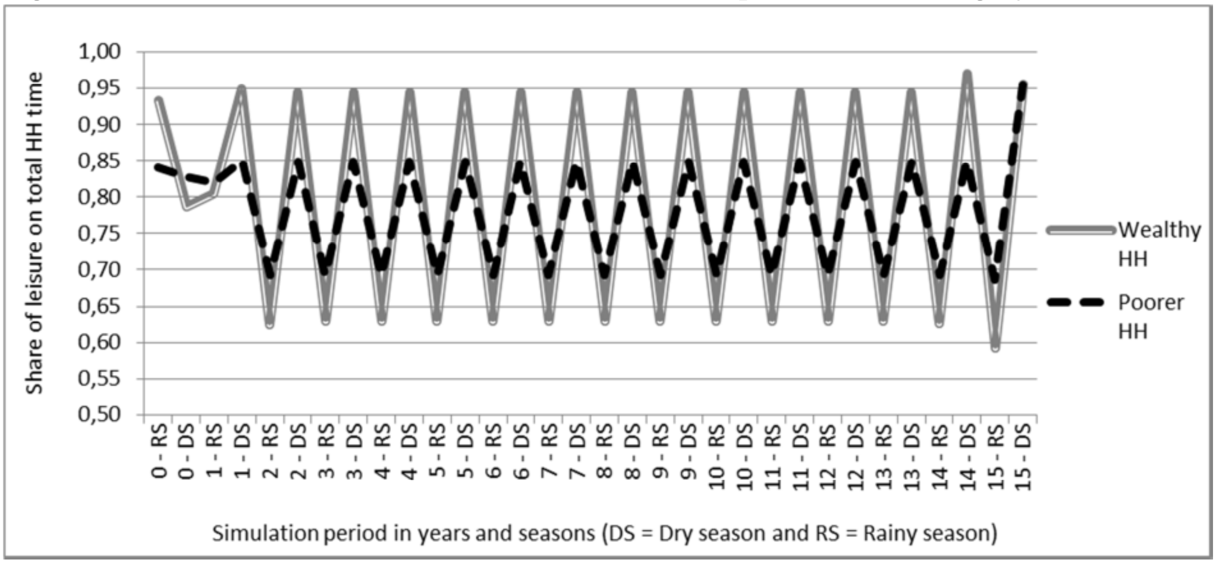
Source: Author's design based on model results.

The difference between both HHs in their reliance on external workers and CA leads to pronounced differences in their leisure levels. Fig. 2.19 presents households' ratios of leisure to total available household time per season and year. It can be seen that in an average dry season, the wealthy HH invest 95% of its available family time in leisure. In an average rainy season, this drops to 63%. This rather large seasonal difference is caused by the fact that most dry season labour is delegated to external workers, (which, due to the higher wage rate and lower upper bound, is not possible in the rainy season). At the same time, it appears that the wealthy are constrained by total land availability (2 ha), i.e. they are not able to invest more labour into farming because they cannot cultivate more land. Thus, they have no other option than to invest their time into leisure or casual labour (which the wealthy HHs only do in the last simulation period).

The poorer HHs achieve leisure levels of 85% in the dry season and 69% in the rainy season, which implies that they invest a relatively higher share of annual labour than the wealthy HHs. This is caused by four factors: first, the poor do not engage in labour-intensive CA; second, they dedicate a smaller area to farming (1.29 ha); third, they do not use external workers; and fourth, they invest as much labour as possible into casual labour.

In general, however, both households are characterized by very high leisure ratios. This can partly be explained by the high shadow wage of family labour, which provides a high level of utility for each hour invested into leisure. But more importantly, this reflects bottlenecks in crop production: the wealthy category cannot invest more because it is land constrained (using the entire available 2 ha), and the poorer category is constrained by the time for traditional field preparation. Therefore, the modelled households are not "lazy," but rather unable to invest more labour into farming.

Fig. 2.19: Ratio of leisure to total available household time per household category in Mashare.

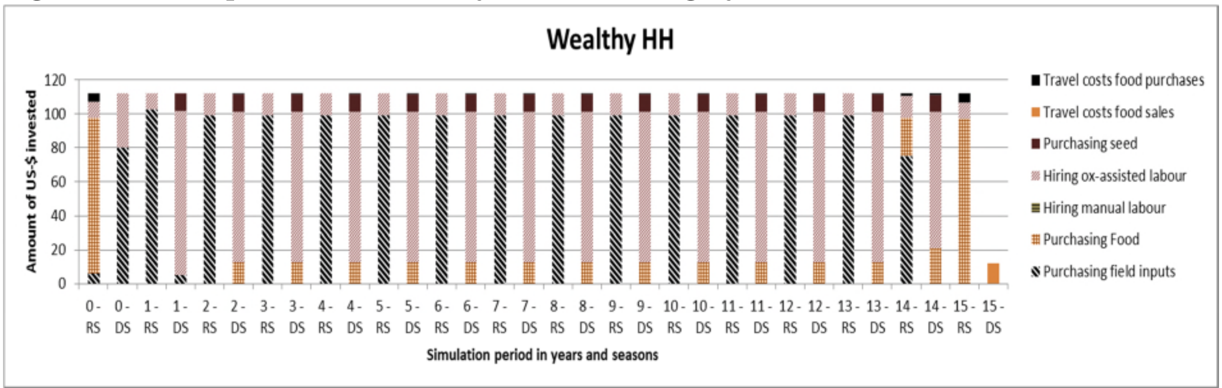


Source: Author's design based on model results.

Cash income and expenses

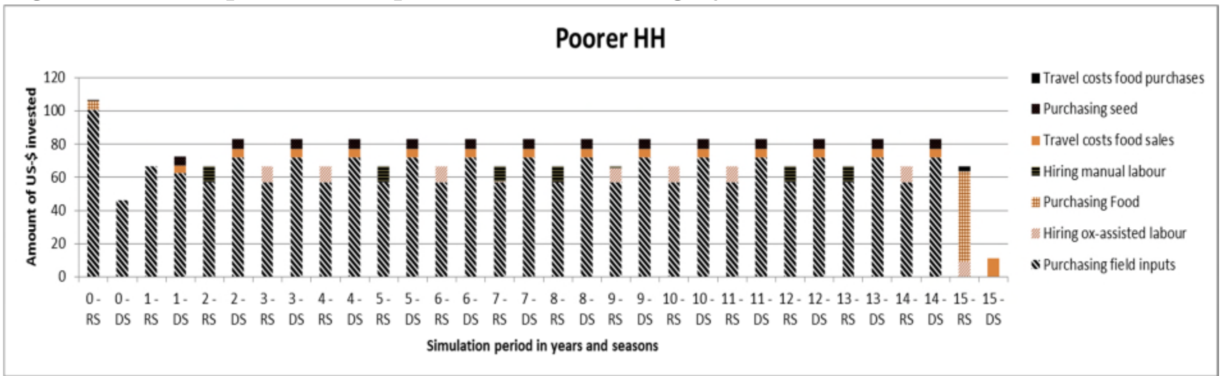
The wealthy HH category relies on its *fixed* cash income of 112 USD per season (i.e. the mean income stemming from non-modelled activities such as natural resource or milk sales, etc.). Although it could, it does not engage in additional income-earning activities. The poorer HH category on the other hand does not have any fixed cash income and has to earn it i) by investing family labour into casual off-farm work[63] (earning 67 USD in each rainy season and 6 USD in each dry season) and ii) via food sales (earning 77 USD every dry season). Both HH categories re-invest this cash to purchase inputs and (especially the wealthy) to hire labour (Figs. 2.20 & 2.21). To a lesser extent, the wealthy HHs invest cash into food purchases.

Fig. 2.20: Cash expenses of the wealthy household category in Mashare.



Source: Author's design based on model results.

Fig. 2.21: Cash expenses of the poorer household category in Mashare.



Source: Author's design based on model results.

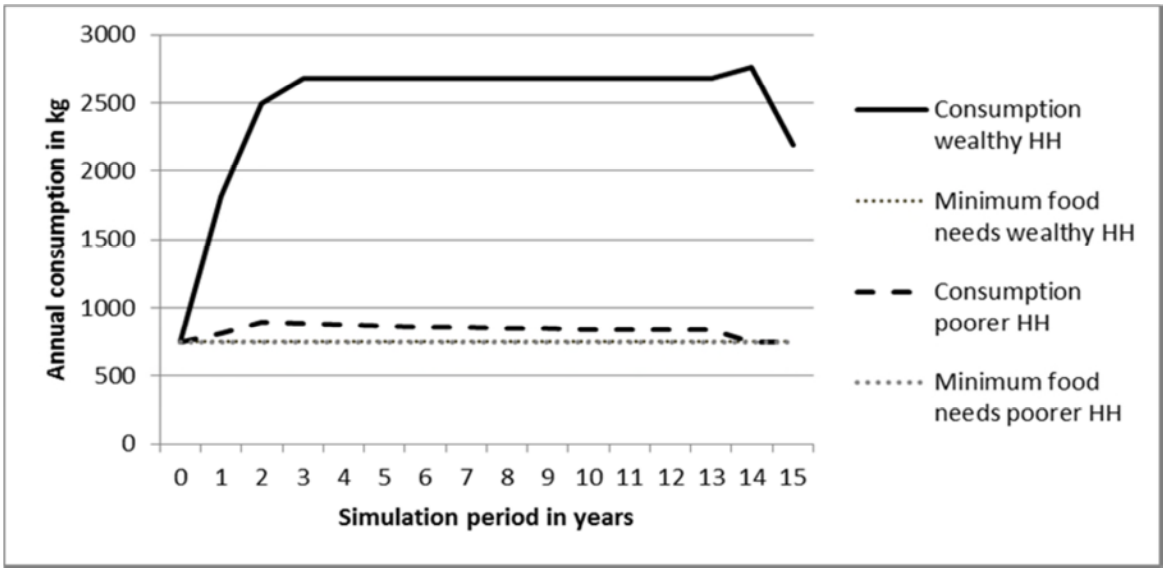
Achieved consumption levels

Although both households manage to consume more than their minimum consumption requirements, only the wealthy achieve consumption levels significantly above their minimum level (Fig. 2.22). Both households derive their food mainly from their own production, while only the wealthy supplement it to a very limited degree with purchased food (on average 35 kg, except for in the last and first simulation periods). The difference between both

[63] In fact, the poorer household category invests as much labour as possible into off-farm labour, i.e. to the upper bound of 350 hours in the rainy season and 100 hours in the dry season. Reminder: These upper bounds on engaging in casual labour were postulated to approximate labour market imperfections. They hold for both HH categories. Furthermore, both HHs earn the same wage rate per hour.

households' consumption levels stems from the fact that the poor cultivate only 1.29 ha using *TR Both*, while the wealthy cultivate 2 ha and rely also on land-efficient CA.

Fig. 2.22: Achieved levels of food consumption per household category in Mashare.



Source: Author's design based on model results.

This concludes the results of the first baseline run, which assumed that households can flexibly switch between CA and traditional agriculture on the same field. The next paragraph will illustrate the changes occurring in optimal household strategies in the second baseline run, where it is assumed that CA and traditional agriculture are always carried out on different fields.

Changes in optimal household strategies between the first and second baseline run

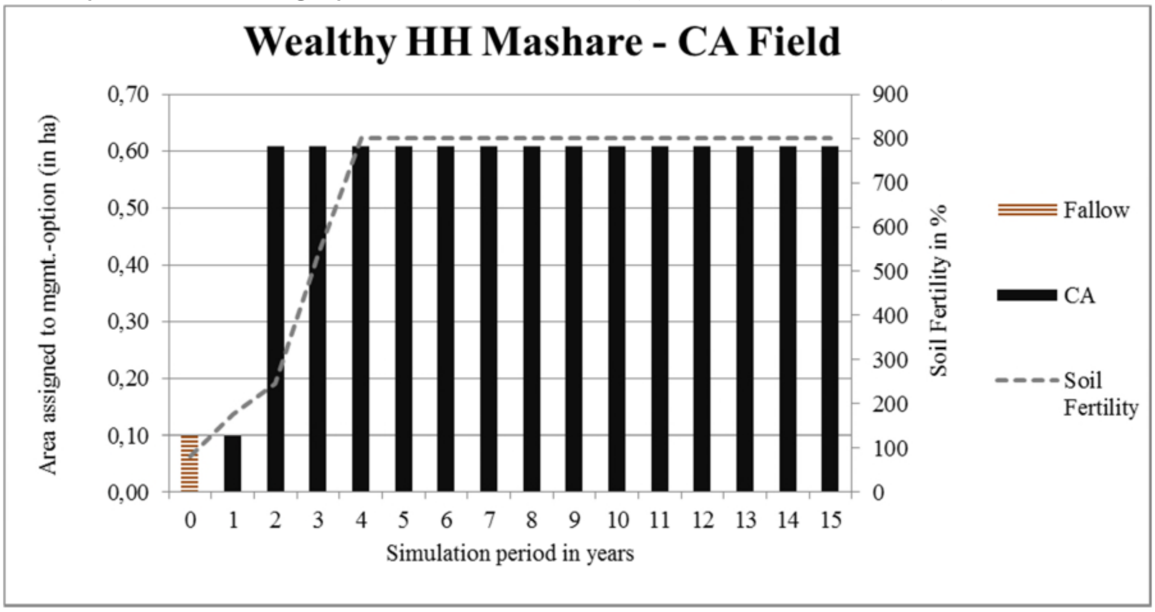
The only observed change between both baseline runs affects the wealthy HHs, i.e. those HHs that rely on both traditional agriculture and CA. Taking away the chance to rotate CA and traditional agriculture on the same field as a way to manage soil fertility induces a change in their optimal farming strategy: compared to the 1-field run, their share of land allocated to CA rises slightly from 0.56 ha to 0.61 ha. At the same time, the land allocated to *TR Both* decreases from 1.44 to 1.39 ha (Figs. 2.23 & 2.24). This seemingly small change leads to significant changes in soil fertility and a corresponding drop of about 400 kg/year in food consumption.

As expected, the two-field assumption has important implications for soil fertility management. This can be seen when comparing the soil fertility levels between both baseline runs: while the CA field quickly reaches its maximum soil fertility level of 800%, the traditional field achieves only a very gradual increase[64]. Its soil fertility value does not rise significantly over 400%, resulting in markedly lower yields for traditional agriculture than in the one-field scenario.

[64] The initial steep rise is again caused by field clearing, which adds the nutrients of fresh soil to the entire nutrient pool.

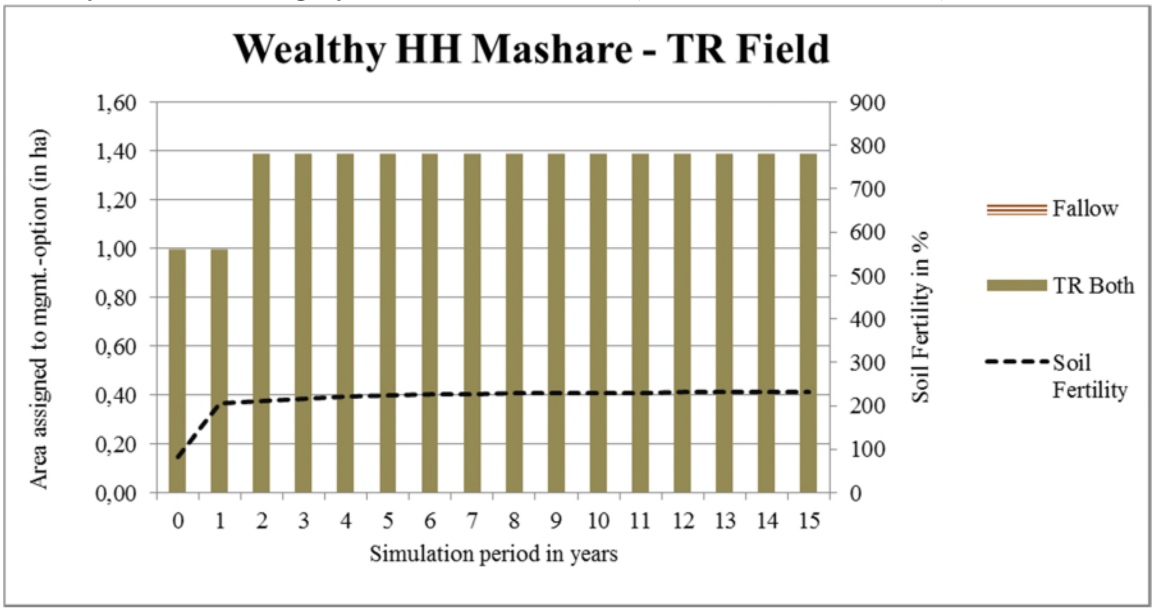
The two-field assumption has little effect on the labour and cash economy of the wealthy because the absolute change in land allocation is small. Moreover, the HH counters the decline in food production with increased food purchases, which might require it to engage in casual labour to generate cash income. In fact, the amount of cash invested in food purchases drops to zero in all but the first and last periods. The reason for it is that more cash is invested into hiring external workers for CA as well as purchasing manure and fertilizer (the use of CA implies that these two main inputs are always applied).

Fig. 2.23: Area cultivated and soil fertility level of the conservation agriculture field of the wealthy household category in Mashare, Namibia (2-field baseline scenario).



Source: Author’s design based on model results.

Fig. 2.24: Area cultivated and soil fertility level of the field for traditional agriculture of the wealthy household category in Mashare, Namibia (2-field baseline scenario).



Source: Author’s design based on model results.

Interpretation of both baseline scenarios for Mashare

Bottlenecks of agricultural production

In both baseline runs, households manage to exceed their minimum consumption requirements. Furthermore, each HH category is affected by one of the two agricultural bottlenecks identified in the farming system analysis: 1) land scarcity and 2) a shortness of the period for traditional field preparation.

The wealthy HH category is constrained by the maximum field size of two hectares. It is affected by land scarcity. Due to its ownership of draught animals, it manages to overcome the second bottleneck and always cultivates all available land.

The poorer HH category is constrained by the period for traditional field preparation. Although it invests the maximum possible amount of family and hired labour into manual field preparation, it does not manage to prepare the entire field of 2 ha, but only 1.29 ha. This leads to consumption levels that lie only slightly above the required minimum level, i.e. at around a third of what the wealthy category achieves. In fact, the poor HHs invest the maximum possible amount of labour into productive activities, i.e. casual labour and *TR Both* (which is the most labour-intensive traditional farming practice). Even if more family labour were available, they would have to invest it into leisure (or switch to CA). The following scenarios will analyse which parameter changes could induce its adoption.

Together, these bottlenecks result in a situation that can often be encountered in smallholder farming: the co-existence of a short period of high-labour inputs with long periods of apparent under-employment.

Not surprisingly, the analysis also revealed that the poorer HHs are constrained by cash availability. The only available cash sources in the model are casual labour and food sales. The poor invest as much family time as possible into casual labour and achieve some additional cash income from food sales. However, their marketable food surplus is too low to generate a large income. Scenario “2” will analyse whether or not reducing the input costs of CA can induce CA adoption.

Theoretically, conservation agriculture (CA) presents an option that could overcome the seasonal constraint of the poor. However, they did not adopt it in the baseline run. Instead, they used their cash to purchase the inputs required for traditional, manure and fertilizer-based agriculture. This allowed them to feed themselves on the small area they managed to cultivate. Scenario 2 will investigate whether a lack of cash is the main obstacle to CA adoption by the poor and if they can be encouraged to adopt it by reducing the input prices by 50%.

Soil fertility management

In both baseline runs, households used *field clearing* as early as possible to boost soil fertility. The poorer HHs then gradually depleted soil fertility it until it reached relatively stable levels towards the end of the modelling period. It appears that even if fallow land is combined with the use of manure and inorganic fertilizer, traditional agriculture alone may not be able to stabilize soil fertility at *high levels*.

This situation is different for the wealthy HHs. In the one-field baseline run, they quickly achieved maximum soil fertility levels by combining CA with *TR Both*. As this was impossible in the two-field run, the situation changes slightly; maximum soil fertility was quickly achieved on the CA field. On the field for traditional agriculture, soil fertility increases only gradually and remains at low levels between 200-230%. Contrary to the poor, the wealthy achieve increasing levels of soil fertility even under traditional agriculture and without the use of fallows. This may be explained by the fact that due to the lower soil fertility levels, the wealthier produce fewer crops per ha than the poor. Therefore, nutrient extraction by harvesting is lower as well. It appears that extraction in the second run is so low that it is balanced out by the nutrients applied via field inputs and that soil fertility gradually increases by a total of 30% over 15 simulation periods. As soil fertility increases, the yield per hectare and thereby the nutrient extractions also increase. At some point, extraction will exceed supply by inputs. The results for Mashare indicate that for *TR Both*, the equilibrium of nutrient supply and extraction may lie between 200% and 300% of soil fertility. This is equivalent to a nutrient pool sufficient to produce 1-1.5 t of maize/ha.

In the model, soil fertility is the only capital that households can build up and utilize in later simulation periods. The poorer HHs especially accumulate soil fertility in the first simulation periods and rely on this stock of natural capital in later periods (via gradual soil fertility depletion). In reality, households would have other options for investing their savings, e.g. in livestock. However, especially in Mashare, there is an on-going breakdown in the cattle economy, probably caused by overgrazing (see chapter 1.6.2). Therefore, it was decided that this investment option is too insecure to be included in the model. Thus, soil fertility was kept as the only means of accumulating capital. In the long run, the gradual breakdown of the livestock economy may in fact lead to a rising importance of soil fertility as a form of capital. The results presented here may then provide valuable insights into the optimal farming strategy of the poorer HHs.

It is important to note that the optimal strategy of the wealthy HHs relies on hired labour[65], which covers a large share of CA's labour needs, especially in the dry season. This is possible because compared to the rainy season, the dry season in the model is characterized by a reduced wage rate (assumed to be 1/3rd of the rainy season) and a higher upper bound on hireable labour (2,000 hours vs. 50 hours). The reason for these seasonal differences lies in the fact that in the research area, the dry season is traditionally a season where there are only a few livelihood options available. For example, as no farming is carried out during this time, there are only limited jobs available for casual labourers. This is a realistic assumption that describes the current situation in the study site. However, any large-scale adoption of CA can be assumed to increase the demand for labour in the dry season and at the very least lead to rising prices for casual labour. A sensitivity analysis will test how far changing wage rates may change this situation. For the baseline scenario, the current labour market situation of low wage rates and high labour availability in the dry season was assumed to persist.

[65] Reminder: In this and all following scenarios, both household categories can hire external workers at the official wage rate.

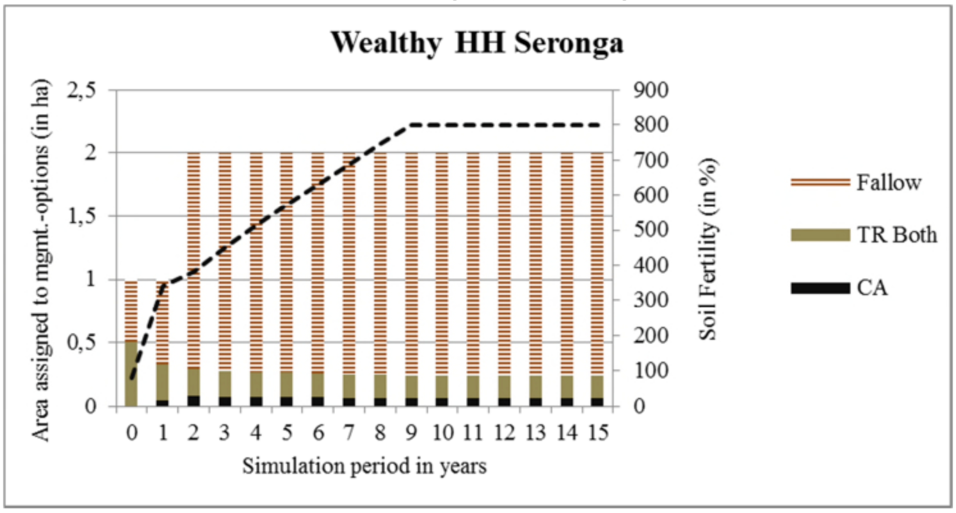
2.5.1.2 Study Site Seronga

In Seronga, both HH categories rely on farming only to a minimum degree. They feed themselves mainly via food purchases and produce only 200 kg of crops (grain equivalents of pearl millet) per year (the lower bound of production). The results indicate that arable agriculture presents an unfavourable livelihood option for Seronga's households.

Area allocated to the respective farming practices

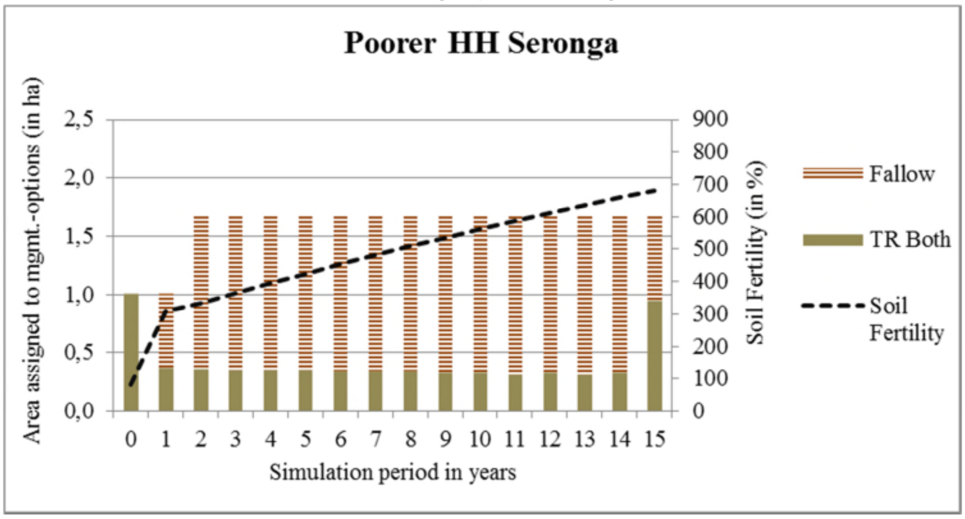
The wealthy HHs rely on both CA (on 25% of its cultivated area) and *TR Both*[66] (75% of the area) in the one-field baseline run (Fig. 2.25). However, total cultivated land is very small: about 0.18 ha are allocated to traditional agriculture and 0.06 – 0.07 ha to conservation agriculture, resulting in an annual harvest of 200 kg.

Fig. 2.25: Area cultivated under different agricultural management options and soil fertility levels of the wealthy household category in Seronga, Botswana (1-field baseline scenario).



Source: Author's design based on model results.

Fig. 2.26: Area cultivated under different agricultural management options and soil fertility levels of the poorer household category in Seronga, Botswana (1-field baseline scenario).



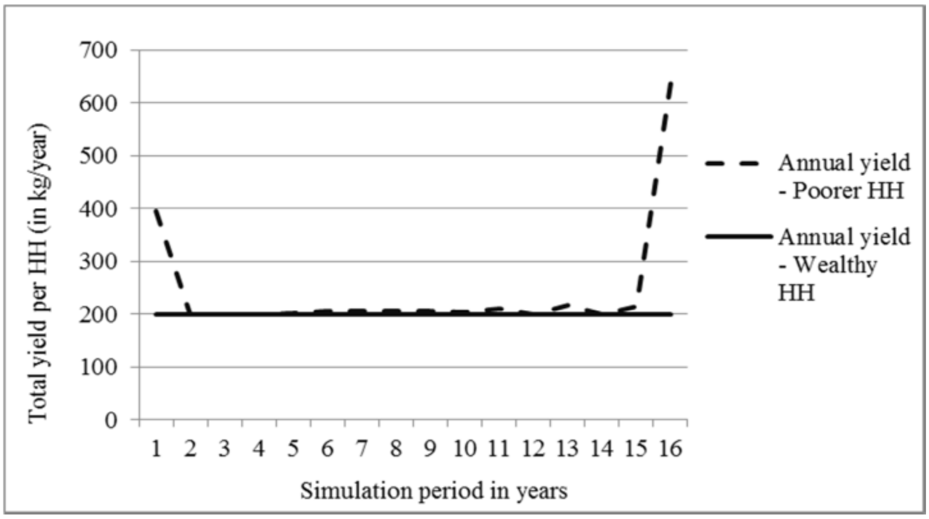
Source: Author's design based on model results.

[66] I.e. traditional agriculture using both 20 kg of inorganic fertilizer and 500 kg of animal manure.

The poorer HHs rely exclusively on 0.30 to 0.34 ha of *TR Both* (Fig. 2.26). This results in production levels slightly above 200 kg. Only in the first and last season of the modelling period does production rise to levels of around 400 kg & 640 kg, respectively. In the first simulation period, this is caused by the initial cash endowment of 40 USD/season (which allows for food purchases) and in the last simulation period by the farm continuation factor (see Chapter 2.4.4.2). During the other periods, it averages 205 kg/year (Fig. 2.27).

Both HH categories leave most of their field in fallow. Interestingly, they also clear all available land in the second simulation period. Together with the inputs applied by *TR Both* and the low harvest levels, this combination allows for achieving continuously increasing soil fertility levels.

Fig. 2.27: Agricultural production levels of both household categories in Seronga.



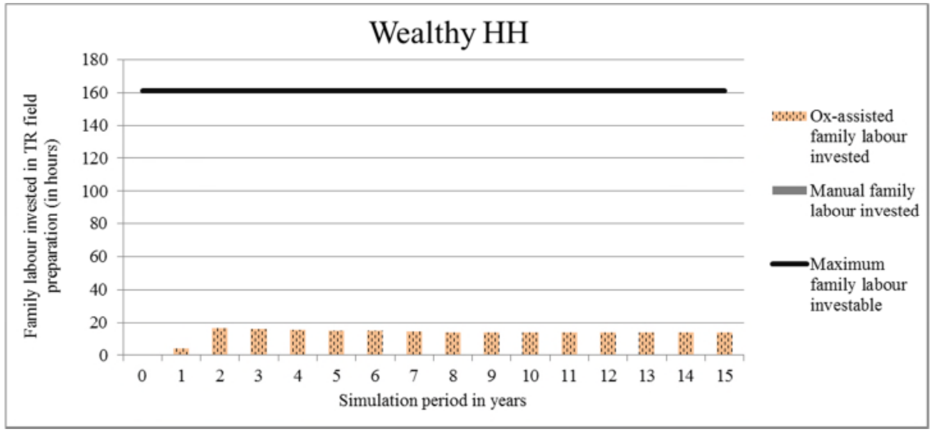
Source: Author’s design based on model results.

Leisure and labour use

Due to the low level of production, both households use only a fraction of their available time on arable agriculture. For traditional farming, the wealthy category relies purely on ox-assisted family labour (and ox-assisted hired labour in the second simulation period). The poorer category uses only manual family labour and both hired ox-assisted and hired manual labour.

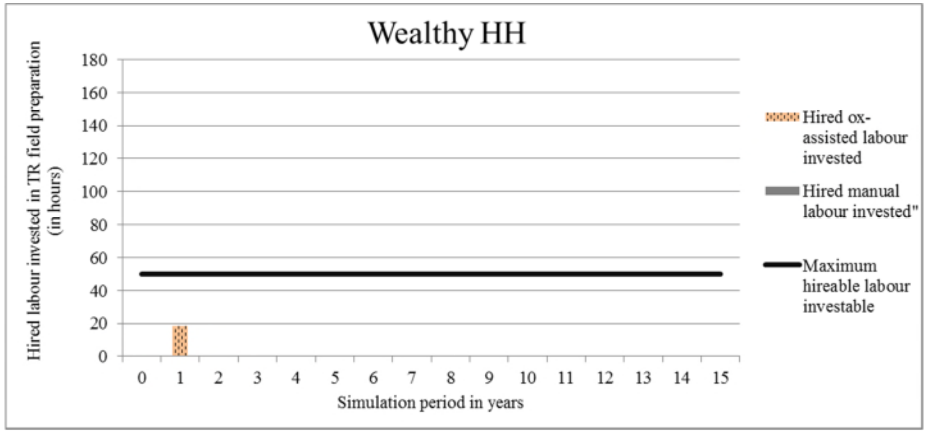
Similar to Mashare, the wealthy HHs do not engage in casual labour at all. This may be connected to their high fixed cash income (348 USD/season) and a very high shadow wage rate (3.70 USD/hour in the rainy season and 1.50 USD/hour in the dry season), which lies above the formal wage rate (1.11 USD/hour in the rainy season and 0.45 USD/hour in the dry season). The poorer do not have a fixed cash income and invest as much time as possible into off-farm work. The shadow wage rate of the poorer HHs lies above the formal wage rate, but less so than that of the wealthy (1.64 USD in the rainy season and 0.67 USD in the dry season). This confirms that the shadow wage is not the sole determinant of whether or not a household engages in off-farm labour.

Fig. 2.28: Family labour invested into field preparation under traditional agriculture by the wealthy household category.



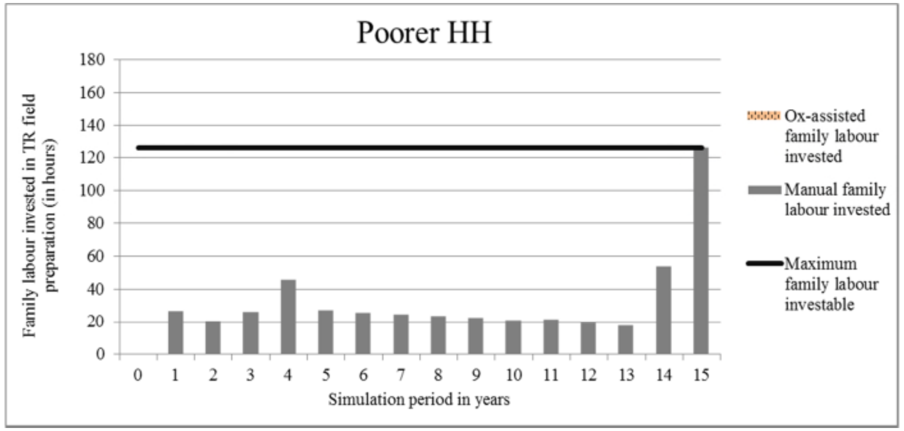
Source: Author's design based on model results.

Fig. 2.29: Hired labour invested into field preparation under traditional agriculture by the wealthy household category.



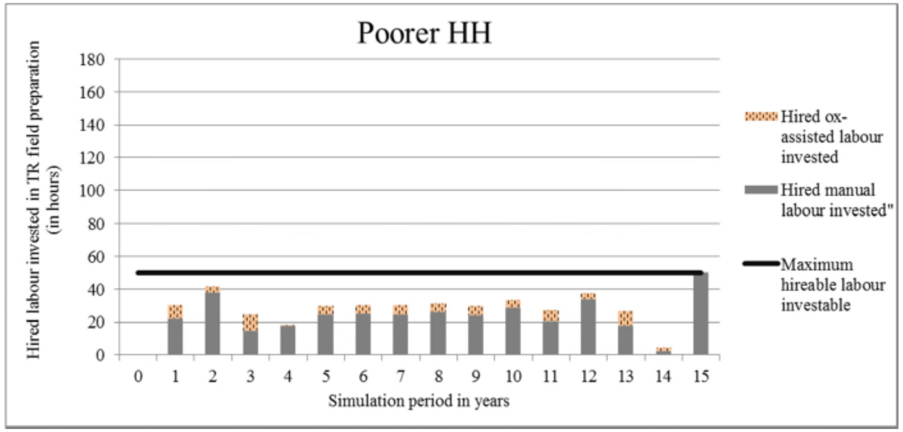
Source: Author's design based on model results.

Fig. 2.30: Family labour invested into field preparation under traditional agriculture by the poorer household category.



Source: Author's design based on model results.

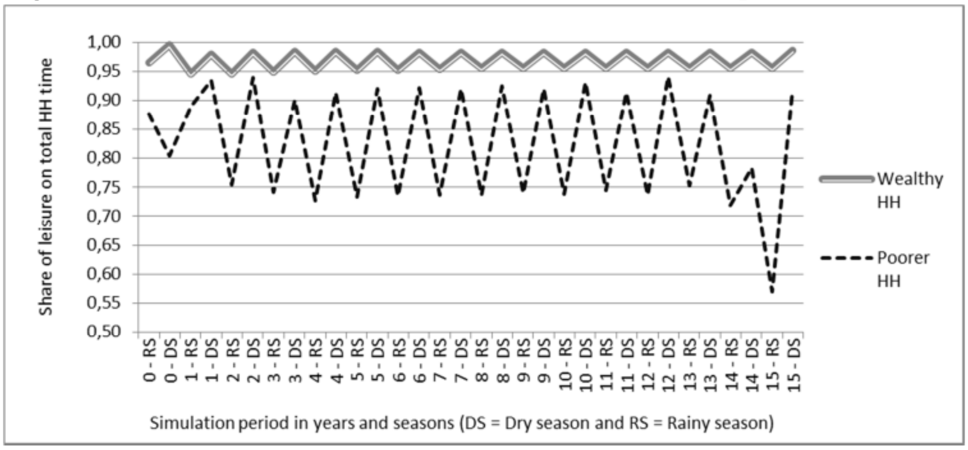
Fig. 2.31: Hired labour invested into field preparation under traditional agriculture by the poorer household category.



Source: Author's design based on model results.

The wealthy HHs especially delegate labour to external workers. For instance, they contribute only 17% of all dry season labour and hire the rest, i.e. 83%. In the rainy season with its tighter upper bound on hired labour (50 hours, all of which are hired), the share of family labour rises to 70%. The poorer HHs, on the other hand, delegate less work to external workers; in the dry season, their share of family labour on total labour drops to 70-80% and in the rainy season to 90-92%. This results in big differences between both HH categories in regards to their respective share of leisure on total household time (Fig. 2.32): for the poorer, leisure drops from just above 90% in the dry season to about 75% in the rainy season. Here, most traditional farm work is carried out within a short period. For the wealthy, leisure oscillates only to limited degree and remains in the high 90s, i.e. more than 90% of family time is invested into leisure. They achieve this high leisure rate by relying on external workers and CA (many tasks of which have to be carried out during the dry season when the wage rate of external labour is low). The poorer, on the other hand, rely on traditional farming and need to carry out most of their tasks in the rainy season (when external labour is more expensive). Due to the low importance of farming for both HH categories, their general leisure share must be regarded as very high. It is more optimal for households to consume leisure than to engage in agricultural activities (and in the case of the wealthy, in casual labour).

Fig. 2.32: Ratio of leisure to total available household time per household category in Seronga.



Source: Author's design based on model results.

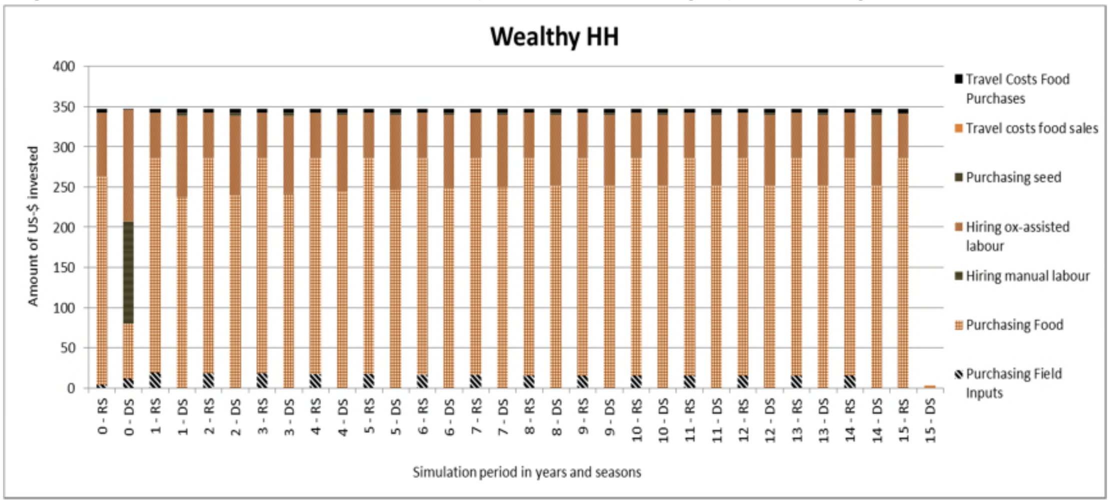
Cash income and expenses

In Seronga, the wealthy HHs rely exclusively on their fixed cash income (348 USD/season – see Fig. 2.33), which stems from non-modelled livelihood activities (the mean annual labour needs of which were deducted from the family labour pool before modelling). The poorer have no fixed cash income and generate most of it via casual labour (about 434 USD/year – see Fig. 2.34). Both households re-invest to a limited degree in field inputs and external workers. However, they mainly invest into food purchases (246 USD for the wealthy & 136 USD for the poorer).

Achieved consumption levels

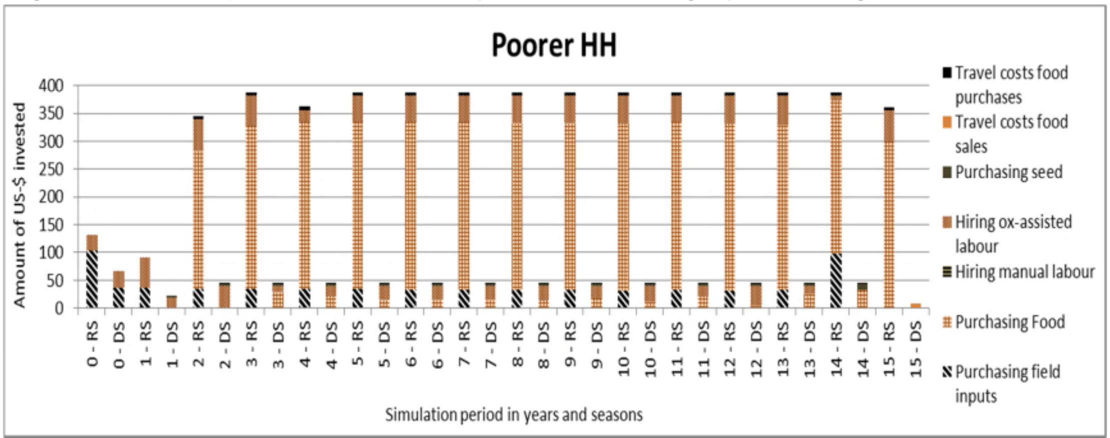
Both HH categories cover their minimum annual food needs not mainly via subsistence, but via food purchases; the wealthy purchase 71% of their food and the poorer 52%. The rest of the consumed food stems from agricultural production, which lies at around 200 kg/year for both categories. By following this strategy, the poorer HHs achieve only the minimum consumption level needed for their survival, i.e. 522 kg/year. The wealthier HHs, on the other side, achieve consumption levels of 167% of their minimum food needs, i.e. 692 kg/year (Fig. 2.35).

Fig. 2.33: Cash expenses of the wealthy household category in Seronga.



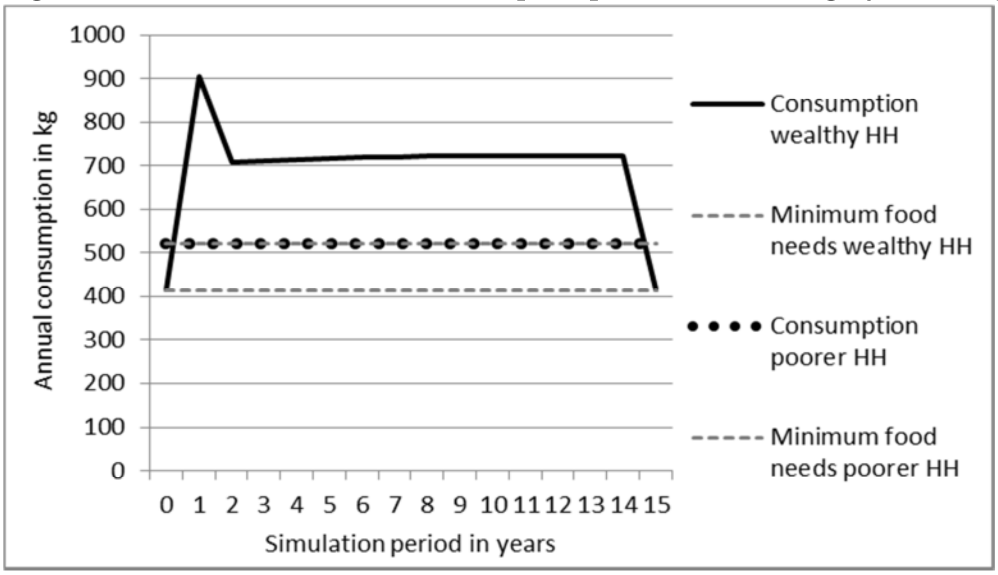
Source: Author's design based on model results.

Fig. 2.34: Cash expenses of the wealthy household category in Seronga.



Source: Author's design based on model results.

Fig. 2.35: Achieved levels of food consumption per household category in Seronga.



Source: Author's design based on model results.

Changes in optimal household strategies between the 1- & 2-field baseline run

For Mashare, the change between the two baseline runs was limited. Now in Seronga, creating separate fields for traditional farming and CA gives more interesting results. In the two-field baseline run, the wealthy abandoned CA completely and turned to a strategy of different traditional farming practices. In most simulation periods, they relied on traditional low-intensity agriculture (without input application). However, every few simulation periods they switched to *TR Both* or *TR Fertilizer* (i.e. traditional farming using only chemical fertilizer, Fig. 2.36). This allowed them to temporarily boost their declining levels of soil fertility. Still, they produced only about 200 kg/year. However, due to the lower yields of traditional agriculture, they needed to cultivate larger areas than in the one-field baseline run. In years of no-input farming, cultivated land covered 1.25 - 1.45 ha.
In both baseline runs, an initial boost of soil fertility was part of an optimal strategy. It was achieved by applying manure and fertilizer in the first simulation period as well as by field clearing. Interestingly, in the two-field baseline run, the wealthy did not achieve constantly increasing soil fertility levels. Instead, they turned to a cyclic management approach (Fig. 2.36), where longer periods of soil mining were interchanged with shorter periods of soil fertility replenishment (via the application of field inputs). Towards the end of the modelling period, soil fertility decreased continuously and fell from a maximum level of 410% to a minimum of 214% in the last simulation period.

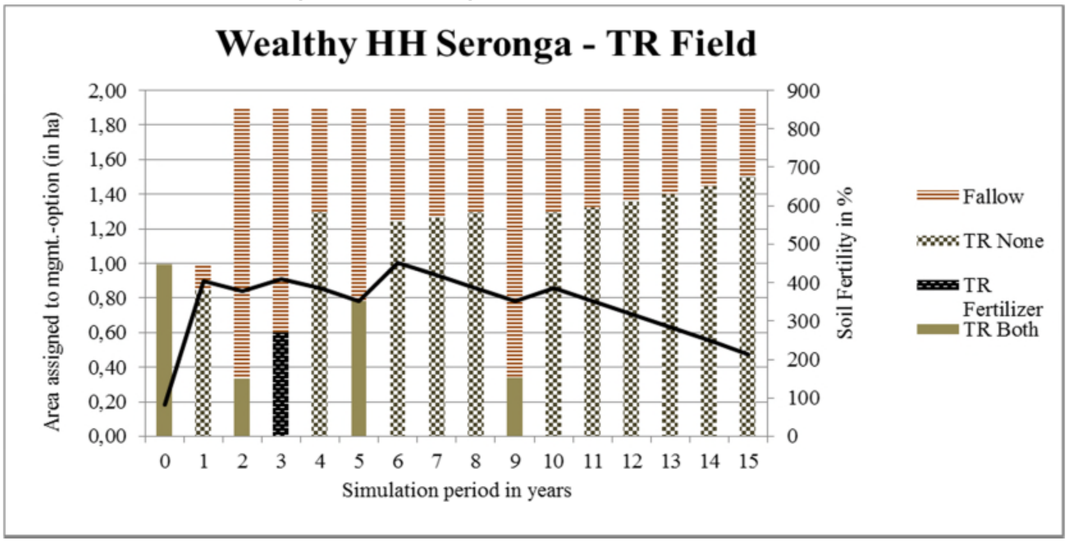
The optimal strategy of the poorer HHs changed as well (Figs. 2.37 & 2.38). They relied on CA as well as *TR Both*. However, instead of cultivating both fields at the same time, they always left one of their two fields in fallow. The benefit of this strategy is that the poorer achieved a continuous increase in soil fertility levels on both fields. However, due to the reduced size of the traditional field (it dropped from 1.68 ha to 1.23 ha), the fallow area was smaller as well, and its effect on soil fertility was less pronounced than in the first baseline-run. Its level rose less steeply and achieved a maximum of only 490% in the last simulation period, while in the one-field baseline scenario it reached 680%.

Naturally, the changes in optimal strategies affect both households' labour economy. However, due to the low importance of farming, the total share of leisure on household time can still be regarded as high for both HH categories.
The wealthy HHs switched from CA to traditional agriculture. Therefore, agricultural labour demand was highest in the rainy season and less pronounced in the dry season. Therefore, they stopped investing in cheap hired labour in the dry season and chose to carry out most agricultural work by using family labour in the rainy season. In order to produce a harvest of 200 kg via traditional farming (instead of CA), the wealthy were forced to cultivate a larger area than before. This increased total labour demand to a level of 152% of the one-field baseline run and reduced the share of leisure on household time. In fact, the new strategy even led to a more pronounced seasonality of labour use than in the one-field baseline scenario (Fig. 2.39). In most simulation periods, the wealthy coped with this seasonality by hiring all

labour available for traditional field preparation (Figs. 2.40 & 2.41). At the same time, they used all ox-assisted hired & family labour for traditional field preparation[67].

For the poorer HHs, the total labour demand rose as well, yet only to a level of 119% of the one-field baseline run. This increase was caused by the adoption of CA and occurred mainly in the dry season. The adoption of CA also resulted in a reduced area dedicated to traditional farming. Both trends resulted in a reduced oscillation of labour demand between the dry and the rainy season and led to reduced peaks of leisure in years where CA was practiced (Fig. 2.39). In the model, no credit was possible, and households relied exclusively on casual labour, food sales, and (the wealthy HHs only) on fixed income for generating cash income. Therefore, in order to purchase the inputs needed for CA, the poorer HHs reduced cash expenses for hiring external labour (expenses reduced to 59% of hours hired in the one-field baseline run). This reduction in hired labour was compensated by investing more family labour into farming.

Fig. 2.36: Area cultivated and soil fertility level of the field for traditional agriculture of the wealthy household category in Seronga, Botswana (2-field baseline scenario).

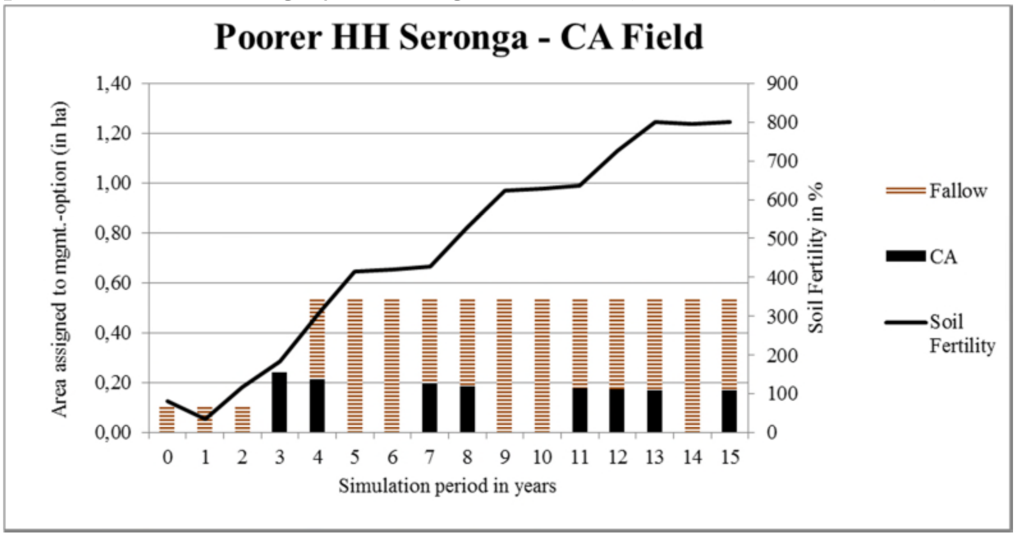


Source: Author's design based on model results[68].

[67] This shows that the reason why the wealthy hire fewer external workers in the two-field baseline scenario lies mainly in the upper bound on available external workers. This upper bound was implemented to reflect labour market imperfections in the study site.

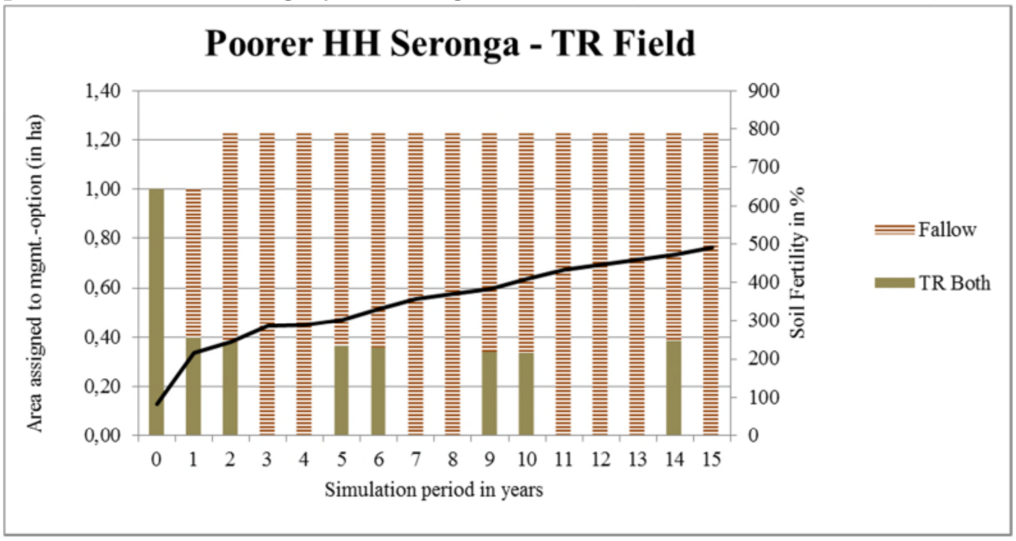
[68] Note that due to model specifications, the CA field cannot fall below an area of 0.1 ha. Therefore, total field size for traditional farming in the baseline run with two fields cannot exceed 1.9 ha. Sensitivity analysis was used to test that even under larger field sizes of 2.1 to 2.4 ha, the basic strategy of both household categories remained unchanged.

Fig. 2.37: Area cultivated and soil fertility level of the conservation agriculture field of the poorer household category in Seronga, Botswana (2-field baseline scenario).



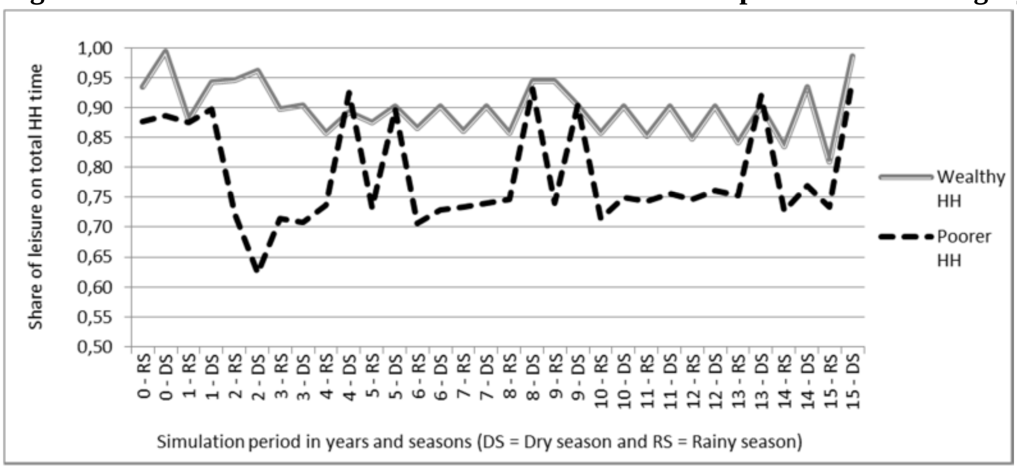
Source: Author's design based on model results.

Fig. 2.38: Area cultivated and soil fertility level of the field for traditional agriculture of the poorer household category in Seronga, Botswana (2-field baseline scenario).



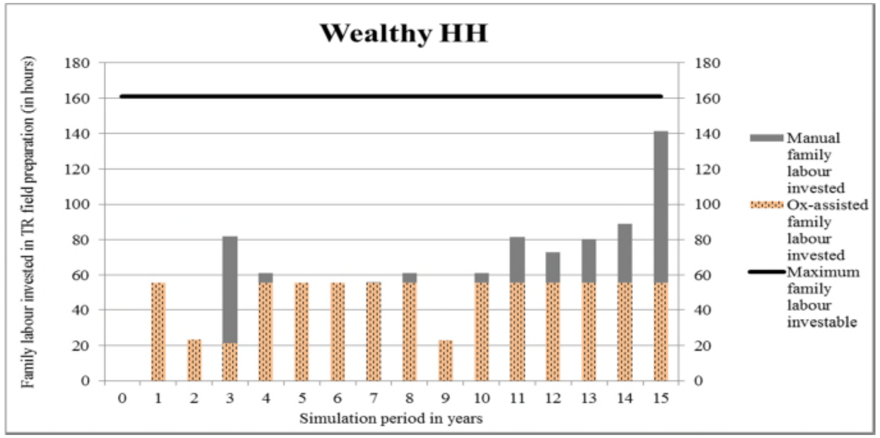
Source: Author's design based on model results.

Fig. 2.39: Ratio of leisure to total available household time per household category in Seronga.



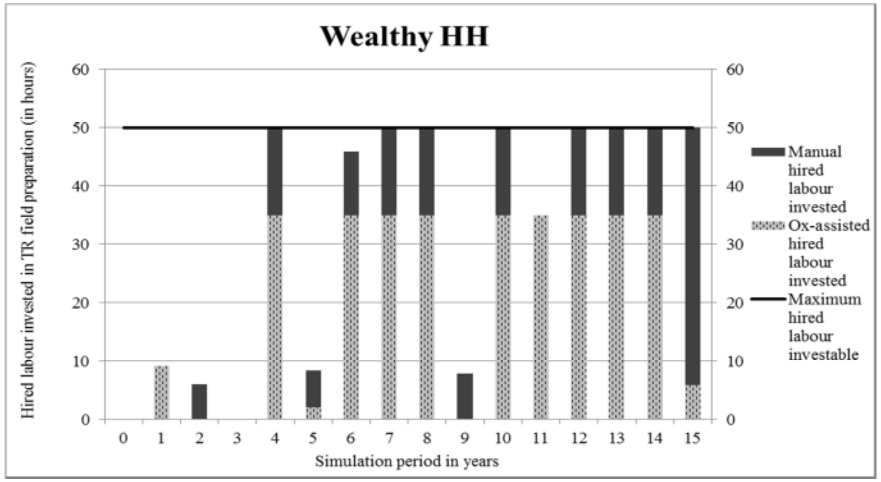
Source: Author's design based on model results.

Fig. 2.40: Family labour invested into field preparation under traditional agriculture by the wealthy household category.



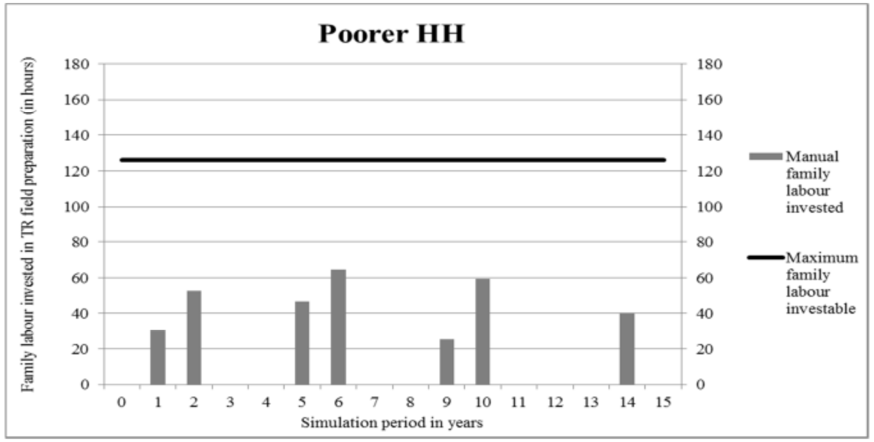
Source: Author's design based on model results.

Fig. 2.41: Hired labour invested into field preparation under traditional agriculture by the wealthy household category.



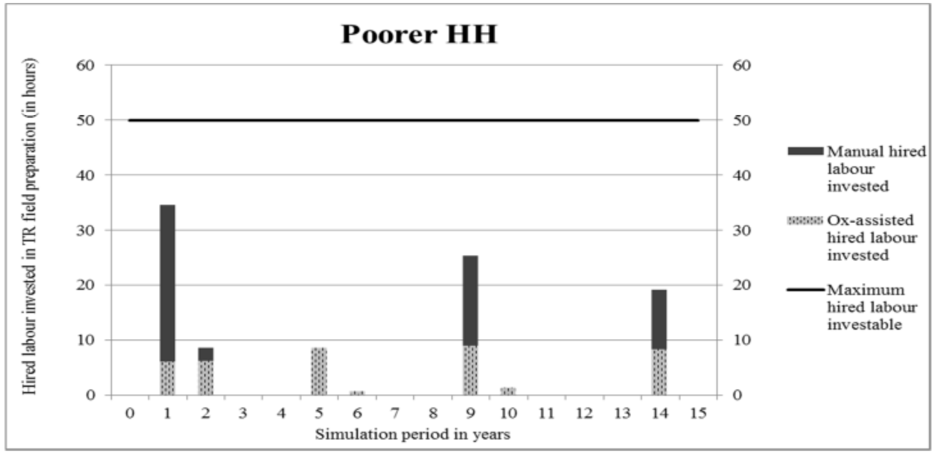
Source: Author's design based on model results.

Fig. 2.42: Family labour invested into field preparation under traditional agriculture by the poorer household category.



Source: Author's design based on model results.

Fig. 2.43: Hired labour invested into field preparation under traditional agriculture by the poorer household category.



Source: Author's design based on model results.

Interpretation of the baseline scenario for Seronga

The change from the one- to the two-field assumptions affects optimal HH strategies. The wealthy HHs invest more labour into farming than before because they lost CA as a means of soil fertility management. Furthermore, they begin to manage soil fertility only to a minimal degree, i.e. via irregular field input application. It appears that maintaining high soil fertility levels, e.g. through more regular input applications or by relying on a larger area of CA, requires too much effort from the wealthy. They therefore abandon long-term investments into soil fertility and follow a least-effort approach – soil fertility and cultivated land are kept at just the levels needed for producing 200 kg/year.

For the poorer HHs, CA becomes a viable option in the two-field baseline run. While they exclusively follow traditional farming practices in the one-field run, they now combine them with CA and choose flexibly between both farming systems. However, it will be described in the next section why it may be unwise to draw too far-ranging conclusions from a comparison of both baseline runs. A tentative interpretation can be made for the question of why the poor HHs switched to a new strategy. In the one-field baseline run, combining CA and traditional farming on the same field would result in an increased mean harvest/ha; this would also increase nutrient exports from harvesting. As has been described in Chapter 2.4.1.3, traditional farming extracts considerably more nutrients than CA (due to the fact that crop residues are grazed under traditional farming[69]). In the one-field scenario, both traditional farming and CA would contribute and deduct nutrients from a joint nutrient pool. Thus, any CA-caused increase in soil fertility would be reduced by harvesting from traditional agriculture. Therefore, building-up soil fertility via CA would be a slower process than in a scenario where both farming systems are cultivated on separate fields. The poorer HHs have very limited cash resources, and maybe it is not worthwhile for them to invest into CA if its positive effects on soil fertility are not very pronounced. It is possible that in the two-field baseline run, the adoption of CA was favoured by a quicker build-up of soil fertility on the CA field.

The results of the baseline scenario in Seronga can be summarized as follows; under current model parameters, arable agriculture is not a worthwhile livelihood source for smallholder households. This finding confirms the qualitative farming system analysis in Chapter 1.6.3. Both the poor and the wealthy engage in farming only insofar as it is required by the model and invest all remaining family time in leisure activities. The low attractiveness of arable agriculture in the model could be caused not only by high household preferences for leisure but also by the high shadow wage of family labour and the relatively low returns on investment in agriculture (the effect of the shadow wage and returns on agriculture will be analysed via sensitivity analysis). Based on this finding, the following conclusion may be made; as soon as households in Seronga are able to base their livelihood strategies on other livelihood options (such as formal employment)[70], arable agriculture may be abandoned by many of them. Thus, if efforts towards sustainable intensification do not find a way to overcome farmers' frustration with arable agriculture, these efforts are likely to fail in Seronga.

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[69] This is captured by the model via greater nutrient extraction from harvesting under TR than under CA.

[70] As already mentioned in Chapter 1.6.3, new livelihood options may arise when a reliable tar road and bridge over the Okavango Delta are constructed, which would connect the study site with Botswana's wider economy.

Remark on the optimal strategy of the poorer households

At a first glance, it is confusing that the poorer HHs change their strategy under the two-field scenario. Under the new strategy, they produce slightly less food than under the one-field strategy and have less leisure time. This results in slightly reduced utility levels. Theoretically, they could have continued relying on the previous strategy, which presented a better option.

It is assumed here that, from a mathematical point of view, both optimal strategies lie close to the global optimum. As has been described before, a global solver was used to identify approximate variable levels near this global optimum. Afterwards, these values were used as variable bounds in a model run with a local solver, which allowed the identification of the global optimum or at least a local optimum close to the global one. The two strategies are assumed to describe just that: two optima that lie very close to each other. Any analysis of why households change to a new strategy should be treated with caution, as the optimal solutions may partly depend on the characteristics of the solvers used in the GAMS software.

However, the finding that CA can play a role for the poorer HHs is realistic. Rainfall in Seronga is very erratic, and CA provides important advantages in terms of efficient water harvesting and rainfall use. It can be assumed that if rainfall stochasticity were included in the model, the relative importance of CA would increase even further. In the long-term especially (as modelled here), this might affect optimal strategies. Therefore, all following scenarios follow the two-field assumption.

General conclusions of the baseline scenarios in Mashare and Seronga

Both Mashare and Seronga are constrained by the bottlenecks to traditional agriculture identified by the farming system analysis (Chapters 1.6.2 & 1.6.3). These are *land scarcity* (a main constraint for the wealthy HHs) and the *relative short duration of the period available for traditional field preparation* (a main constraint for the poorer HHs).

Cash endowment is an important constraint for the poorer HHs. To be able to adopt input-based agriculture, they need to follow a sophisticated strategy for generating cash income. By slowly building-up soil fertility, they increase their yield levels and finally achieve a marketable crop surplus. Moreover, they invest as much time as possible into casual labour.

The role of CA in optimal household strategies depends strongly on (changing) parameter levels. CA may be too labour and capital intensive for households for which farming is not a worthwhile livelihood source (see Giller et al. 2009). For poorer HHs with scarce cash resources, CA may complement traditional farming. And for households aiming to achieve high production levels, it may provide the best available means of achieving this goal.

In regards to soil fertility management, the following approaches were identified. In Seronga's two-field baseline run, the wealthy follow a cyclical strategy of soil mining and regeneration. The poorer achieve continuously increasing soil fertility levels by combining traditional agriculture with fallow periods, input application, and low yield levels. In Mashare, the wealthy invest in soil fertility and quickly reach its maximum level. The poorer achieve an early peak in soil fertility by clearing land. Then they gradually deplete this stock of soil fertility until the end of the modelling period. It can be assumed that under a longer modelling period, they would either achieve an equilibrium of low yields and stable soil fertility or be forced to re-invest into soil fertility and thus follow the cyclic management strategy of Seronga's wealthy HHs.

2.5.1.3 Sensitivity analysis

Deterministic sensitivity analyses were applied to determine the impact of parameter-level changes in the optimal solution. The parameters included in this sensitivity analysis are i) the shadow wage of family labour, ii) the upper bound on soil fertility, iii) the retail price of staple food, iv) farm gate prices, v) the wage rate of both ox-assisted and manual hired labour, and vi) the coefficient of soil fertility in the production function, which varied from the baseline value of 2.53 to 3.03 and 2.03, respectively.

The sensitivity analysis was conducted with GAMS using the local solver CONOPT. As mentioned in the previous chapter, the CONOPT version of the model was based on starting levels of variables that had been determined in a previous model run, i.e. a version using the global solver BARON. This global solver delivered a feasible yet non-optimal solution. This means the identified solution (i.e. the levels of variables) was likely to lie *near* yet not *at* the global optimum. Therefore, the BARON solution was used to define a lower bound of the variable *Amount of land allocated to the various management practices*. Afterwards, a second model run was conducted with the local solver CONOPT and the lower variable bounds identified with BARON. This allowed us to find an optimal solution that lies at (or at least very close to) the global optimum. However, this means that the sensitivity analysis is also based on these lower bounds. Therefore, its results have to be interpreted accordingly.

If a change in parameter levels leads to a solution within the bounds of the model, this is usually revealed by the level of important decision variables. If the change in parameter levels leads to a solution outside the feasible region of the model, this will yield an “infeasible” result and indicate that the baseline scenario solution is no longer optimal. Therefore, even under the CONOPT model, a sensitivity analysis provides insights into the variability of optimal household strategies depending on changing parameter levels.

The baseline runs showed that variable levels vary strongly over the simulation periods. Therefore, in order to present the results of the sensitivity analysis in a concise way, the model output was simplified into two main variables (*Area dedicated to traditional farming*, *Area dedicated to conservation agriculture*, and *Annual food consumption*). It is presented here together with households’ leisure ratio. Tables 2.18–2.21 report the level of these variables for each sensitivity run, but only their mean values over the entire modelling period are presented.

The results of the sensitivity analysis can be generalized as follows: the optimal solution varied only minimally with changing parameter levels. Infeasible solutions could only be found for very strong changes in parameter levels, i.e. i) where the production-function coefficient of soil fertility was reduced from 2.53 to 2.03 (*infeasible* in both study sites), ii) where the farm gate prices was reduced by 20% (*infeasible* in Mashare only, which is more cash constrained than Seronga), and iii) where the wage rate and availability of hired labour in the dry season were set equal to the levels of the rainy season (*infeasible* in Seronga). This indicates that in these cases, the optimal household strategies would be different than those identified by the baseline scenario. In general, however, minor changes in parameter levels lead to only minimal changes in the level of output variables. This indicates that the optimal solution identified in the baseline scenario is a stable solution over the relatively wide range of those parameter levels that were included in the sensitivity analysis.

Tab. 2.18: Results of sensitivity analysis for the wealthy household category in Mashare.

Varied parameter	Output variables			
	CA area (in ha)	**TR area** (in ha)	**Leisure-share** (in %)	**Food consumption** (in kg/a)
Baseline scenario (two-fields version)	0.54	1.34	0.80	1,969
Shadow wage of family labour - 10%	0.54	1.34	0.80	1,969
Shadow wage of family labour + 10%	0.54	1.34	0.80	1,968
Shadow wage of family labour - 20%	0.87	1.02	0.65	2,274
Shadow wage of family labour + 20%	0.54	1.34	0.80	1,968
SF.up = 700%	0.54	1.34	0.80	1,945
SF.up = 900%	0.54	1.34	0.80	1,991
Retail price per kg staple food + 10%	0.54	1.34	0.80	1,967
Retail price per kg staple food - 10%	0.54	1.34	0.80	1,971
Retail price per kg staple food + 20%	0.54	1.34	0.80	1,896
Retail price per kg staple food - 20%	0.54	1.34	0.80	1,973
Farmgate-prices + 10%	0.72	1.17	0.80	2,362
Farmgate-prices - 10%	0.61	1.27	0.80	2,121
Farmgate-prices + 20%	0.72	1.16	0.80	2,057
Farmgate-prices - 20%	***Infeas.***	***Infeas.***	***Infeas.***	***Infeas.***
Wage hired manual & oxen labour + 20%	0.53	1.35	0.78	1,959
Wage hired manual & oxen labour - 20%	0.61	1.27	0.80	2,036
Availability & wage rate of hired labour in Dry Season equals Rainy Season	0.81	1.07	0.61	2,417
Soil fertility coefficient + 0.05	0.88	1.00	0.64	3,443
Soil fertility coefficient - 0.05	***Infeas.***	***Infeas.***	***Infeas.***	***Infeas.***

Source: Author's design based on model results.

Tab.2.19: Results of sensitivity analysis for the poorer household category in Mashare.

Varied parameter	Output variables			
	CA area (in ha)	**TR area** (in ha)	**Leisure-share** (in %)	**Food consumption** (in kg/a)
Baseline scenario (two-fields version)	0	1.25	0.78	832
Shadow wage of family labour - 10%	0	1.25	0.78	832
Shadow wage of family labour + 10%	0	1.25	0.78	832
Shadow wage of family labour - 20%	0	1.25	0.78	832
Shadow wage of family labour + 20%	0	1.13	0.79	794
SF.up = 700%	0	1.25	0.79	834
SF.up = 900%	0	1.25	0.78	832
Retail price per kg staple food + 10%	0	1.25	0.78	832
Retail price per kg staple food - 10%	0	1.25	0.78	832
Retail price per kg staple food + 20%	0	1.25	0.78	829
Retail price per kg staple food - 20%	0	1.25	0.78	832
Farmgate-prices + 10%	0	1.25	0.78	823
Farmgate-prices - 10%	0	1.22	0.78	763
Farmgate-prices + 20%	0	1.25	0.78	839
Farmgate-prices - 20%	***Infeas.***	***Infeas.***	***Infeas.***	***Infeas.***
Wage hired manual & oxen labour + 20%	0	1.25	0.78	865
Wage hired manual & oxen labour - 20%	0	1.25	0.78	799
Availability & wage rate of hired labour in Dry Season equal Rainy Season	0	1.25	0.78	838
Soil fertility coefficient + 0.05	0	1.23	0.78	1,399
Soil fertility coefficient - 0.05	***Infeas.***	***Infeas.***	***Infeas.***	***Infeas.***

Source: Author's design based on model results.

Tab.2.20: Results of sensitivity analysis for the wealthy household category in Seronga.

Varied parameter	Output variables			
	CA area (in ha)	**TR area** (in ha)	**Leisure-share** (in %)	**Food consumption** (in kg/a)
Baseline scenario (two-fields version)	0.006	1.09	0.90	833
Shadow wage of family labour - 10%	0.006	1.09	0.90	833
Shadow wage of family labour + 10%	0.006	1.09	0.90	795
Shadow wage of family labour - 20%	0.006	1.14	0.90	830
Shadow wage of family labour + 20%	0.006	1.14	0.90	790
SF.up = 700%	0.006	0.95	0.91	753
SF.up = 900%	0.006	1.09	0.90	771
Retail price per kg staple food + 10%	0.013	1.05	0.91	656
Retail price per kg staple food - 10%	0.006	1.09	0.90	802
Retail price per kg staple food + 20%	0.006	1.09	0.91	683
Retail price per kg staple food - 20%	0.006	1.09	0.90	874
Farmgate-prices + 10%	0.006	1.19	0.89	742
Farmgate-prices - 10%	0.006	1.03	0.91	706
Farmgate-prices + 20%	0.006	1.19	0.89	742
Farmgate-prices - 20%	0.021	0.92	0.92	692
Wage hired manual & oxen labour + 20%	0.022	0.95	0.91	706
Wage hired manual & oxen labour - 20%	0.006	1.14	0.90	725
Availability & wage rate of hired labour in Dry Season equal Rainy Season	***Infeas.***	***Infeas.***	***Infeas.***	***Infeas.***
Soil fertility coefficient + 0.05	0.06	0.86	0.92	756
Soil fertility coefficient - 0.05	***Infeas.***	***Infeas.***	***Infeas.***	***Infeas.***

Source: Author’s design based on model results.

Tab.2.21: Results of sensitivity analysis for the poorer household category in Seronga.

Varied parameter	Output variables			
	CA area (in ha)	**TR area** (in ha)	**Leisure-share** (in %)	**Food consumption** (in kg/a)
Baseline scenario (two-fields version)	0.095	0.22	0.79	522
Shadow wage of family labour - 10%	0.095	0.22	0.79	522
Shadow wage of family labour + 10%	0.095	0.22	0.79	522
Shadow wage of family labour - 20%	0.095	0.24	0.78	522
Shadow wage of family labour + 20%	0.095	0.22	0.79	522
SF.up = 700%	0.096	0.22	0.79	522
SF.up = 900%	0.095	0.22	0.79	552
Retail price per kg staple food + 10%	0.095	0.24	0.78	522
Retail price per kg staple food - 10%	0.095	0.22	0.79	522
Retail price per kg staple food + 20%	0.095	0.25	0.78	522
Retail price per kg staple food - 20%	0.095	0.22	0.80	522
Farmgate-prices + 10%	0.095	0.22	0.79	522
Farmgate-prices - 10%	0.095	0.22	0.79	550
Farmgate-prices + 20%	0.095	0.22	0.79	522
Farmgate-prices - 20%	0.095	0.22	0.79	522
Wage hired manual & oxen labour + 20%	0.095	0.22	0.80	522
Wage hired manual & oxen labour - 20%	0.097	0.3	0.76	522
Availability & wage rate of hired labour in Dry Season equal Rainy Season	***Infeas.***	***Infeas.***	***Infeas.***	***Infeas.***
Soil fertility coefficient + 0.05	0.095	0.3	0.80	522
Soil fertility coefficient - 0.05	***Infeas.***	***Infeas.***	***Infeas.***	***Infeas.***

Source: Author’s design based on model results.

2.5.2 Scenario 2 - Reduced input-prices for CA

Scenario 2 simulates a situation where decision makers of the Okavango basin decide to promote the adoption of CA by local smallholders. It is assumed that they implement a 50% subsidy on the input costs of CA, i.e. on the costs of both inorganic fertilizer and cattle manure (which needs to be purchased by the poor HHs only, while the wealthy produce it on their own holding). This means that the *household-specific* costs of CA are reduced by 50%. This means the poorer still have to pay relatively more per hectare of CA than the wealthy because, contrary to the wealthy cattle owners, they have to purchase manure. Tab. 2.22 shows the prices for the respective study sites and household categories. The results will be presented separately for wealthy and poor HHs.

Tab. 2.22: Input costs of conservation agriculture per study site in Scenario 2

Study site	**Household category**	**Costs** (USD/ha)
Seronga	Wealthy HH	120
	Poorer HH	262
Mashare	Wealthy HH	80
	Poorer HH	222

Source: Author's design.

A subsidy on manure could for instance be achieved with improved rangeland management and appropriate manure processing technologies. This would increase its availability and reduce its price (although rising demand for manure might result in an increased price). Thus, an even more important contribution of improved rangeland management is that it might allow poorer HHs to invest in cattle and produce manure on their own. At the moment, high cattle mortality due to a lack of grazing and widespread diseases (Chapter 1.6.2) makes this a very risky investment.

2.5.2.1 Study site Mashare

Poorer household category

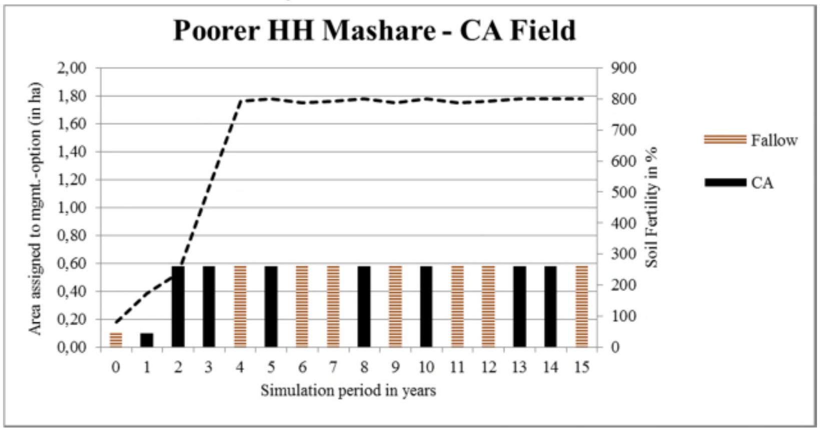
Field sizes and soil fertility

Compared to the baseline scenario, the poorer abandon their strategy of relying exclusively on traditional farming. Instead, they switch to a mixed strategy that combines both traditional farming and CA. The area assigned to these two practices resembles that of the wealthier HHs in the baseline scenario, i.e. 0.58 ha for CA and 1.29 ha for *TR Both* (Figs. 2.44 & 2.45). However, they follow a more cyclic strategy, where one or two years of traditional farming alternate with one or two years of CA. This allows focusing the cultivation on one field only and leaving the majority of the other field fallow. Furthermore, the subsidies in this scenario result in continuously increasing levels of soil fertility (as opposed to its early peak and ensuing gradual decline in the baseline scenario). On the field for traditional farming, this is achieved mainly by fallowing[71]. On the CA field, a stable level of soil fertility near the

[71] In most consecutive years of cultivation a slight decrease in soil fertility can be observed, which appears to be then balanced out by a fallow period. This interpretation can be confirmed by the baseline scenario; here,

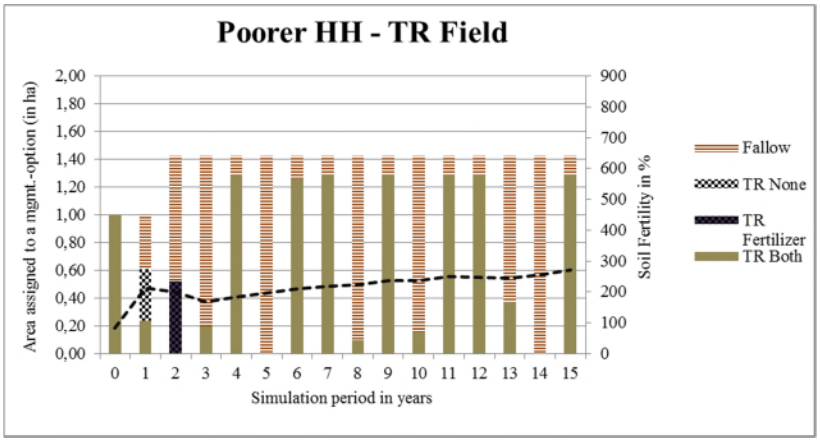
maximum is quickly achieved. It remains unclear whether this maximum is achieved via input application or fallow periods[72].

Fig. 2.44: Area cultivated and soil fertility level of the conservation agriculture field of the poorer household category in Mashare, Namibia (Scenario 2).



Source: Author’s design based on model results.

Fig. 2.45: Area cultivated and soil fertility level of the field for traditional agriculture of the poorer household category in Mashare, Namibia (Scenario 2).



Source: Author’s design based on model results.

Cash economy

Despite the subsidy, the poor still need to follow a complex strategy for earning sufficient cash income to adopt CA. Their strategy relies on the shifting of cash expenses away from hired labour towards the purchase of manure and fertilizer needed for CA. Total expenses remain at nearly the same level as in the baseline run. The poor use both available cash income sources, i.e. *casual labour* and *food sales*. Again, food sales are made possible by gradually building up soil fertility, which increases the annual harvest. However, the purchase of CA inputs in simulation periods 1 and 2 required a relatively large amount of cash. As at this point surpluses were still too low to earn sufficient income, the poor reallocated cash from purchasing field inputs for traditional farming to purchasing CA inputs. This forced them to reduce the area of TR both and instead switch to no-input farming and fertilizer-based farming in periods 1 and 2 (Fig. 2.45).

[72] *TR Both* under similar soil fertility values of 200-300% led to a continuous decline in soil fertility. Therefore, the increase in soil fertility in Scenario 2 must stem from fallowing.

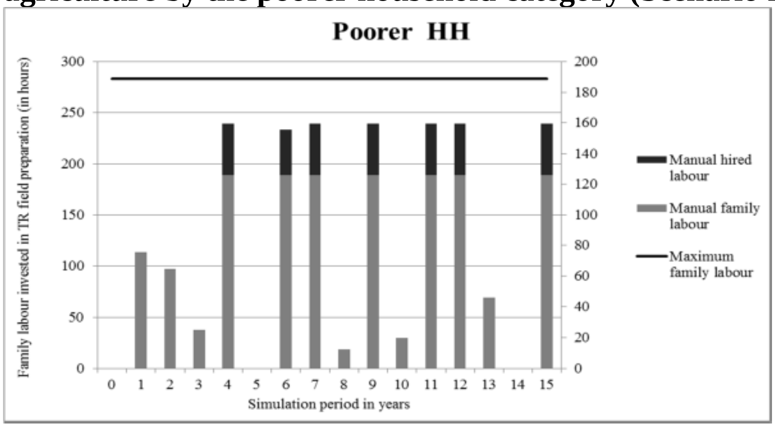
Food consumption

In Scenario 2, the poor achieved lower consumption levels than under the baseline scenario. Only in years of CA cultivation did the level of annual consumption rise above the minimum level of nutrition. In years of traditional farming, it remained near this minimum level (Fig. 2.48.). The reason behind this is that the soil fertility level of the field for traditional farming, and thus also its yield, were now lower than in the baseline run. Ultimately, the lower fertility levels were caused by the fact that less land was allocated to the field for traditional farming and that therefore i) the fallow area was reduced and ii) the initial boost in soil fertility from field clearing on the non-CA field was lower (however, *total* clearing per HH remains unaffected). Another reason for the reduced consumption was that for purchasing CA inputs, food sales needed to be increased.

Labour economy and bottlenecks for production

The adoption of CA has effects upon the poor's labour economy. First, its high labour demand leads to a decrease of the mean leisure share by 4% as compared to the baseline scenario (Fig. 2.47). The poor are not able compensate for this by hiring more external workers because they need to invest cash into purchasing field inputs. Due to CA's high cash demand, the poor still do not invest into ox-assisted labour for traditional field preparation. Obviously, the benefits of investing into field inputs for *TR Both* and CA outweigh the benefits of increasing the area of traditionally cultivated land (which could be achieved by ox-assisted labour). In those years where households cultivate only the field for traditional agriculture (and not the CA field), the time for traditional field preparation constrains production. During this time, households use all available manual labour (both hired and family labour) for this task. Contrary to this, in years of CA, only a fraction of the maximum labour for traditional field preparation is used. As the leisure share of the poor remains relatively high, it is assumed here that the area allocated to CA is constrained rather by a lack of cash and not a lack of labour. In years of CA production, the poor would be able to increase production by increasing the area dedicated to traditional farming. However, it appears non-optimal to do so.

Fig. 2.46: Family & hired labour invested into field preparation under traditional agriculture by the poorer household category (Scenario 2).



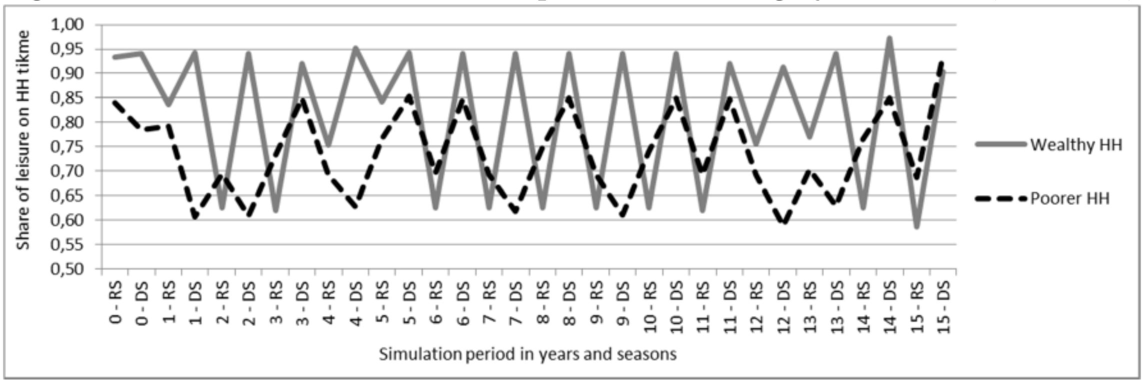
Source: Author's design based on model results.

Summary of scenario 2 for the poorer households

The poor achieve high & continuously increasing soil fertility levels by adopting a cyclic cultivation strategy (which switches between CA and traditional farming practices). However, this comes at a cost: leisure drops slightly, and in many simulation periods, annual food consumption drops to the minimum nutrition level.

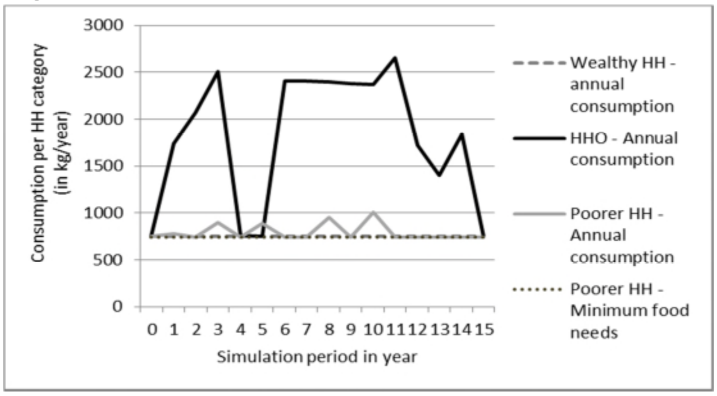
Scenario 2 shows that even when the costs of CA are reduced by 50%, this practice offers only slight advantages over the optimal, traditional farming-based strategy of the baseline scenario. However, it also shows that the poor are able to adopt CA to a certain extent. Scenario 5 will analyse how optimal strategies change when the subsidy on CA is combined with higher land scarcity, which should increase the comparative advantages of land-efficient practices such as CA over traditional farming.

Fig. 2.47: Ratio of leisure to total HH time per household category in Mashare (Scenario 2).



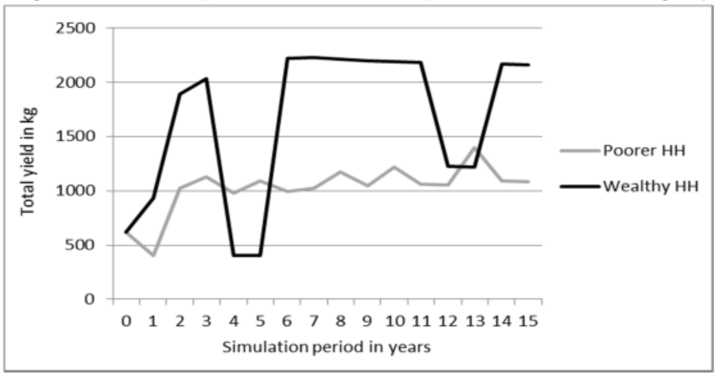
Source: Author’s design based on model results.

Fig. 2.48: Achieved levels of food consumption per household category in Mashare (Scenario 2).



Source: Author’s design based on model results.

Fig. 2.49: Total production levels per household category in Mashare (Scenario 2).



Source: Author’s design based on model results.

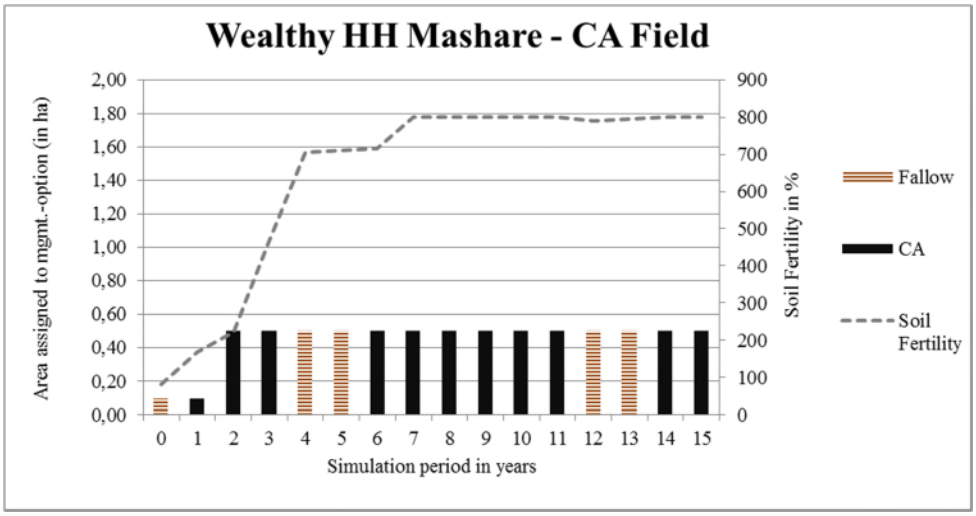
Wealthy household category

In Scenario 2, the wealthy abandon the stable ratio of CA and traditional farming of the baseline run and turn to a more variable strategy. On their CA field, they adopt a cyclical strategy of either cultivation or fallowing. On their field for traditional farming, they rely mainly on *TR Both* but also introduce one least-effort period by applying no-input farming (*TR None*). In general, the subsidy of CA results in reduced production vs. increased leisure levels.

Field sizes and soil fertility

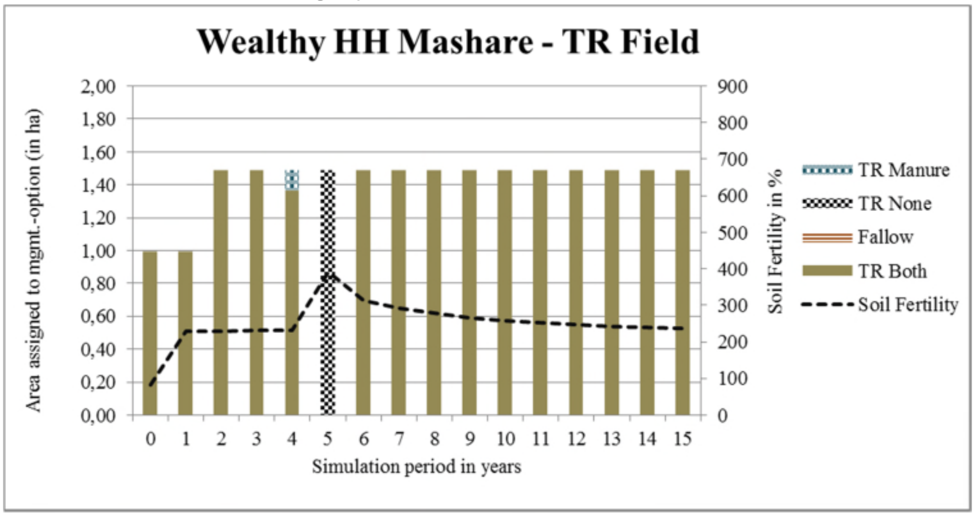
Compared to the baseline scenario, the mean area allocated to CA decreases slightly from 0.61 ha to 0.5 ha, while that of traditional farming increases from 1.4 to 1.5 ha. Together with the use of fallow periods, this allows for continuously increasing levels of soil fertility on the CA field and stable fertility levels on the field for traditional farming (Figs. 2.50 & 2.51).

Fig. 2.50: Area cultivated and soil fertility level of the conservation agriculture field of the wealthier household category in Mashare, Namibia (Scenario 2).



Source: Author's design based on model results.

Fig. 2.51: Area cultivated and soil fertility level of the field for traditional agriculture of the wealthier household category in Mashare, Namibia (Scenario 2).



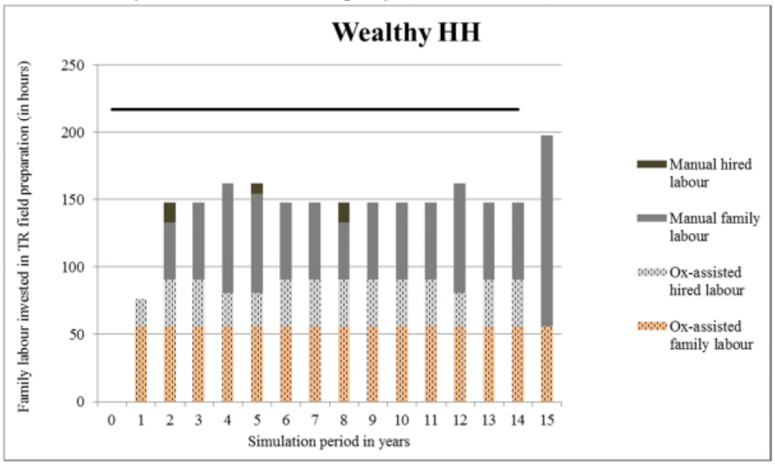
Source: Author's design based on model results.

Labour economy and bottlenecks for production

In Scenario 2, the wealthy replaced CA in four of 16 simulation periods with traditional farming. This allowed them to increase leisure during these periods (although the effect on the mean leisure level is limited: it increases from 80% to 82% of HH time).

As in the baseline scenario, the wealthy used all available *ox-assisted family* labour and most of the available *ox-assisted hired* labour for traditional field preparation. However, the increased area of traditional agriculture forced them to also increase the amount of *manual family* labour invested in traditional field preparation (Fig. 2.52). Theoretically, they would have been able to invest even more labour into this task yet were constrained by their maximum field size (2 ha).

Fig. 2.52: Family & hired labour invested into field preparation under traditional agriculture by the wealthy household category (Scenario 2).



Source: Author’s design based on model results.

Scenario 2 has small but important implications on food consumption, leisure, labour use, and cash use of the wealthy HHs.

Cash economy

Fixed income was the only cash source of the wealthy category and was not complemented by food sales or casual labour. The subsidy on CA allowed the wealthy HHs to re-allocate cash expenses away from input and towards food purchases (which played no role in the baseline).

Food consumption

The variance of food consumption increased compared to the baseline scenario, but the mean level of food consumption decreased by 20%. During periods where the CA field is left fallow, consumption even dropped to the minimum level required to ensure household survival (Fig. 2.48). As the wealthy quickly put all available land under cultivation, they had to rely only on the remaining land to increase consumption: first, by increasing the level of soil fertility on the field for traditional farming and thus yields (achieved mainly on the CA field, yet less so on the traditional field), or second, by purchasing food.

Interpretation of Scenario 2 for Mashare’s wealthy households

In four of the 16 simulation periods, CA was abandoned. This implies that CA played an important, yet only complementary role to traditional agriculture (which remained the main livelihood source of the wealthy HHs). On the one hand, the reason for this lesser role may stem from the higher flexibility in labour and input use of traditional agriculture, which allowed households to switch between no-input and input-based production practices (i.e. between more and less labour-intensive practices). On the other hand, the reduced input costs of CA may have been another reason for its reduced importance: while in the baseline run, most cash was spent on field inputs and hiring workers, it could now be invested in food purchases. The wealthy achieved sufficiently high consumption levels by working less (in some periods). This implies that a subsidy on input costs could have had unexpected effects on CA adoption. If widespread CA adoption is the goal of decision makers, the subsidy should maybe be discriminatory and target the less well-off households. On the other hand, if the wealthy were to reduce their share of CA this might take pressure from the use of manure or mulch biomass, both of which may become scarce goods in the future.

2.5.2.2 Study site Seronga

Scenario 2 had almost no effect upon the optimal strategies of both households in Seronga. Just as in the baseline, households followed a least-effort strategy that allowed them to achieve minimum production needs (both households achieved a lower bound of 200 kg annual production) and low consumption levels (the poorer HH category achieved exactly its minimum annual consumption level, while the wealthy category surpassed it by 80%).

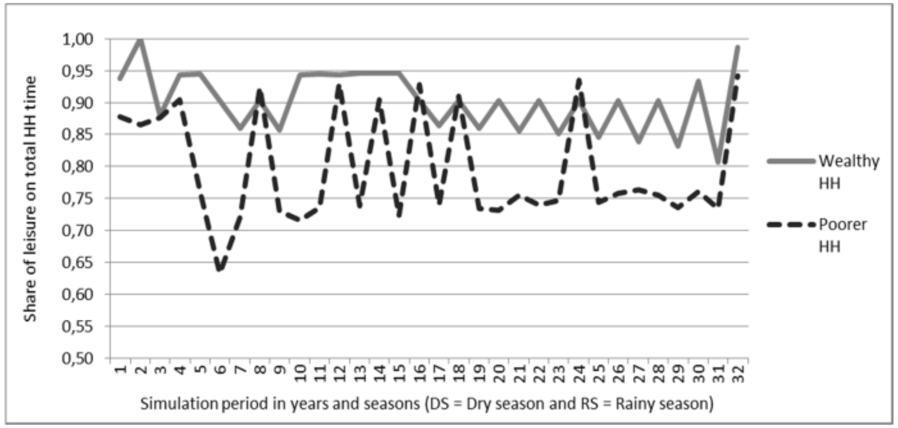
All changes in consumption levels, labour use, or leisure lay between 0-3%, and changes in cultivation practices resulted from a slight change in their distribution over time. There are only a few notable changes between the baseline and this scenario. The most pronounced change for the *wealthy* was in the 5th simulation period, where one period of *TR Both* on 0.8 ha was replaced with three consecutive periods of *TR Both* on only 0.34 ha (Fig. 2.54). In both cases, the wealthy achieved the same peak level in soil fertility, yet in Scenario 2 this peak occurred at a later moment in the modelling period (i.e. 8th instead of 6th simulation period). This has further implications: households no longer needed to apply both inputs in the 9th period to counter the gradual decline in soil fertility following this peak. Instead, due to the late peak no replenishment of soil fertility was needed during the modelling period, and a gradual decline from the 8th period peak to the last period could be observed. This finding indicates that there are different ways in which traditional farming practices can be used to achieve a cyclic management of soil fertility.

For the poorer, the optimal strategy of Scenario 2 is basically the same as in the baseline run. The two main changes are i) CA is practiced one simulation period less than in the baseline, which causes soil fertility on the CA field to peak at a later point in time, and ii) a re-allocation of cash. The money saved due to the reduced cash needs of CA is now re-invested into hiring ox-assisted labour (+16% or 3 USD annually) and increasing food purchases (+3 USD annually), but also to reduce household engagement in casual labour (yielding 4% less income per year). These minimal changes in household resource allocation do not affect the optimal household strategy in a notable way.

Interpretation of Scenario 2 in Seronga

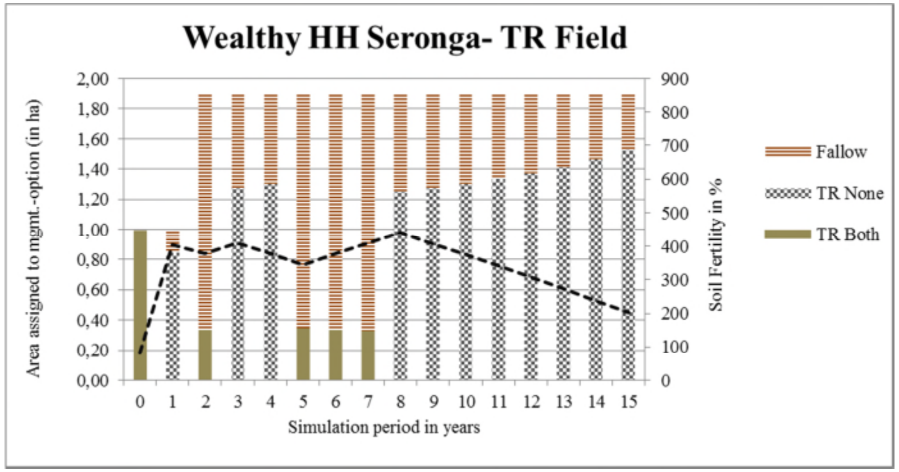
Reducing the input costs of CA by 50% had only minimal effects upon either household in Seronga. Due to the low importance of farming, input prices were not primary constraints to production. Moreover, both households continued to rely on food purchases rather than on their own agricultural production.

Fig. 2.53: Ratio of leisure to total HH time per household category in Seronga (Scenario 2).



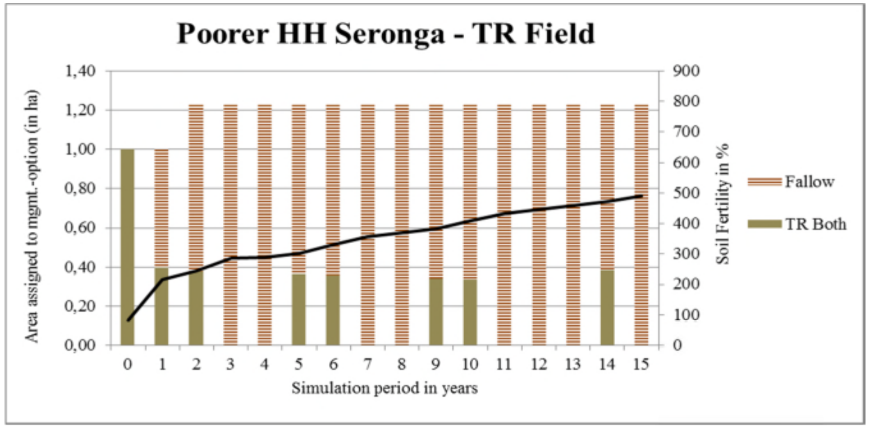
Source: Author's design based on model results.

Fig. 2.54: Area cultivated and soil fertility level of the field for traditional agriculture of the wealthy household category in Seronga, Botswana (Scenario 2).



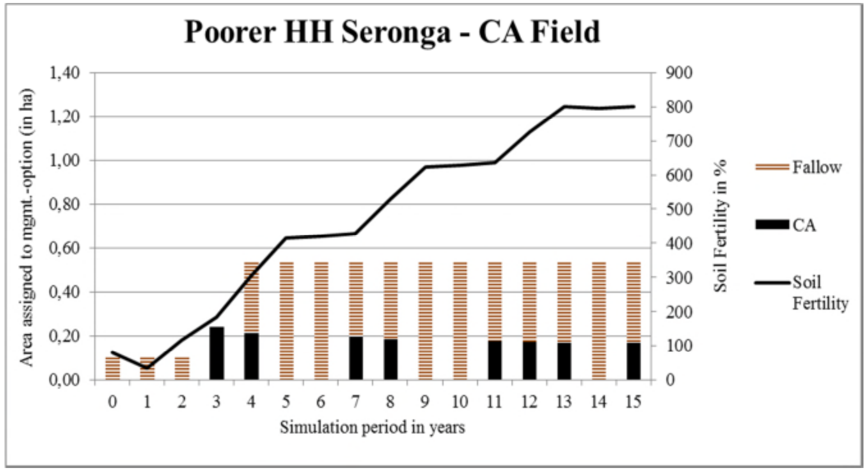
Source: Author's design based on model results.

Fig. 2.55: Area cultivated and soil fertility level of the field for traditional agriculture in Seronga, Botswana (Scenario 2).



Source: Author's design based on model results.

Fig. 2.56: Area cultivated and soil fertility level of the field for traditional agriculture of the poorer household category in Seronga, Botswana (Scenario 2).



Source: Author's design based on model results.

2.5.3 Scenario 3 – Relaxing the time constraint for traditional field preparation

Rainfall amount and its temporal distribution determine the time available for traditional field preparation in the lower Okavango basin. Scenario 3 simulated a year of good rainfall, where the period available for traditional field preparation had doubled to 14 days (as compared to seven days in the baseline scenario). This relaxed the main constraint of the poorer households and could have been expected to reduce the comparative advantages of CA over traditional farming, i.e. it could be expected that traditional farming played a much more important role in the optimal strategy of Scenario 3 than CA. The implications of such a result would be that a few consecutive years of good rainfall might reduce the success likelihood of any (policy) effort towards endogenous intensification. This scenario analyses whether or not Boserup's (1965) assumption is correct that endogenous intensification is less likely under favourable production conditions. If it is confirmed, decision-makers should be aware that any change in biophysical conditions can affect the speed and success of intensification efforts in the ORB.

2.5.3.1 Study site Mashare

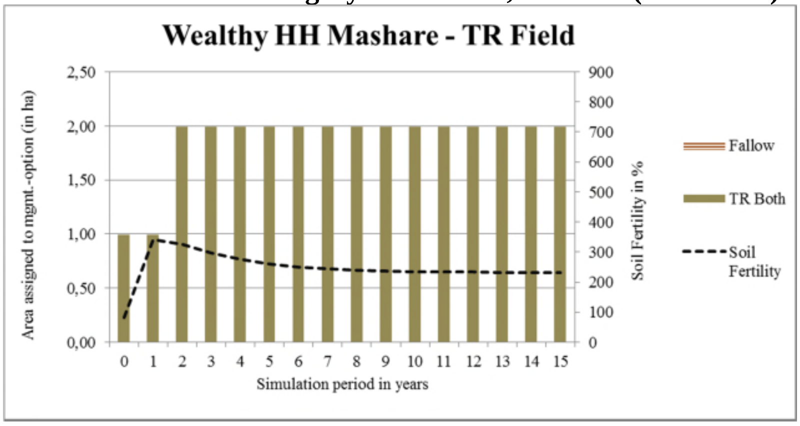
In Mashare, both households switch to strategies that relied exclusively on traditional farming practices. CA did not play a role anymore. For both households, the land available for cultivation represented a main constraint to farming. The results of this scenario imply that CA was adopted by necessity and that as long as traditional farming practices covered household needs, it was unlikely that sustainable intensification would occur.

Wealthy household category

Field sizes and soil fertility

The wealthy HHs abandoned CA and cultivated all available land using *TR Both* (Fig. 2.57). In all simulation periods, they cultivated all available land (2 ha) and never relied on fallows. Field clearing allowed them to achieve an early peak in soil fertility (simulation period 1), which then gradually declined until the end of the modelling period.

Fig. 2.57: Area cultivated and soil fertility level of the field for traditional agriculture of the wealthier household category in Mashare, Namibia (Scenario 3).



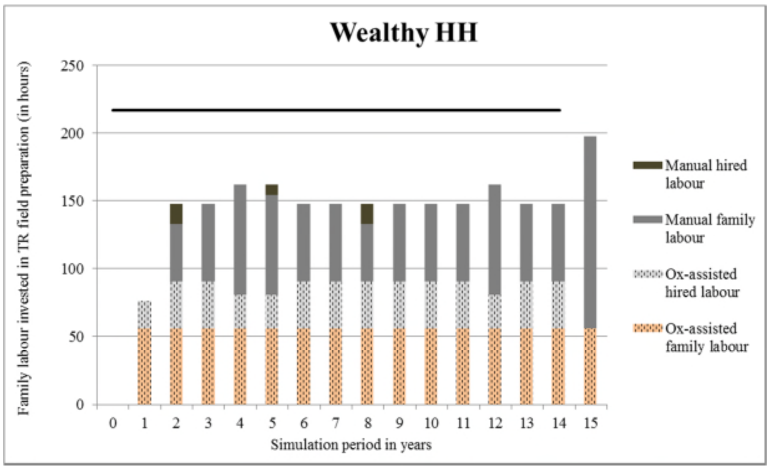
Source: Author's design based on model results.

Labour economy and main bottlenecks for production

In scenario 3, the wealthy invested slightly more family labour into farming than in the baseline scenario (+8%). This is on the one hand related to the larger area cultivated with traditional farming practices, which increased the labour demand of agriculture. On the other hand, it was caused by a reduced reliance on external work. During the baseline, workers were hired mainly to cover the labour demand of CA in the dry season (i.e. an important comparative advantage of CA was that its labour needs could be delegated to hired labour). The opposite was true for traditional farming; its labour needs were highest in the rainy season and, as most of its work was carried out in the rainy season, the wage rate of external workers was considerably higher (19 US cents/h vs. 6 US cents/h). Therefore, the households now relied on family labour instead of on external workers.

Naturally, traditional field preparation became a central task due to the complete switch to traditional agriculture. Although the potential length of the ploughing period was doubled for scenario 3, the wealthy still invested the maximum amount of ox-assisted *family* labour into this task and (on average) 33% of available *hired* ox-assisted labour (Fig. 2.58). Manual family labour accounted for only 7% of the labour inputs for field preparation. Taken together, these labour inputs allow for the cultivation of 2 ha, i.e. of all available household land. This shows that the wealthy were constrained by field size and not by the length of the ploughing period.

Fig. 2.58: Family & hired labour invested into field preparation under traditional agriculture by the wealthy household category (Scenario 3).



Source: Author’s design based on model results.

Cash economy

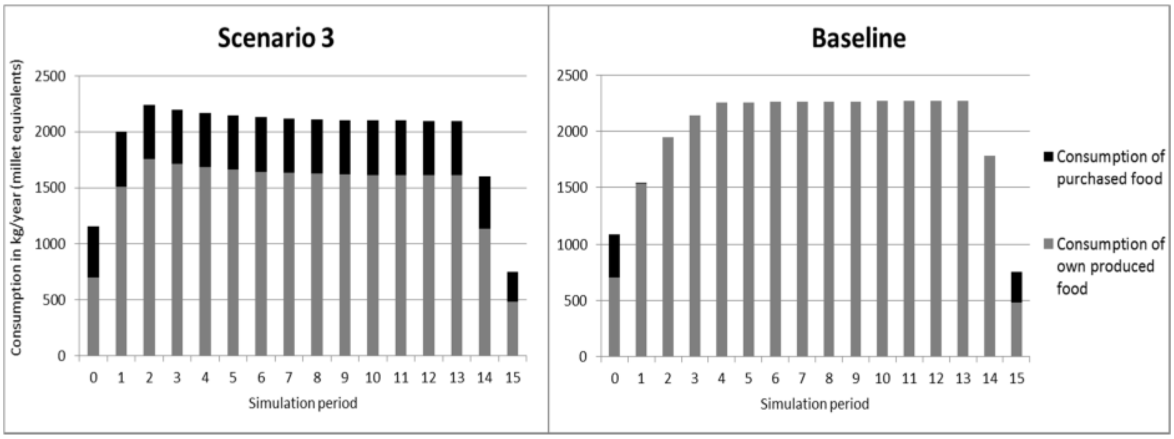
As in the baseline, fixed cash income remained the only cash source of the wealthy; it appeared non-optimal to sell crops or engage in casual labour.

By abandoning CA, the wealthy significantly reduced input costs (on average by 87% per year) and re-invested the saved income into food purchases. Consequently, the food obtained from purchases rose from an average of 42 kg/year to 268 kg/year. At the same time, the longer time window for traditional field preparation decreased their dependence on hired ox-assisted labour. This allowed them to reduce expenses for ox-assisted hired labour by 82%.

Summary of wealthy households in Scenario 3

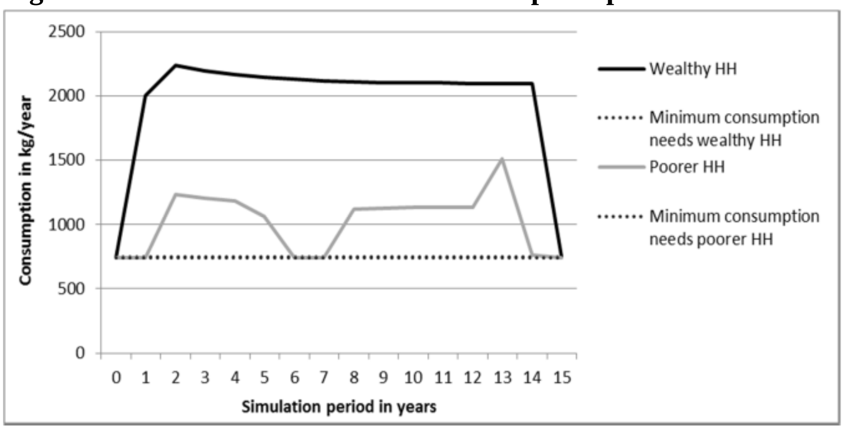
In the baseline, the wealthy HHs applied CA and delegated most tasks of the dry season to external workers. By abandoning CA in Scenario 3, they carried out most agricultural work by relying on family labour in the rainy season. The comparison of Scenario 3 with the baseline indicates that there was a trade-off in the utility derived from *increased leisure* and *consumption of purchased foods* versus *utility derived from the consumption of home-grown food* (which is valued in the utility function at a higher price than market-purchased food). By abandoning CA and reducing the amount of cash invested into field inputs, the wealthy relied more strongly on food purchases than before (Fig. 2.59). They also increased the share of leisure in the rainy season, where leisure was valued at a higher shadow wage rate than in the dry season. Taken together, these changes increased household utility.

Fig. 2.59: Food consumption and food sources of the wealthy compared between Scenario 3 and the baseline.



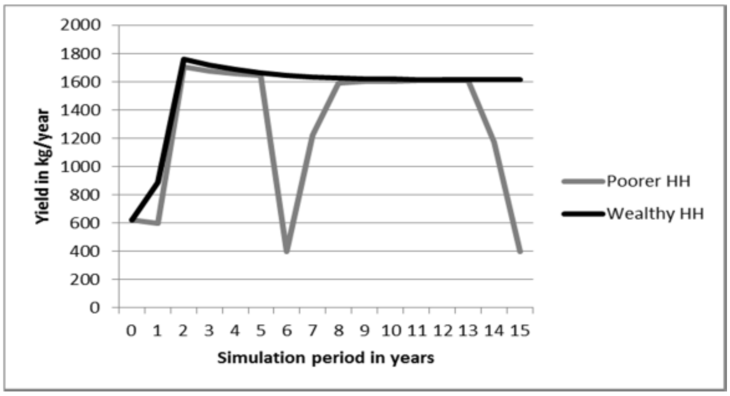
Source: Author's design based on model results.

Fig. 2.60: Achieved levels of food consumption per household category in Mashare (Scenario 3).



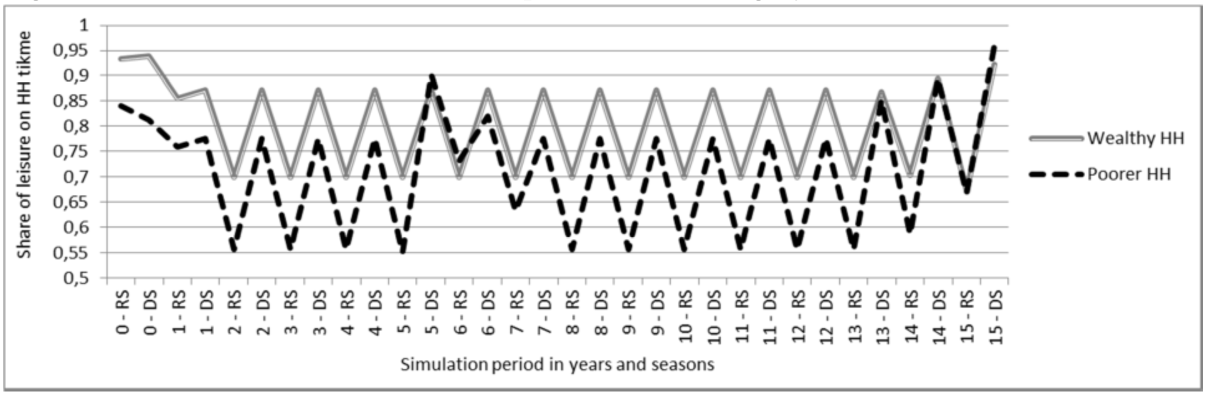
Source: Author's design based on model results.

Fig. 2.61: Total production levels per household category in Mashare (Scenario 3).



Source: Author's design based on model results.

Fig. 2.62: Ratio of leisure to total HH time per household category in Mashare (Scenario 3).



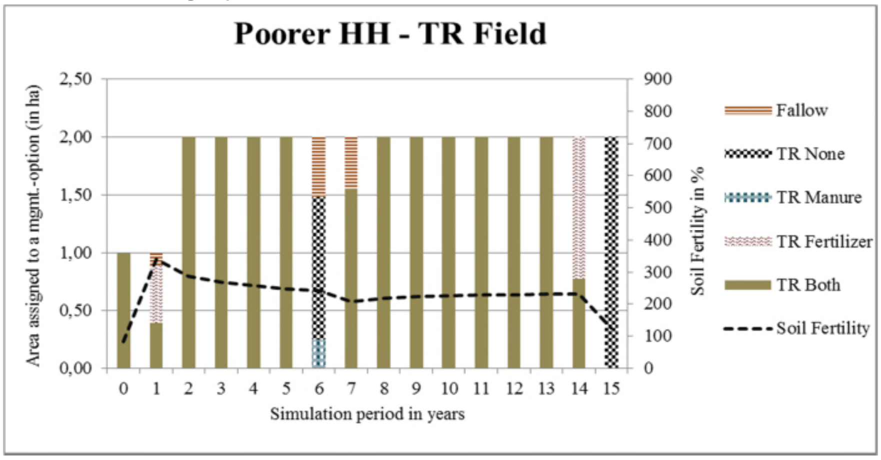
Source: Author's design based on model results.

Poorer household category

Field sizes and soil fertility

The poor HHs followed a strategy that was essentially the same as in the baseline. However, they cultivated all available land using traditional agriculture, i.e. 2 ha instead of 1.29 ha (Fig. 2.63). On the one hand, this increased their level of food consumption (Fig. 2.60). On the other hand, they were no longer able to rely on fallow fields as part of their soil fertility management strategy, which reduced their mean level of soil fertility (on average -15%). As in the baseline, the poor achieved an early peak in soil fertility which gradually decreased until the middle of the modelling period. In simulation period 6, households chose to switch from *TR Both* to no-input agriculture (*TR None*), which was the least labour and cash-demanding farming practice. This one-season lack of field inputs resulted in a slight drop in soil fertility. Afterwards, the poorer households again applied both manure and fertilizer to achieve a balanced soil fertility level of 228%. It appears that the soil fertility and yield levels of Scenario 3 were in equilibrium, i.e. nutrients lost from harvesting equalled nutrients replenished by input application. Only in the last two simulation periods, when *TR Both* was again abandoned in favour of less labour and cash-intensive practices, did soil fertility fall below this equilibrium level.

Fig. 2.63: Area cultivated and soil fertility level of the field for traditional agriculture of the poorer household category in Mashare, Namibia (Scenario 3).



Source: Author's design based on model results.

Labour economy and main bottlenecks for production

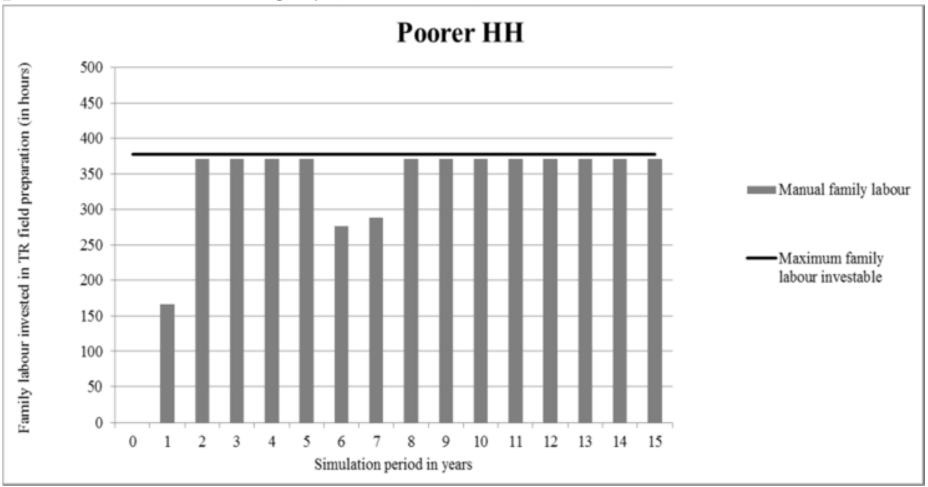
In simulation period 6, the poor switched to a least-effort strategy, where they covered their basic food needs only by combining *TR None* with a small area of *TR Manure,* and increased food purchases[73]. This period was also the only time during which external workers were hired to aid in field work. The cash expenditures for food and external labour of period 6 became possible because during this period, cash was saved on field inputs. In period 6, this led to a reduced level of food consumption, but also to a peak in consumption of leisure (Fig. 2.62). Interestingly, this leisure peak occurred at the end of a process of declining soil fertility and just before the nutrient equilibrium was reached. It is possible that it was optimal for the poor to use up the remaining soil fertility "surplus" (compared to the following equilibrium level) as a means to temporarily increase their leisure levels. A second leisure peak occurred at the end of the modelling period, in simulation periods 14 & 15. This latter peak is caused partly by the reduced importance of soil fertility in the last simulation period. Maybe due to high discount rates, the farm continuing factor does not manage to completely avoid nutrient depletion in the last simulation period.

Cash economy

The ability to cultivate all available land has implications on the poorer HHs' cash income; crop surpluses allowed them to increase cash income from food sales by 42% annually so that mean total annual cash income rose by 16% compared to the baseline scenario. This increased income was used mainly for purchasing the inputs needed for these high production levels. The initial capital for achieving these high production levels came from field clearing, which led to the peak in soil fertility and high production levels described above. Without this option, households would have been forced to slowly build up soil fertility in order to achieve gradually increasing crop surpluses.

[73] Reminder: the study aimss to assess whether or not the labour & cash needs of CA are too high for households to adopt it – due to this (& due to lack of data on rangeland dynamics) manure provision is not modelled. To facilitate the wanted analysis, it is assumed that at the market there is always a sufficient supply of manure. Furthermore, the wealthy do not need to purchase manure because it is produced for free on their farm in sufficient quantities.

Fig. 2.64: Family & hired labour invested into field preparation under traditional agriculture by the poorer household category (Scenario 3).



Source: Author's design based on model results.

Summary of scenario 3 for the poorer households

Contrary to the baseline scenario, the poor HHs managed to cultivate all available land and raised their mean annual food consumption levels by 23%. Therefore, doubling the time available for traditional field cultivation makes this constraint non-binding for the poor. Furthermore, they achieved a stable level of soil fertility, which allowed them to increase food consumption during most periods and short, intermittent periods where higher leisure levels were achieved via soil fertility exploitation and accepting minimum consumption levels.

Interpretation of Scenario 3 in Mashare

In the model, the main seasonal bottleneck for traditional agriculture was the limited time for (traditional) field preparation. CA is a technology that can overcome this bottleneck by shifting field preparation into the dry season (see Chapter 1.6.4). In Scenario 3, the time available for traditional field preparation was doubled from 7 to 14 days. This should have reduced incentives to adopt labour and capital-intensive CA and increase the importance of traditional agriculture in optimal farming strategies. The results of Scenario 3 confirm this; the wealthy HHs abandoned CA in favour of traditional farming practices (the poor did not manage to adopt CA due to high input prices – see Scenario 2). The results imply that CA is adopted out of necessity, i.e. to cope with the constraints to traditional farming, but not because it represents a more land-efficient production technology.

However, it also has to be kept in mind that the main constraints simulated by the model relate to *land availability* and *seasonality*. The risk of droughts for crop production is not modelled. In reality, both Seronga and Mashare suffer from regular droughts, where traditional farming practices may fail to yield any harvest. In the model, however, traditional farming practices provide reliable yields. As in reality, CA may help overcome the risk associated with erratic rainfalls. It may play a more important role for rural livelihoods than implied by Scenario 3. However, a general result is that a few years of sufficient rainfalls (and thus sufficient time for traditional field preparation) may make endogenous intensification less likely.

2.5.3.2 Study Site Seronga

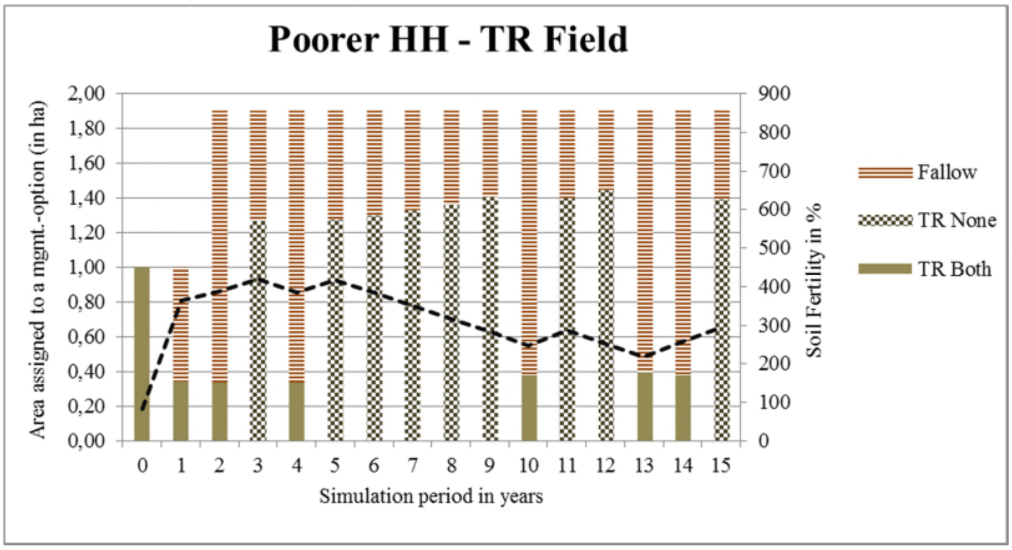
In Scenario 3, both household types relied on basically the same cyclic strategy, i.e. switching between *TR None* (on a relatively large area) and *TR Both* (on a relatively small area). Both options yield the same minimum harvest demanded by the model – i.e. 200 kg. However, while *TR None* leads to soil mining, *TR Both* results in a temporary replenishment of soil nutrients. Due to this, both households follow a strategy of cyclic soil degradation and soil rehabilitation that relies exclusively on traditional agriculture. The similarity between both household strategies in Scenario 3 is caused by the relaxed constraint on time for traditional field preparation. The poor abandon CA and manage to cultivate a sufficiently large area under traditional agriculture.

Poorer household category

Field sizes and soil fertility

The poor HHs alternated between longer periods of *TR None* on 1.27-1.45 ha with short periods of *TR Both* on 0.34-0.4 ha. The annual fallow area was relatively large and varied between 0.5-1.5 ha. This was exactly the same as in the baseline; annual production remained at 200 kg, which was the minimal amount required by the model. As indicated by the development of soil fertility (over the modelling period: Fig. 2.65), the main purpose of applying both animal manure and inorganic fertilizer (*TR Both*) was a temporary rehabilitation of soil fertility.

Fig. 2.65: Area cultivated and soil fertility level of the field for traditional agriculture of the poorer household category in Seronga, Botswana (Scenario 3).



Source: Author's design based on model results.

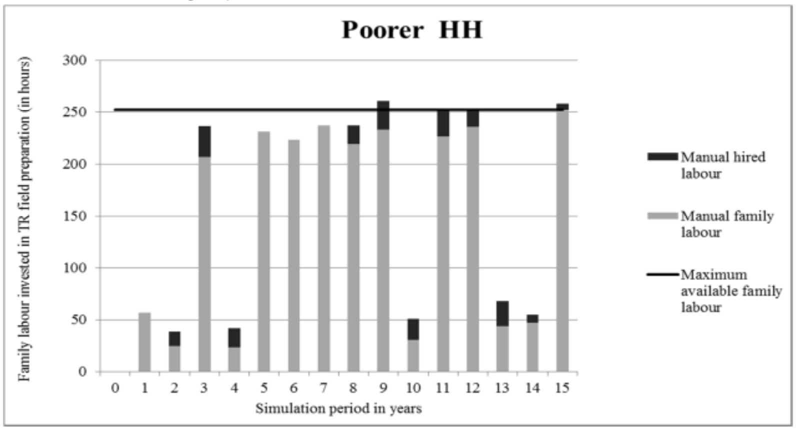
Food consumption and cash economy

As said above, annual food consumption remained at the baseline level. Due to the change from CA to traditional agriculture, the mean input costs dropped by 72% (from 36 to 10 USD/year). This resulted in reduced annual cash needs and a re-allocation of this cash to hiring ox-assisted labour (the mean costs of which increased by 68% from 19 to 32 USD/year).

Labour economy

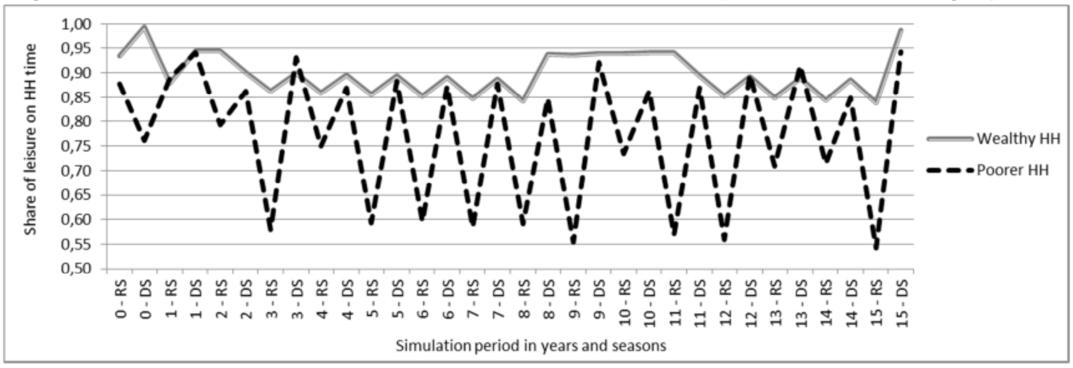
Scenario 3 resulted in a significant increase in family labour invested in manual field preparation (715% of the baseline level) as well as in hired labour (325% of the baseline level). The amount of hired ox-assisted labour still remained very low (i.e. about 4 hours per year, which was too low to be detected in Fig. 2.66). The effect of Scenario 3 on leisure is re-distributed over the seasons, with increasing leisure levels in the dry season and decreasing leisure levels in the rainy season.

Fig. 2.66: Family labour invested into field preparation under traditional agriculture by the poorer household category.



Source: Author’s design based on model results.

Fig. 2.67: Ratio of leisure to total available household time per household category in Seronga.



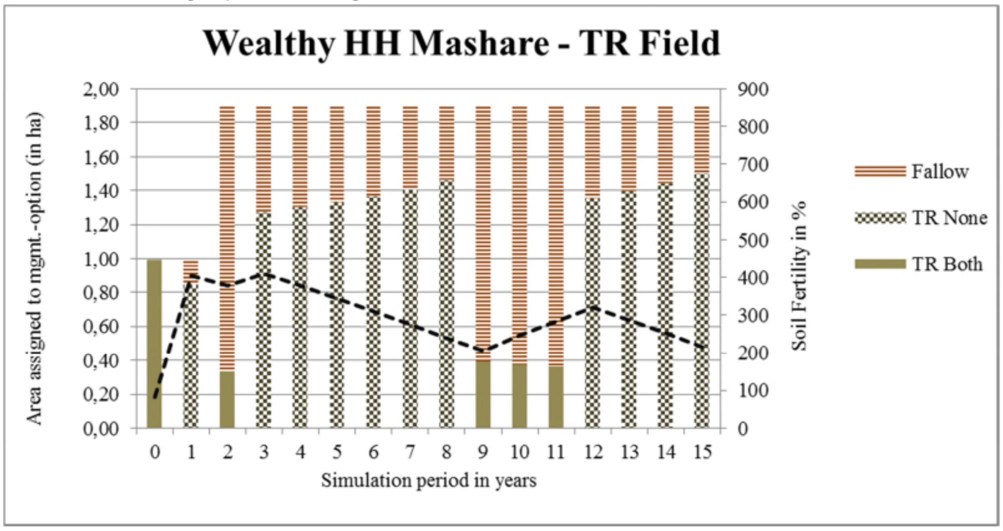
Source: Author’s design based on model results.

Wealthy household category

Field sizes and soil fertility

Just as the poor HHs, the wealthy HHs relied on a strategy where *TR None* on 1.28-1.50 ha alternated with *TR Both* on 0.34-0.40 ha. Again, the main purpose of this alternation appears to be soil fertility management (Fig. 2.68). The most notable change to the baseline is that both households apply *TR Both* at a later point in the modelling period, i.e. in the three consecutive periods 9 to 11 and on only 0.35 ha (Fig 2.68). This leads to slightly lower mean soil fertility levels over the modelling period (-14%, or mean level of 290%). At the same time, it results in increased levels of leisure during these three periods, especially in the rainy seasons.

Fig. 2.68: Area cultivated and soil fertility level of the field for traditional agriculture of the wealthy household category in Seronga, Botswana (Scenario 3).



Source: Author's design based on model results.

Cash economy

By relying more on ox-assisted family labour, here for field preparation (+61%), the wealthy HHs reduced expenditures for hiring ox-assisted labour and invested instead in additional food purchases (+ 10 USD/year or +10 kg/year).

Labour economy

The mean level of leisure remains unchanged from the baseline (Fig. 2.67). An increase of leisure in the three mentioned periods (9-11) is balanced by minimally reduced leisure rates over the other simulation periods (-1%) and a marked leisure-drop in simulation period 3 (which is caused by replacing *TR Fertilizer* in the baseline with *TR None* in Scenario 3).

Interpretation of Scenario 3 in Seronga

Scenario 3 relaxed the main constraint of the poorer HHs, i.e. the time for traditional field preparation. Therefore, both households followed similar strategies to achieve the minimum harvest of 200 kg/year and applied a cyclic strategy of soil fertility management (where longer periods of soil mining interchanged with shorter periods of soil rehabilitation).

Just as in Mashare, the results of Scenario 3 for Seronga implied that after a few consecutive years of good rainfalls, endogenous (voluntary) intensification may be even less likely than suggested by the farming system analysis of Seronga (Chapter 1.6.3). In other words, CA will in this case not play an important role in optimal farming strategies.

Moreover, as long as households are able to rely on other livelihood sources than arable agriculture (and use farming rather as a safety net), traditional farming may in fact allow for balanced soil fertility management. Thus, if carried out correctly, traditional agriculture may be considered part of a sustainable livelihood strategy.

2.5.4 Scenario 4 – Simulating increased land scarcity

Scenario 4 analysed the effect of increasing *land scarcity* on optimal household strategies. This scenario simulated an extreme situation, where households have to rely on a few, small plots for their survival.

Land scarcity is seen here as the result of ongoing *population growth* and rising *competition from other land uses*. It is seen as the most direct impact that these two drivers have on smallholders in the ORB. Accordingly, the model parameter *maximum field size* is set to 1.0 ha in Seronga and 1.2 ha in Mashare[74]. Furthermore, *initial field size* is also set to these values. Thus, households cannot increase soil fertility by clearing land. Lastly, in order to force a solution where households feed themselves only via the little land they have at their disposal, *food purchases* are not possible in Scenario 4.

In order to implement the additional constraints of Scenario 4, some adaptations of the GAMS code were needed. The *Amount of Purchased Food* was fixed at value 0, and initial field sizes were set to maximum field sizes. This means that in the first simulation period, the area allocated to traditional agriculture was set to 1 ha (Seronga) & 1.2 ha (Mashare) and that of CA to 0[75]. In order to be able to determine the optimal land allocation in the different management options, it was necessary to reformulate the model in a more flexible way. In earlier scenarios, land allocated to one of the two fields could not be re-allocated to the other field in a later period. The land allocation decision was final.

For Scenario 4, the model was reformulated in such a way that land swaps from the *field for traditional farming* to the *field for CA* became possible – but not the other way around, i.e. from the *CA field* to the *traditional field*. Thus, the baseline assumption was maintained that area allocated to conservation agriculture was permanently attributed to this practice.

By swapping land from the traditional field to the CA field, the land's soil fertility level was attributed to the nutrient pool of the other field. To capture this, the function determining the level of the nutrient pools per field was extended by the following term:

*[FieldSize(hh,"TRField",t-1) –FieldSize(hh,"TRField",t)] * Nutrientlevel(nut,hh,"TRField",t-1)* **(2.34)**

FieldSize(hh,"TRField ",t-1):	Area allocated to traditional farming by household *hh* in the previous simulation period *t-1*
FieldSize(hh,"TRField",t):	Area allocated to traditional farming by household *hh* in the current simulation period *t*
Nutrientlevel(nut,hh,"TRField",t-1):	Nutrient level *nut* of the field for traditional agriculture per household *hh* in the previous period *t-1*

[74] In Mashare, no optimal solution could be identified in the model for land sizes smaller than 1.2 ha.

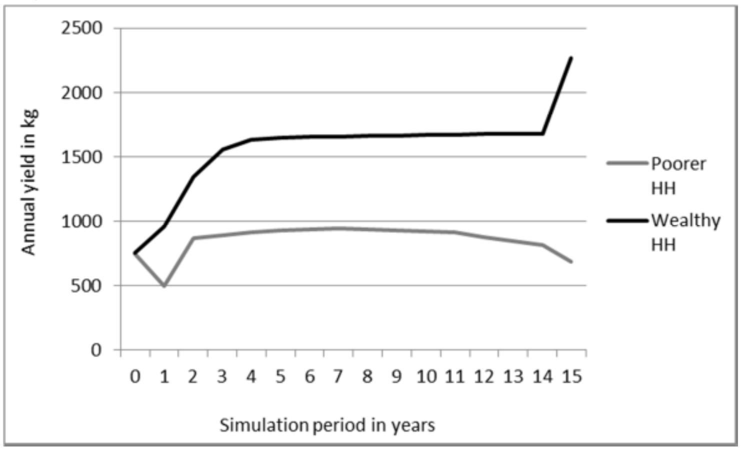
[75] In fact, it was set to 0.01 ha. An initial value of 0 created problems of „division by 0“, thus this level was chosen as a starting value. The actual *maximum field size* in scenario 4 was 1.01 and 1.21 ha, but for reasons of simplification this was changed to 1 and 1.2 ha in the text.

As the reallocation of farmland is only possible in one direction (i.e. from the field for traditional farming to the CA field), this term indicated under (2.34) can simply be added to the equation calculating the nutrient pool of the conservation agriculture field and subtracted from the equation calculating the nutrient pool of the field for traditional farming.

2.5.4.1 Study Site Mashare

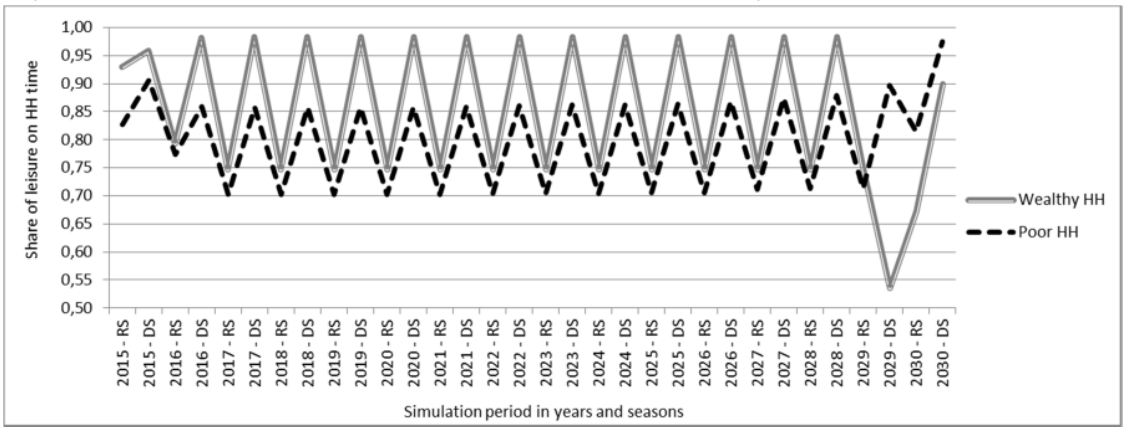
The results of Scenario 4 indicate that, despite increased land scarcity and the inability to purchase food, the basic household strategy of either household in Mashare did not change between this scenario and the baseline. The wealthy HHs still relied on a mixture of CA and traditional agriculture while the poorer HHs relied exclusively on traditional farming practices (Figs. 2.71, 2.73, & 2.74). However, total food consumption of both categories dropped. In fact, for the poor it dropped to the minimum amount needed for household survival. Soil fertility management remained largely unaffected and was characterized by stable, yet low equilibria for traditional farming and a stable equilibrium in its upper bound for CA.

Fig. 2.69: Achieved levels of food production per household category in Mashare (Scenario 4).



Source: Author's design based on model results.

Fig. 2.70: Ratio of leisure to total HH time per household category in Mashare (Scenario 4).



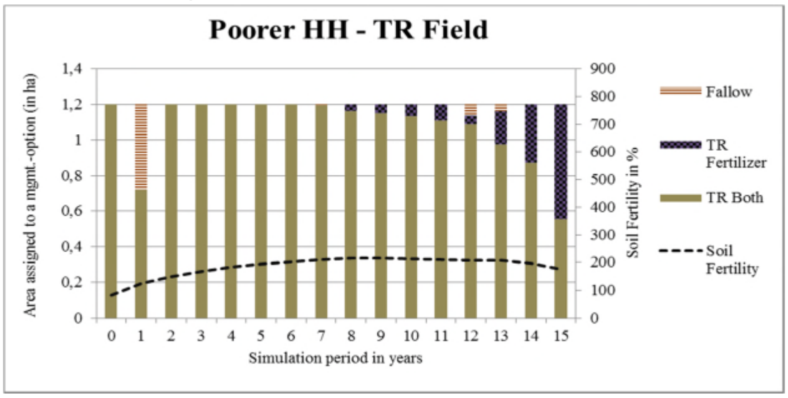
Source: Author's design based on model results.

Poorer household category

Field sizes and soil fertility

The poor HHs relied exclusively on traditional farming; fallow is virtually non-existent[76]. The main cultivation practice is *TR Both*, which towards the end of the modelling period was (to a limited extent) replaced with *TR Fertilizer* (Fig. 2.71). This allowed for a gradual build-up of soil fertility in the initial simulation periods, which stabilized at a low-level equilibrium of about 210% after the 8th simulation period. Towards the end, the level of soil fertility decreased proportionally to the area treated with inorganic fertilizer (which implied a reduction in the amount of animal manure applied to the field). This observation does not necessarily describe cyclic soil fertility management (as identified in other scenarios). Rather, it may be caused by the very high discount rate[77] (of future utility) of the poor of 25%, which reduced the contribution of the farm continuation factor to HH utility and thus of high fertility levels during the last period.

Fig. 2.71: Area cultivated and soil fertility level of the field for traditional agriculture of the poorer household category in Mashare, Namibia (Scenario 4).



Source: Author's design based on model results.

Food consumption and cash economy

Annual consumption shrank by 10%, i.e. to the minimum level needed for survival. Annual production decreased as well (by 18%); yet it remained above the minimum level needed for survival. The resulting crop surplus was sold at the market, turning food sales into a nearly as important cash income source as casual labour; while casual labour was invested up to its upper bound and yielded 34 USD annually, food sales earned on average 24 USD annually. This is mainly invested into inputs and to a very limited degree in external workers. Due to the smaller field size, total cash needs decreased slightly when compared to the baseline scenario.

Labour economy

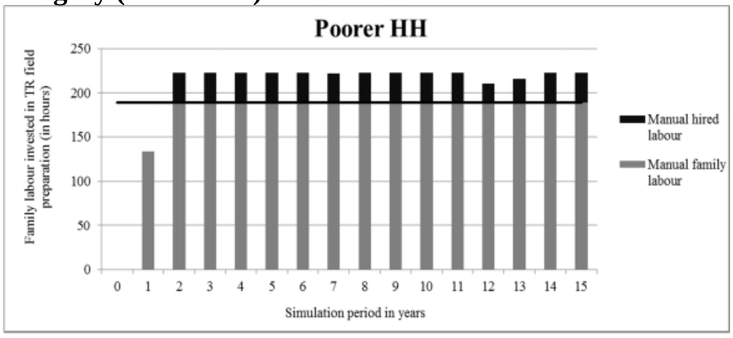
As in the baseline, the poor HHs used as much family labour as possible as well as some hired labour for traditional field preparation. This allowed them to cultivate all available land by using

[76] The fallow period in simulation period 1 is caused because the household could feed itself in period 0 by using the *starting level of stored food*. It can therefore wait with consuming the harvest of simulation period 0 and add it to the food produced in period 1. Together, both amounts allowed consuming the minimum amount needed for survival.

[77] Reminder: The model does not allow for credit.

manual preparation methods. At the same time (due to the reduced field size), they were able to reduce the total amount of hired labour. Seasonal leisure levels remained largely unaffected by Scenario 4 (+1 % in both seasons).

Fig. 2.72: Family & hired labour invested into traditional field preparation by the poorer household category (Scenario 4).



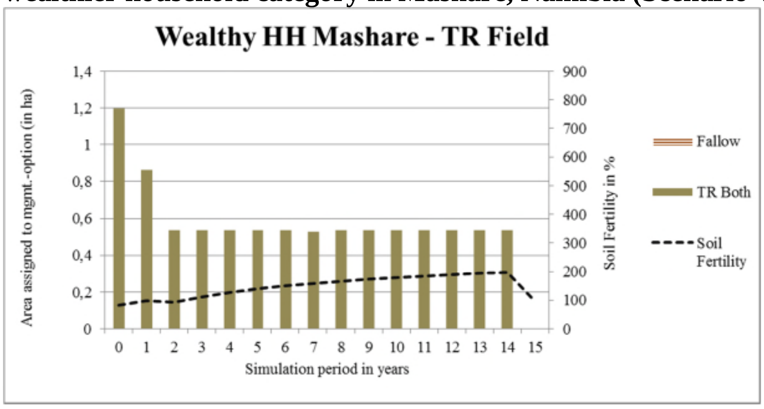
Source: Author's design based on model results.

Wealthy household category

Field sizes and soil fertility

In Scenario 4, the wealthy HHs slightly increased the average area dedicated to CA (from 0.6 ha to 0.67 ha) and reduced that of traditional farming from 1.4 ha to 0.54 ha (Fig.2.73 & 2.74). In each simulation period, they cultivated all available land and never allowed any fallow. As in the baseline, soil fertility levels of both fields continuously increased (reaching an early maximum on the CA field and increasing only slowly on the traditional agriculture field[78]). Except for the initial and end periods, the ratio of area allocated to CA and traditional farming practices remained stable[79].

Fig. 2.73: Area cultivated and soil fertility level of the field for traditional agriculture of the wealthier household category in Mashare, Namibia (Scenario 4).

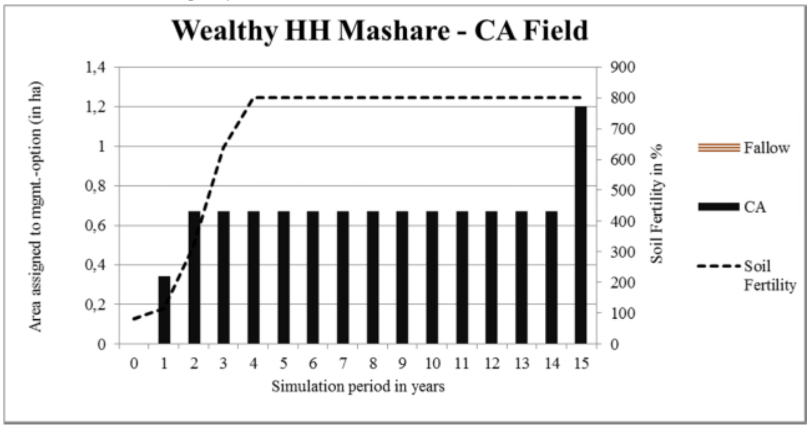


Source: Author's design based on model results.

[78] At least until this entire field (and its nutrient pool) was reallocated to CA, which explained the drop in soil fertility on the traditional field in the last simulation period

[79] In the last simulation period, all land was allocated to CA. This was probably caused by the farm-continuing factor, which induces households to sell as much food as possible. Therefore, this should not be interpreted as an abandonment of traditional farming after several simulation periods, but instead as an attribute of the modelling period coming to an end.

Fig. 2.74: Area cultivated and soil fertility level of the conservation agriculture field of the wealthier household category in Mashare, Namibia (Scenario 4).



Source: Author’s design based on model results.

Food consumption

In Scenario 4, the main food source became CA (which produced 74% of all food), while traditional agriculture was of a rather complementary nature (producing 26% of all food). However, compared to the baseline, total food consumption decreased by 25% and total food production by 23%. Still, production levels were high enough to allow consumption of more than twice than what is needed for survival.

Labour economy

The reduced area for traditional agriculture allowed reliance exclusively on ox-assisted family labour for traditional field preparation (i.e. on the field for traditional agriculture). The wealthy did not hire any labour for traditional field preparation and were never constrained by the time available for this task. Together, an increased use of CA and ox-assisted labour on the field for traditional agriculture as well as a reduced area of traditional agriculture had beneficial effects on the leisure level of the wealthy: on average, leisure increased by 5% annually. Except for the last simulation period, where CA was practiced on all available land, mean seasonal leisure increased by 12% in the rainy season (from 63% in the baseline to 75%) and 3% in the dry season (from 95% to 98%). These increases result from a reduced annual demand for family labour (-25%) and slightly increased investments in external workers during the dry season. In fact, the wealthy delegate 96% of their dry season labour to external workers, compared to 88% in the baseline (Fig. 2.70).

Cash economy

The cash economy of the wealthy remained largely unaffected by Scenario 4. Allocating a larger area to CA caused a slight increase in expenditures for inputs (+13% or +6 USD), which was balanced out by missing expenditures for food purchases.

Interpretation of Scenario 4 in Mashare

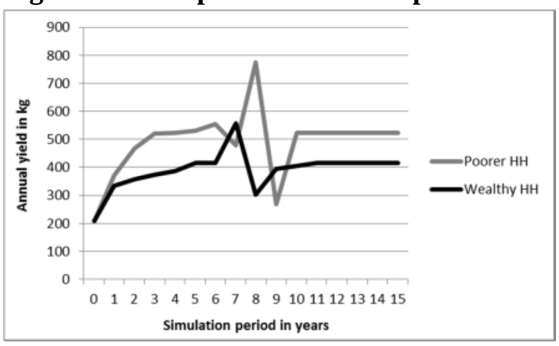
Land scarcity and the inability to clear new land led to reduced production and consumption of food for both household categories in Mashare. The wealthy managed to adapt to land scarcity by focusing on CA and reducing traditional agriculture to a complementary role. Land scarcity also resulted in a reduction in overall labour demand for farming, which in turn increased leisure rates. Contrary to this, the poorer HHs still had capacities too limited to adopt CA. As they could not compensate for increased land scarcity by increasing land productivity, their consumption level fell to the minimum amount required by the model, and no feasible model solution could be generated for a maximum field size of 1.0 ha. Together, these findings indicate that the poorer HHs were too resource constrained to adopt CA.

2.5.4.2 Study site Seronga

As in the baseline, both HH categories relied on agriculture only for meeting their basic food needs. As food purchases were disabled in this scenario, production levels rose to the level of annual minimum consumption needs, i.e. 522 kg/year for the poorer HHs and 415 kg/year for the wealthy HHs[80]. The most important change between the baseline and Scenario 4 was that both households initially relied only on *TR Both*. Yet in Scenario 4, at the middle of the modelling period, they now started to switch to a strategy relying solely on CA. This shows that they adopted CA to cope with the constraints imposed by Scenario 4 (land scarcity and no food purchases). The reason for the gradual change to CA will be analysed below.

Furthermore, households achieved constantly increasing levels of soil fertility (Figs. 2.76-77 + Figs. 2.80-81) and did not rely on cyclic nutrient mining and replenishment[81]. This was made possible by low per-hectare yields and the fact that on both fields, animal manure and inorganic fertilizer were applied. Due to land scarcity, fallow periods played a slightly less important role in traditional farming than in the baseline scenario. Figs. 2.77 & 2.81 indicate that these reduced fallow periods allowed stabilization rather than a build-up of soil fertility levels.

Fig. 2.75: Total production levels per household category in Seronga (Scenario 4).



Source: Author's design based on model results.

[80] However, some variation in production levels can be observed (Fig. 2.75). This is possible because in the model, households were able to consume the harvest achieved in the rainy season of one year either in the same year's dry season and/or in the rainy season of the following year.

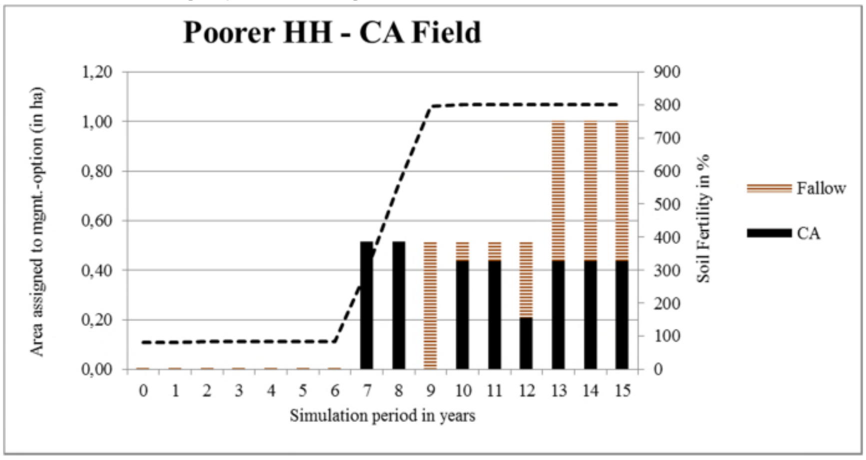
[81] The drop in soil fertility on the traditional field in simulation period 7 (Fig. 2.77 & 2.81) stemmed from the fact that land (and therefore nutrients) are reallocated to the CA field, thus reducing the nutrient pool (= soil fertility).

Poorer household category

Field sizes and soil fertility

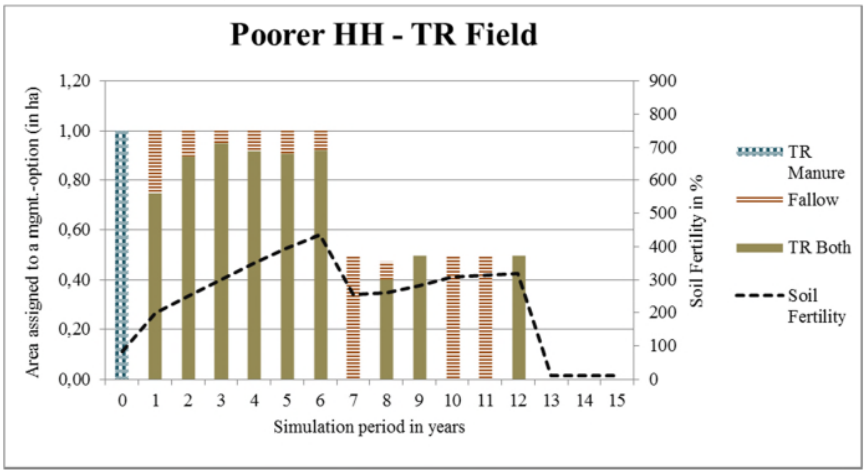
After an initial period of manure application (*TR manure*), households relied exclusively on *TR Both*. This resulted in a gradual build-up of soil fertility levels (Fig. 2.77). Over the same time, the yield level of traditional agriculture increased, i.e. from 207 kg/year[82] in simulation period 0 to 554 kg/year in period 6[83]. Starting in simulation period 7, the poorer HHs gradually switched to CA by abandoning traditional agriculture (Fig. 2.76). As households needed to produce all food on their own farm, they doubled (compared to the baseline) the area allocated to either CA or *TR Both*.

Fig. 2.76: Area cultivated and soil fertility level of the conservation agriculture field of the poorer household category in Seronga, Botswana (Scenario 4).



Source: Author's design based on model results.

Fig. 2.77: Area cultivated and soil fertility level of the traditional field of the poorer household category in Seronga, Botswana (Scenario 4).



Source: Author's design based on model results.

[82] Reminder: Harvest has been standardized into millet-equivalents, i.e. each kg provides kcal equivalent of 1 kg millet (3,480 kcal/kg).

[83] The low initial production levels are possible because of their starting level of stored food of 700 kg.

A rapid soil fertility increase could be observed on the CA field during periods 6-9. It resulted from land re-allocation from the traditional field to the CA field – and thus from a re-allocation of its soil fertility. Under such soil fertility levels, CA needed to be carried out on an area of 0.51 ha in order to produce the minimum amount of food required by the poor. However, as soon as the maximum level of soil fertility was achieved, this area could be reduced to 0.44 ha.

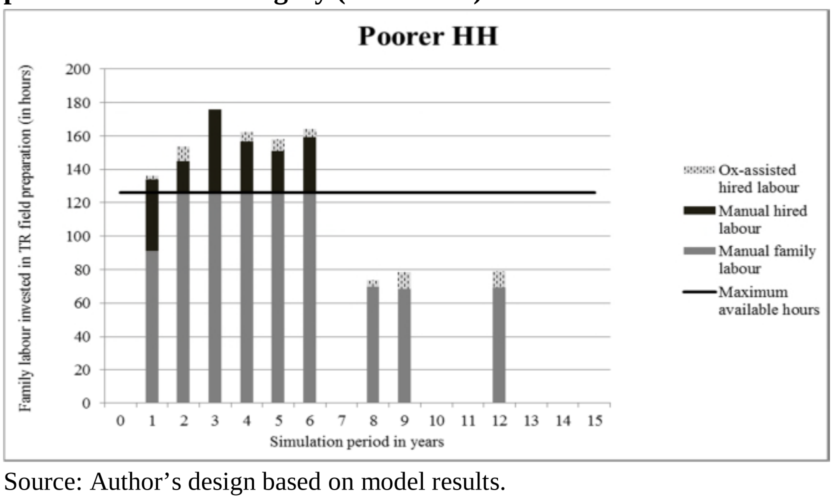
Cash economy

For financing the inputs needed for CA, the poor are forced to engage more strongly in casual labour during the middle of the modelling period. Compared to the earlier periods of traditional agriculture, the income derived from casual labour rose by 48%. However, compared to the baseline, the mean income obtained from casual labour decreased from 198 USD/year to 119 USD/year. This income drop was caused by the fact that no food purchases were possible in Scenario 4. In the baseline, more labour was invested into casual labour to purchase food items at the market.

Labour economy

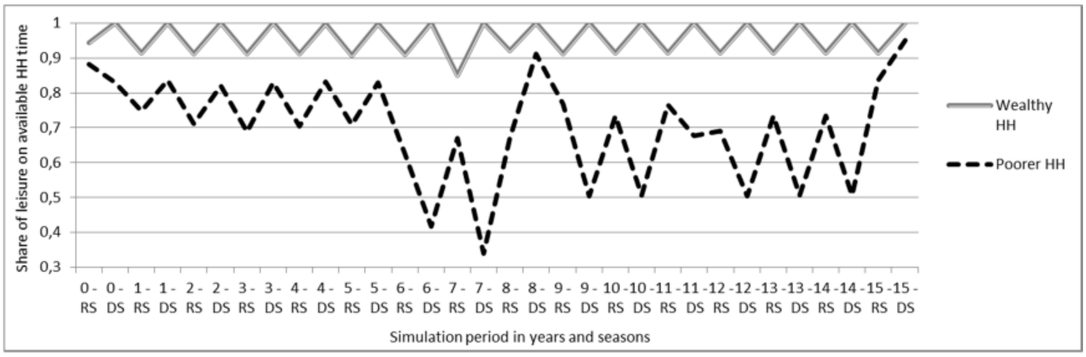
During the initial build-up period, households were regularly constrained by the time for traditional field preparation. They therefore relied to a certain extent on hired labour, both manual and ox-assisted (Fig. 2.78). More importantly, leisure levels dropped significantly, from on average 79% per year in the baseline to 70% per year. It even dropped to an absolute minimum level of 34%, which is lower than for any other HH category in any other scenario (Fig. 2.79). Therefore, tightening the land constraints had a negative impact upon the poorer HHs' consumption of leisure. In the first simulation periods of Scenario 4, these households were constrained by the time available for traditional field preparation. For this task they used all available *family* labour as well as both ox-assisted and manual *hired* labour. Later, by switching to CA, they managed to overcome this constraint. The switch to CA led to an increased demand for labour in the dry season. The poorer dealt with this by re-allocating cash from expensive labour in the rainy season (for traditional agriculture) to hiring cheaper labour in the dry season.

Fig. 2.78: Family & hired labour invested into field preparation under traditional agriculture by the poorer household category (Scenario 4).



Source: Author's design based on model results.

Fig. 2.79: Ratio of leisure to total available household time per household category in Seronga.



Source: Author's design based on model results.

Summary of Scenario 4 for the poor in Seronga

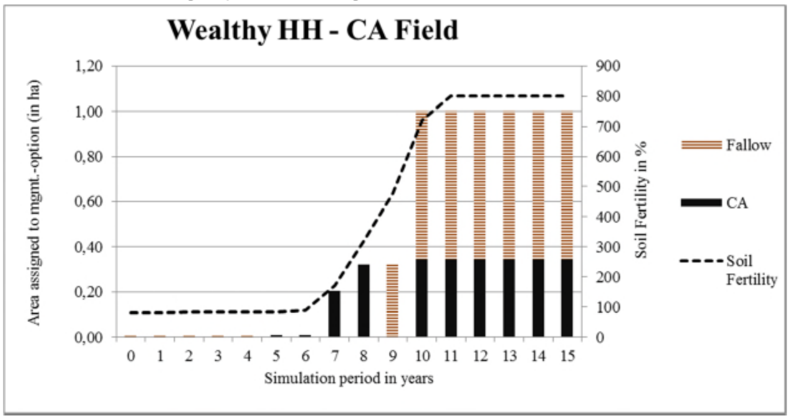
The results imply that the poor HHs could manage to adopt sustainable intensified farming practices and survive under extreme situations by cultivating an area of only 0.34 ha – 0.51 ha (following the unlikely assumption that all other livelihood sources provided a stable and reliable food income). Therefore, Scenario 4 indicates that within certain limits, the poor HHs in Seronga were able to successfully adapt to increasing land scarcity.

Wealthy household category

Field sizes and soil fertility

The wealthy HHs abandoned their baseline strategy (alternating periods of *TR None* and *TR Both*) and followed a strategy similar to that of the poor. In initial simulation periods, the wealthy relied on *TR Both*[84] and switched to CA[85] in the middle of the modelling period. However, in contrast to the poor, this switch occurred swiftly. It was not accompanied by a longer period where both practices were carried out simultaneously (Fig. 2.80 & 2.81).

Fig. 2.80: Area cultivated and soil fertility level of the conservation agriculture field of the wealthier household category in Seronga, Botswana (Scenario 4).

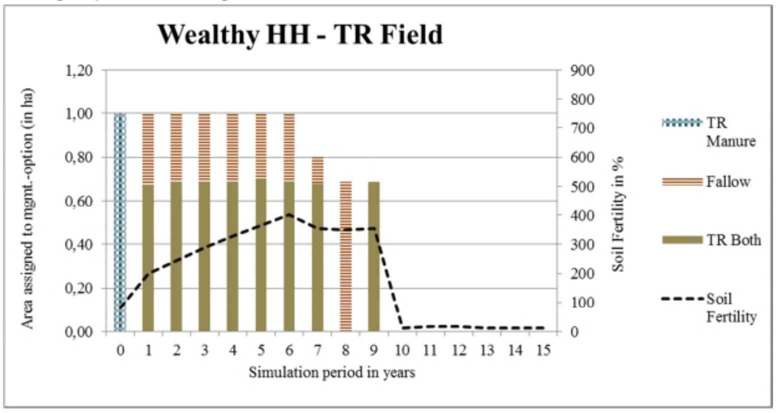


Source: Author's design based on model results.

[84] *TR Both* is defined as traditional agriculture using both available inputs in fixed quantities, i.e. 20 kg of fertilizer and 5 t of manure

[85] CA is defined here as the combination of planting basins with 0.5 t of fertilizer and 15 t of manure, using minimal tillage.

Fig. 2.81: Area cultivated and soil fertility level of the traditional field of the wealthier household category in Seronga, Botswana (Scenario 4).



Source: Author's design based on model results.

Labour economy

Due to their reliance on traditional agriculture in the first periods, the wealthy HHs used nearly all available, ox-assisted family labour for traditional field preparation. However, the time for traditional field preparation never became a binding constraint.

In simulation period 10, the wealthy abandoned traditional agriculture and switched to CA. This had a profound impact on leisure and labour use; the wealthy now delegated all field preparation labour to external workers, which led to an increase in their leisure levels (from on average 90% in the baseline to 96% in Scenario 4, which became possible because here, cash cannot be invested in food purchases). In fact, after switching to CA, they achieved leisure levels of 100% in the dry season. In the rainy season, the wealthy continued to hire all available external workers. However, due to the upper bound of 50 hours on external labour in the rainy season (as opposed to 2,000 in the dry season), leisure levels of the rainy season remained unaffected.

Cash economy

Just as in the baseline, the wealthy HHs continued to rely on fixed cash income as the sole income source. However, as Scenario 4 does not allow food purchases, households re-invested this income into field inputs and hired ox-assisted labour.

Summary of Scenario 4 for the wealthy in Seronga

Remember, in the baseline, the wealthy HHs relied on a least-effort strategy of food purchases and cyclic soil fertility management to achieve minimum consumption levels. In Scenario 4, food consumption had to be achieved on less land and exclusively by their own agricultural production. This changed the optimal household strategy. Soil fertility was now continuously increased, and households followed a new least-effort strategy: i.e. by switching to CA. Now, they were able to delegate most labour to external workers. The cash for hiring labour was re-allocated from food purchases.

Interpretation of Scenario 4 in Seronga

In Scenario 4, land scarcity and the inability to purchase food induced a switch from traditional agriculture to CA. None of the households were constrained in cash because both types could increase income from casual labour. This meant that both would have already had the resources to adopt CA in the first period. However, they switched to it only gradually. This surprising finding may be explained a) by the high initial food endowment as well as b) the rising soil fertility levels.

First, there was an initial food endowment of 700 kg. Since it could be consumed in the first simulation period, the harvest achieved in the first period could be saved and consumed only in the following, i.e. the second period (and part of the food produced in the second period could be consumed in the third period and so on). This resulted in trickle-down effects, which were the main reason why households managed to feed themselves by using traditional agriculture. In fact, only in simulation period 6 did the poor actually start to produce an amount large enough to cover their minimal food needs. This was the simulation period where they achieved a peak level of soil fertility under traditional agriculture, and still they managed to produce only 30 kg more than their minimum food requirements (554 vs. 522 kg/year[86]). Therefore, traditional farming alone was insufficient to ensure household survival under the scarce land conditions of Scenario 4. Households needed to rely on complementary means to feed themselves. Up until the middle of the modelling period, this was the initial food endowment, which "trickled through the simulation periods" but became smaller each year. As soon as it was used up, households were forced to switch to CA.

However, there may be a second reason for the late switch. Theoretically, the poor managed to produce sufficient food until simulation period 6. Why did they not continue with this practice? Previous scenarios indicated that there may have been a certain moment in traditional agriculture where nutrients lost due to harvesting exceeded those of nutrients supplied by field inputs. This level generally lay between 200-300% of soil fertility. In period 6, soil fertility of the poor already exceeded 400% and increased their yield to such a level that nutrients extracted by harvesting may have been higher than those supplied by field inputs. The equilibrium between nutrient supply and extraction is likely to vary with field size, yield level, and fallow area. It may be assumed that traditional agriculture in Scenario 4 cannot sustain production levels above 554 kg/year over the long run. Soil fertility and therefore yields will drop to a level below the minimum food needs (this could indicate the existence of Ruthenberg's (1971) low-level equilibrium trap). Households therefore switched to CA, where they quickly achieved maximum soil fertility levels and stable yields at 522 kg/year (which they could easily increase by cultivating more land).

The optimal strategy of Scenario 4 can also be interpreted in a different way. CA requires significantly more cash and labour/ha than traditional farming. Therefore, it is possible that

[86] Reminder: it is assumed here that population growth has no influence on household structure but rather on the total number of households and resources available for each household.

investments into CA only became worthwhile after soil fertility had reached a certain minimum level to ensure sufficient returns on investments (in terms of food produced). In Scenario 4, both households appeared to rely on traditional agriculture to build up soil fertility. Only after having achieved a level of approx. 400% of soil fertility did they allocate part of their field to CA. This interpretation implies that for achieving a sustainable intensification of smallholder farming, it can be optimal to first use improved traditional farming practices to create better growing conditions that favour the adoption of CA. Therefore, in order to induce sustainable intensification, an intermediary stage of improved farming practices may (under certain conditions) be required.

These findings help in understanding the trade-off decisions between traditional farming and CA. Scenario 4 revealed that CA could be carried out by both HH categories and that a growing scarcity of land increased the comparative advantages of CA over traditional agriculture.

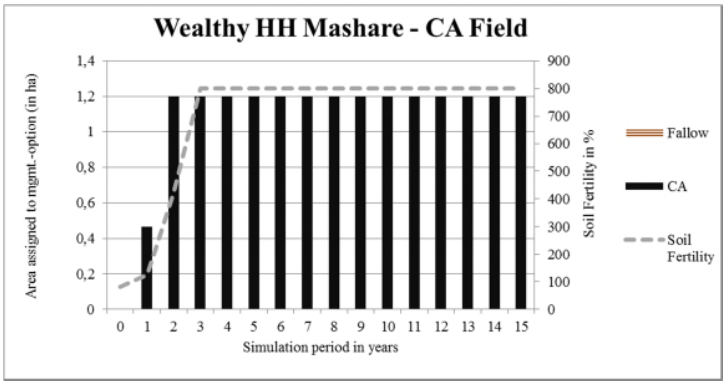
Due to the drought-prone character of traditional farming (which was not simulated), its potential role for building up soil fertility is an optimistic assumption. However, initial investments into soil fertility cannot only be achieved by improved traditional farming. For instance, an increased (temporary) reliance on one of the non-modelled livelihood sources may allow households to reduce the intensity of farming and achieve increased levels of soil fertility. Therefore, the second interpretation of Scenario 4 (i.e. investments into soil fertility may be needed to pave the way for CA) appears logical and merits the attention of future research.

In general, Scenario 4 confirmed the conclusions on sustainable intensification drawn in part 1 of this study; with increasing land scarcity, the likelihood of voluntarily adopting CA will increase in the study sites.

2.5.6 Scenario 5 – Combining reduced input prices of CA with an elevated land constraint

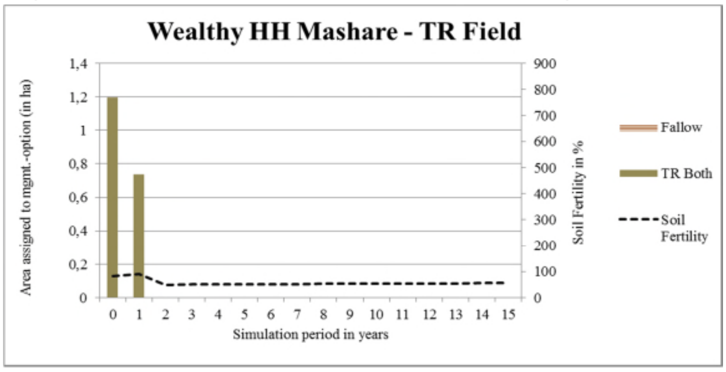
The results of Scenario 4 in *Mashare* implied that the poorer HHs may have wanted to adopt CA but were too constrained in resources (mainly cash) to do so. Therefore, the last scenario will combine the assumptions of Scenario 4 (land is scarce and food purchases not possible) and Scenario 2 (CA costs reduced by 50%). The goal is to assess whether or not the adoption of CA increased compared to Scenario 4. Therefore, the results presented here will show only the area allocated to the various production practices per study site.

Fig. 2.82: Area allocated to CA by the wealthy households in Mashare in Scenario 5.



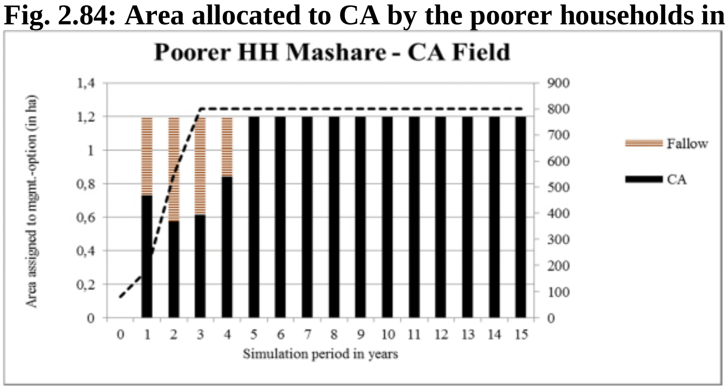
Source: Author's design based on model results.

Fig. 2.83: Area allocated to traditional farming by the wealthy households in Mashare in Scenario 5.



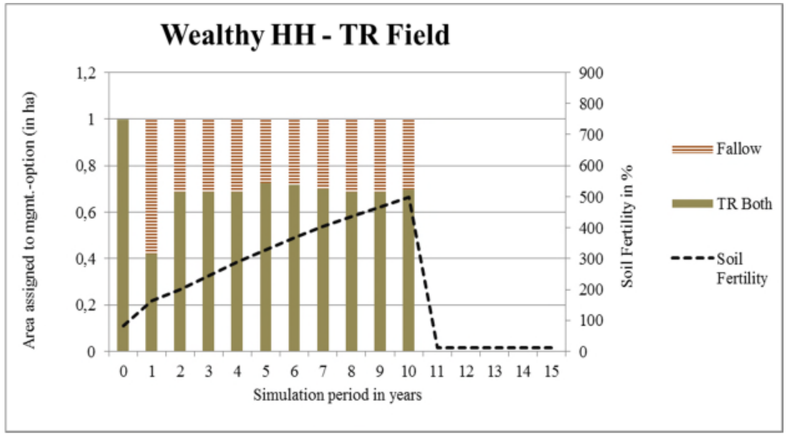
Source: Author's design based on model results.

Fig. 2.84: Area allocated to CA by the poorer households in Mashare in Scenario 5.



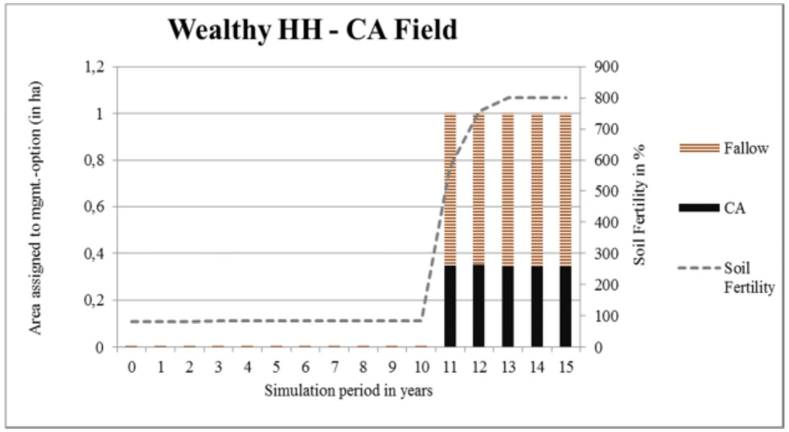
Source: Author's design based on model results.

Fig. 2.85: Area allocated to traditional farming by the wealthy households in Seronga in Scenario 5.



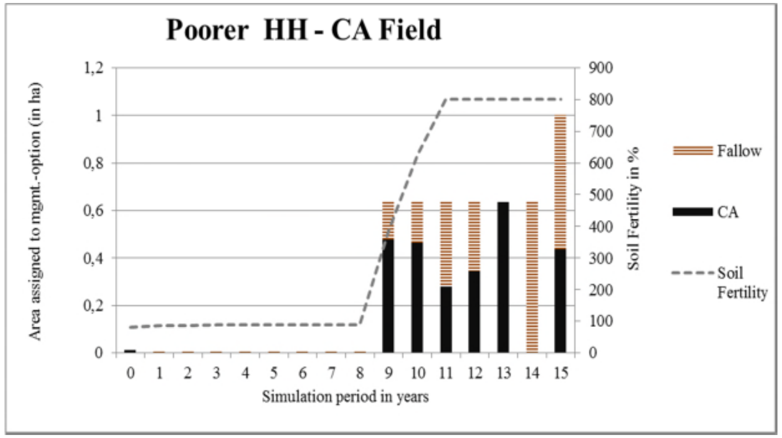
Source: Author’s design based on model results.

Fig. 2.86: Area allocated to CA by the wealthy households in Seronga in Scenario 5.



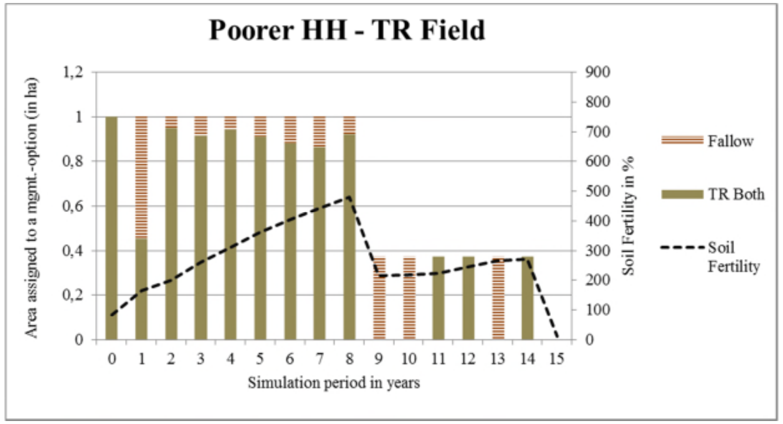
Source: Author’s design based on model results.

Fig. 2.87: Area allocated to CA by the poorer households in Seronga in Scenario 5.



Source: Author’s design based on model results.

Fig. 2.88: Area allocated to traditional farming by the poorer households in Seronga in Scenario 5.



Source: Author’s design based on model results.

Results & interpretation of Scenario 5

The results for Mashare (Figs. 2.82 - 2.84) illustrated the following:

i) So far, it was a lack of cash that kept the poor from adopting CA.

ii) Under increased land scarcity and inability to purchase food, a subsidy of 50% on the input costs of CA would cause households to completely switch to CA on all available land.

The results for Seronga (Figs. 2.85 - 2.88) re-affirm previous findings: It was not a lack of cash that caused the late switch to CA. As in Scenario 4, CA was adopted only after a few periods. This indicates that adoption occurred primarily out of necessity because traditional agriculture did not manage to provide sufficient food over the entire modelling period. Another possible reason is that investments for CA paid off only after a certain soil fertility level was achieved (see interpretation of Scenario 4 for Seronga). It appears as if it was not mainly the costs of CA, but the labour needs that slowed its adoption in Seronga. This was probably the result of the low importance of farming in Seronga.

2.6 Conclusion

This study set out to explore options for the sustainable intensification of smallholder farming systems in the Okavango river basin (ORB). It followed Boserup's (1965) theory of *endogenous (Boserupian) intensification* and Ruthenberg's (1971) framework for the analysis of tropical farming systems.

In part I, I identified the basin's dominant smallholder farming systems and their main drivers of change. I also assessed their ecological sustainability as well as the most likely future development pathways.

Building on the results of the farming system analysis, part II of the study developed a bio-economic model of typical farm households of the lower Okavango river basin. The model can be used to identify optimal household strategies for each typical household, i.e. a wealthier and a poorer household category. It specifically evaluates the role that conservation agriculture (CA), as an example of a sustainably intensified farming practice, may play in these optimal farming strategies.

Currently, there is considerable debate on the role of CA for the future of smallholder farming, especially in Sub-Saharan Africa. This study sought to answer the following questions:

1) How can the dominant smallholder farming systems in the study sites and the experimental CA approach be characterized, and what are the respective constraints to crop production?
2) Are the dominant smallholder farming systems ecologically sustainable?
3) Is *Boserupian intensification* likely to occur and succeed in the study sites in the near future?
4) What are the optimal household strategies in these farming systems and which role does CA play?
5) Are these optimal household strategies ecologically sustainable?

The insight generated is of considerable importance for the ORB because the region is currently transitioning from a relatively isolated and sparsely populated state of development (in an near-pristine environment) towards a more densely populated state. This transition is accompanied by a high urbanization rate and the proliferation of a consumption-driven, cash-based lifestyle. Together, these trends lead to growing pressure on local natural resources. Therefore, there is need to identify land use strategies that meet the resource needs of a growing population while maintaining the stability of local ecosystems (such as the Okavango Delta as a UNESCO world heritage site).

This study contributed to the goal of assessing options for future farming system development by i) generating insights on what contributes optimally to smallholder farming strategies in the different parts of the ORB and ii) how sustainable intensification may be achieved in its drier mid- and low-river areas where farming is stationary and less characterized by shifting cultivation. The following paragraphs synthesize the empirical findings from this study with respect to the individual research questions. Afterwards, implications from these results (for future research) as well as policy implications will be deducted. The chapter concludes with a critical look at this study's main limitations and a summary of its main take-home messages.

Empirical findings

The main empirical findings are both study site specific and household category specific. They were presented in detail in Chapter 1.6 of part I of this study as well as in Chapter 2.5 of part II of this study. Below, they are synthesized for each research question:

1) ***How can the dominant smallholder farming systems in the study sites and the experimental CA approach be characterized and what are the respective constraints to crop production?***
   a) The farming systems in all study sites can be characterized as being in a typical stage of tropical smallholder agriculture defined by Ruthenberg (1971), i.e.: *shifting cultivation* under long-term forest fallow in Cusseque, Angola; *semi-permanent* to *permanent rain-fed agriculture* in Mashare, Namibia; and *semi-permanent agriculture* in Seronga, Botswana. CA as practiced in Mashare represents an approach that aims to rehabilitate soil fertility. Although this is not a labour-saving approach, it is characterized by reduced seasonality of labour demand.
   b) The three study sites can be analytically linked by the same main drivers of change. They are part of the farming system continuum described within the Boserup-Ruthenberg framework. This framework helps identify *scarcity of arable land* as a main driver of change in all farming systems considered. Land scarcity is caused mainly by increasing population densities and natural resource use.
   c) Constraints to agricultural production are caused by the biophysical setting of each study site as well as the degree of permanency of farming. While the Angolan highlands are characterized by semi-humid conditions that are relatively favourable for crop production, the Kalahari basin is characterized by low and erratic rainfall levels and a lower natural soil fertility. Seasonality of labour demand is another main constraint to farming in Mashare & Seronga, while it is of lesser importance in Cusseque.
   d) The adoption of production practices is situation specific and depends on important efficiency trade-offs; while CA is the most land-efficient practice, traditional farming practices (especially *shifting cultivation* in Cusseque) are more labour efficient.

2) ***Are the current dominant smallholder farming systems ecologically sustainable?***
   a) As a shifting cultivation system, Cusseque in Angola is characterized by the exploitation of soil fertility during the cultivation period and its replenishment during fallow. Land availability (which allows long-term fallow periods) is therefore the key to the system's ecological sustainability. This finding puts the perceived land abundance of Angola into perspective. Any large-scale reduction of land under management of rural communities, e.g. via the planned establishment of agro-industrial projects, may destabilize the nutrient equilibrium achieved in Cusseque and cause soil nutrient mining.
   b) Mashare in Namibia is characterized by degraded soils of low fertility. It is likely that a low-level equilibrium between yields and natural soil nutrient regeneration has been already achieved. At a punctuated equilibrium of low fertility, households are rarely able to feed themselves with crop production alone. At the same time, there was a breakdown

of the cattle economy during the last decades. This hints at overgrazing and thus the degradation of other livelihood sources. The farming system in Mashare must be regarded as ecologically unsustainable.

c) Seronga in Botswana is in a comparable situation to Mashare. However, overexploitation remains a localized phenomenon and can be observed mainly around Seronga Town and the cattle posts. When considering all land available to Seronga's rural community, farming in this study site could theoretically be carried out in an ecologically sustainable way. However, current trends, such as population concentration along the panhandle and the restriction of crop production to this area (zoning), turn the farming system into an ecologically unsustainable one.

d) If evaluated over a longer time period, none of the current farming systems can be considered ecologically sustainable. Under increasing population densities and resource use rates, none of the traditional systems will be able to both i) provide for their rural population and ii) avoid the ecosystem degradation.

3) *Is* Boserupian *intensification likely to occur and succeed in the study sites in the near future?*

a) Regular government intervention in Seronga and Mashare (e.g. disaster relief) can be interpreted as disincentives to endogenous adaptation efforts. *Boserupian* intensification is therefore unlikely to occur on a large scale in either study site. In Cusseque, due to the persistence of subsistence production (which achieves regular crop surpluses), there is not yet any need for smallholders to develop and adopt intensified farming practices.

b) The best chance to **induce** *Boserupian* intensification is in Mashare, where the main production constraints (*scarcity of arable land* and pronounced *peaks in seasonal labour demand*) could be overcome by adopting CA. In Seronga, smallholders are frustrated with crop losses due to livestock and wildlife damages. This makes it unlikely that households will voluntarily invest in farming. The highest adoption likelihood may exist for households who own small fields near Seronga Town, i.e. where animal damages are less common and where arable land is scarce. In Cusseque, the voluntary adoption of CA is highly unlikely. Here, only a dramatic decline in land availability or a commercialization of farming might provide sufficient incentives for intensification.

4) *What are the optimal household strategies and which role does CA play?*

Optimal farming strategies differ strongly between study sites and household categories. These differences stem largely from changing parameter levels (e.g. in prices, coefficients of the production constraint, etc.) as well as the weights of the utility function. The following main observations could be made:

a) While the wealthy households were constrained more by *land availability*, the poor were constrained by *time available for traditional field preparation* (i.e. peaks in seasonal labour demand). These constraints resulted in a very high annual leisure rate that lay mainly between 70-90% for both household categories.

b) CA can play a role for the wealthy and poor households. In general, relaxing the two production constraints (mentioned above) reduced the relative importance of CA, while elevating these constraints increased CA's role in optimal farming strategies.
c) Cash availability determined how easily a household adopted CA. The fixed income of the wealthy households allowed them to switch flexibly between farming practices, while the poorer needed to follow a complex strategy of cash income generation before they were able to purchase inputs. For example, in Mashare the poor needed to gradually build up soil fertility[87] in order to generate a crop surplus that could be sold at the market. At the same time, Scenario 5 revealed that under reduced land availability, it was mainly a lack of cash that kept the poor from using CA[88].

5) *Are these optimal household strategies ecologically sustainable?*
Due to the way the model was programmed, all identified household strategies were ecologically sustainable over the modelling period. This was due to the way that ecological sustainability was defined; as long as periods of soil rehabilitation and soil mining achieved nutrient equilibrium, they were considered as ecologically sustainable. However, if the goal was to continuously build up soil fertility, then only a few strategies achieved this – and maybe it would be better to label such farming strategies as *soil rehabilitating* instead of *sustainable*.

Synthesis of findings

Smallholders in the study sites are part of a global continuum of agrarian societies and their respective farming systems. This does not suggest that they will undergo a predetermined evolution from one typical stage of development to the next one. Nevertheless, such a classification helps identify typical opportunities and threats during their future development. In fact, the results indicate that smallholders at the study sites are affected by a common set of drivers of change and constraints to agricultural production. In all study sites, the two most important constraints are the *levels of land scarcity* and the role of *seasonality in labour demand* (approximated by *time available for traditional field preparation*). In the future, the levels of these drivers can be expected to increase even further because the ORB will continue to be affected by population growth and rising pressure on natural resources (due to its economic transition and the effects of climate change). These findings illustrate that smallholders in the study sites are not in a static state but in a process of constant adaptation to changing levels of these drivers.

[87] Reminder: *Soil fertility* is defined here as a ratio of the current level of macronutrients N, P, and K compared to the level of these nutrients needed for producing a per hectare harvest of 500 kg. It is increased by the application of field inputs (macronutrient content of manure or inorganic fertilizer) and decreased by harvesting.
[88] It has to be noted that the installment costs of conservation agriculture, i.e. mainly for constructing fences, have not been considered. Instead, the focus of analysis lay on the role that either practice may play in an optimal farming strategy.

The implications of this finding are important because they indicate that smallholders (if not assisted by appropriate policies) are likely to continue on a pathway of gradual resource degradation. In the long to medium term, households are in danger of falling into vicious cycles of soil degradation and household impoverishment. At the same time, model results imply that smallholders have the potential to adopt sustainably intensified household strategies. Projections also imply that under tightening production constraints, the voluntary adoption of these strategies will become more likely. The remaining results of this study can be generalized as follows:

- As a result of increasing land scarcity and a slow rate of smallholder adaptation to this scarcity, land availability remains the main determinant of the ecological and economic sustainability of farming systems in the study sites.
- A smallholder's decision whether or not to adopt a certain production practice depends to a certain degree on achieved *levels of soil fertility* and the level to which *land scarcity* and *seasonal peaks in labour demand* constrain crop production.
- Traditional agriculture and CA may complement or replace each other. Traditional agriculture may even pave the way for an improved management based on CA.

  There are big differences between these practices in terms of land, labour, and energy use efficiency as well as their cash needs. This creates various potential trade-offs. Site-specific conditions determine which trade-offs are optimal for a specific household. However, the following generalization can be made: with increasing land constraints and rising seasonal peak in labour demand (for traditional field preparation), CA is more likely to play an important role in the stabilization and improvement of rural livelihoods in the study sites.
- Within the model, soil fertility represents the core means for (natural) capital accumulation. Depending on resource endowment & scenario specification, it is:
  - i) used as a quasi-bank account into which households make initial investments from which they sustain themselves over the course of the modelling period.
  - ii) managed in a cyclic way where a longer period of nutrient mining is balanced out by a shorter period of nutrient rehabilitation via input application.
  - iii) kept at low-level equilibrium between yields & soil fertility levels.
  - iv) continuously increased until it reaches its upper bound.

  Thus, soil fertility may serve as a quasi-bank account for smallholders (natural capital) in the study sites. This is important especially for the poor households that have a limited ability to invest in livestock or for whom these investments are too risky (due to high livestock mortality in Mashare or the effects of droughts in general).
- Building up soil fertility may allow households to reduce labour or input investments in agriculture. In the model, households had no choice but to re-invest the time saved by increasing soil fertility into leisure or casual labour. In reality, labour and/or cash could theoretically be invested to achieve a diversification or specialization of livelihood strategies. This might even provide a stepping stone out of agriculture. Therefore, improved farming systems and household strategies may play an important role even for policies that aim to reduce smallholder dependence upon agriculture.

Theoretical implications

This study argues that it is possible to link very different models of tropical smallholders by using the analytical framework developed by Boserup (1965) and Ruthenberg (1971). This framework allows an in-depth farming system analysis (which lies at the heart of each smallholder model) based on a globally valid set of indicators, which thereby allows for a certain degree of standardization in model formulation. In this study, one of the most binding constraints for crop production was the 'seasonality of labour-demand'. It especially kept the poorer households from cultivating all available land and caused a high leisure (or unemployment) rate. Ignoring seasonality and focusing only on total household resource endowment would have led to wrong results. The same holds true for soil fertility. This study argues that a correct representation of any smallholder farming system requires that at least an analysis needs to be done on how the respective system copes with the typical challenges to tropical farming identified in the framework (soil fertility management, seasonality of labour demand, etc.).

Policy recommendations

This study argues that current smallholder policies in the ORB are insufficient to reduce the danger of vicious cycles of soil degradation and household impoverishment. If policy makers do not adopt more decisively pro-smallholder policies, it is likely that extreme rural poverty will increase over the next decades. Via rural-urban migration, this has the potential to also affect regional urban centres.

Currently, the speed with which land is getting scarce appears to be higher than the speed with which smallholders adapt to this scarcity. This process is likely to accelerate, because in addition to climate change and population growth, governments in Angola and Namibia plan to introduce agro-industrial irrigation projects. Together, these trends will further reduce land availability for smallholders in the ORB.

Increasing smallholders' access to arable land is a naive answer to this challenge; it may only postpone the current crisis into the future and thus result in an even more severe degradation of the ORB's ecosystems. Boserup (1965) argues that increasing access to land will in fact reduce the likelihood of intensification. Therefore, a better option than increasing land access may be to assist smallholders in developing and adopting sustainably intensified farming systems. The term *assist* suggests that there is no prescribed recipe that should be promoted – instead, smallholders' innate ability to develop locally adapted solutions should be strengthened. This may occur over the short run in the form of promoting and subsidizing various improved production practices, based on both traditional practices and sustainably intensified practices. CA certainly represents one of the best available options for sustainable intensification in the ORB and should be promoted as an important land use practice in any pro-smallholder policy. However, in Mashare current levels of manure and mulch biomass production is too low to sustain the widespread adoption of CA. A main reason for this may lie in inadequate rangeland management, which results in overgrazing and reduced animal health. The resulting lack of biomass and manure will be a central bottleneck for the adoption of CA. Future research is needed to identify means for the production of sufficient amounts of animal manure and mulch biomass.

In the long run, pro-smallholder policies may include investments into infrastructure, which improve smallholder's market access and increase their commercialization. Such a trend has its own challenges and would need to be accompanied by appropriate research. The results presented here may lose their validity for commercialized smallholder households.

The role of land scarcity in the ORB's smallholder communities also indicates that current government plans for the establishment of large-scale agro-industrial irrigation schemes in Namibia and Angola may have more severe effects on rural livelihoods than what policy makers may expect. Although they potentially increase casual employment opportunities, they also restrict the land available to smallholders. Therefore, they drive local impoverishment processes.

Limitations of the study

First, the presented bio-economic model ignored the gender specificity of labour, i.e. the fact that some tasks are carried out mainly by males and others by females (Hecht 2010). This simplification helped to achieve a fairer comparison of traditional agriculture with CA (which assumes equality of labour between the sexes). It is assumed here that as soon as CA is adopted by a majority of smallholders, a rethinking of gender roles will set in, which will dissolve the traditional division of labour also for traditional farming. In fact, this process can already be observed in the study sites and has been identified by Ruthenberg (1971) as typical for more permanent stages of agriculture.

Second, the model compared only the *annual* input needs of traditional farming and CA. As the goal was to assess whether or not CA can play a stable role in household strategies, initial investments, e.g. into fencing or biochar, were not considered. It can be expected that especially the poor depend on assistance during the first period for the successful adoption of CA.

It also has be noted that the optimal household strategies (identified here) are based on dynamic optimization over an entire modelling period, i.e. under the assumption that farmers are aware of the effect that decisions have on production levels in any period. This approach does not reflect actual "optimal" household behaviour because no household is aware of the exact effect of its actions on future yield levels. Instead, the optimal strategies (identified here) show pathways towards improved systems and indicate important bottlenecks in production. The results can be used to assist decision makers in policy design or deepen extension services' understanding of the farming systems. They are not to be used as guidelines for actual smallholder decision making[89].

Lastly, the findings apply mainly to subsistence-oriented smallholders (selling up to 50% of their harvest) that rely on manual labour. Under full commercialization and the use of machinery and fossil fuel–based inputs, the results of this study may lose validity. However, this study argued that even over the medium run, the majority of rural smallholder households will stay dependent on manual labour-based, subsistence-oriented agriculture. Therefore, efforts towards the sustainable intensification of current farming systems are the best available option for avoiding

[89] In this case, a stochastic model relying on recursive optimization, i.e. where each simulation period is optimized individually, would have been better suited.

Summary

This study sets out to identify optimal strategies of farm households in three study sites within the Okavango River Basin (ORB). Specifically, it assesses the role which conservation agriculture may play for the sustainable intensification of smallholder agriculture in the ORB; a main focus lies on whether or not households have sufficient resources to adopt this improved practice.

By conducting an in-depth farming system analysis, this study confirms that the assumptions of the Boserup-Ruthenberg framework for the analysis of agrarian societies hold true for the research area. This means that local farming systems can be understood as belonging to a continuum of tropical smallholder farming systems which are linked by *land scarcity* as a main driver of change. Furthermore, the study sites in the mid- and low-river areas are affected by increasingly binding constraints to farming, mainly in regards to a pronounced *seasonality in labour-demand, scarcity of arable land* and *erratic rainfalls*.

Currently, the farming systems in all three study sites are affected by degradation dynamics and likely to follow a pathway of *agricultural involution* (while *Boserupian,* or endogenous, *intensification* appears less likely). However, this process may create just those conditions that favour the likelihood of success of externally induced efforts towards the sustainable intensification of smallholder agriculture.

Building on the farming system analysis, a bio-economic farm household model is developed. Its goal is to assess which specific combinations of farming practices (traditional practices and/or conservation agriculture) allow for the sustainable intensification of smallholder agriculture in the study sites. To achieve this goal, the model simulates i) seasonality in demand for labour and field inputs and ii) the dynamic feedback between farm-management and empirically assessed levels of soil fertility. The model regards family labour as a household's central resource, which is needed to activate the other productive resources *land* (via the time constrained task of land preparation) and *capital* (by engaging in casual labour or selling crop surpluses). Scenario analysis is applied to assess the effect of i) increasing land scarcity (a main impact of population growth on households' farming strategies), ii) subsidies on input prices and iii) favourable rainfall conditions on optimal farming strategies and likelihood of endogenous intensification.

Model results indicate that optimal household strategies in the study sites are determined by the degree to which households cope with seasonal peaks in labour demand and land scarcity. The more binding these constraints are for production, the more likely it is that conservation agriculture plays an important role in optimal household strategies. The less binding they are, the less willing are smallholders to adopt conservation agriculture. Furthermore, results indicate that all households have a sufficiently large labour pool to adopt conservation agriculture; however, the poorer households may be too cash-constrained to do so.

Considering that increasing land scarcity and climate change will continue to drive agricultural involution and degradation dynamics in the ORB, this study argues that externally induced sustainable intensification is needed. Conservation agriculture is one of the best available options to achieve this goal; it should be promoted via adequate pro-smallholder policies.

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Annex I – Questionnaires

1. Focused interviews: Smallholder [90]

Introduction: Would you please show me your field?

FARMING SITUATION

- What is the thing you like the most about farming?
- What worries you the most when you think of the next growing season? Do you prepare yourself for this problem?

CROPPING

- When you plant your fields, how do you decide which crops to grow?
- What different things do you have to think of before deciding which crop to grow on which field?
- If you wanted to, what do you have to do to be allowed to clear a new field?
- How easy would it be?
- Is there still enough land for your village? (Near the river, inland)?
- Is there enough good, fertile land available?
- Did you ever clear some land from the forest to make a new field?
- What do you do if you don’t have enough harvest?
- What are the main reasons for low harvests?
- How much of your crop do you eat while it’s still green?

LABOR

- Imagine many people from your household go to town to find a job. Would that be a problem for you and your farm? Why?
- What would be the biggest problem?
- For which tasks would you need your family members the most?
- How would you solve this problem?
- If you are not able to prepare all your fields after the rains - maybe because you don’t have an ox or because you don’t have the time - is there any other/additional way for you to get food/ survive until the next growing season?
- Imagine you don’t have any Oxen: What would change for you if you cannot use Oxen? (ploughing, weeding) ? What would you do then? Would you do other things / would you change the way you do things on your farm?
- *Only if farmer has Oxen:* How much of your field would you be able to prepare if you suddenly didn’t have oxen? The same amount? Does it make a difference if you have just one or two or if you have many Oxen?

USE OF CASH

[90] The list of questions was used as checklist, i.e. to prepare field interviews – during the interviews, just the questions in the sections on *farming situation*, *cropping* and *soil fertility* were asked systematically; questions on the other sections were dynamically adapted to interview situation to ensure a smooth discussion.

- How does it help you if a member from your family earns cash? Does it change anything in regard to what you do on your farm, what you do with your harvest, your livestock?
- *Only if a member is a cash earner:* What would you do, if no-one from your family suddenly had a job anymore and you would not get any cash: What does change for you if you don't have any cash anymore? Would you do anything different compared to now?

FERTILITY

- If you use your field for many years without a break, does the amount of your harvest change or does the field get tired?
- Do you do anything to stop this from happening?
- Do you know the meaning of letting the field rest/Fallow?
- Do you think it is necessary to do this sometimes?
- Why and who taught you this?
- Do you let your field rest? If you cannot do this, are there other ways to help your fields stay fertile?
- *HH with just one field and no cattle for manure:* What can you do to keep your fields fertile?

LIVESTOCK (if owner)

- Why do you keep cattle? Why go through all the "trouble"?
- What do you use it for? (Use & sell manure?)
- Does keeping cattle help you in surviving? How does it help you?
- What would be different for you if you wouldn't have any cattle?
- Who takes care of the cattle?
- What kind of work with your cattle takes the most time?
- What do you have to do to make sure your herd survives the year? What do you have to do to bring your herd through the year? (Medicine, herding, buying extra forage)
- Where do you let your cattle graze? Do you graze your cattle in the forest?
- Do you follow any grazing plan or rules regarding the herd?
- Do you send the animals to special grazing areas for special purposes?

NATURAL RESOURCE USE

- Do you regularly collect anything in the forest or do you regularly get anything out of the river?
- How important are these things for you?
- Imagine you have a bad harvest: does the importance of these things change for you?
- What are the main products you collect if there is a bad harvest?

DROUGHT & FLOOD RELIEF

- Do you know the government's drought & flood relief programmes? Do you sometimes need to accept food from the government? Why and how often? What would you do if the government stopped delivering food?

FUTURE

- If you wanted to make farming easier for you, what would you need the most, what is missing right now that you would like to have? [If he says cash: What would you do with the cash?]

2. Questionnaire for Focused Interviews: NGO/ Scientists/ Officials

Feedbacks: Rangeland Management ←→ Livestock keeping

- Can you describe the current management practices?
- How do they effect/ interact with the natural system and forage availability?
- Traditional & New Grazing plans vs. no grazing plan:
  Implementation costs in regard to labour & cash vs. long-term effect on cattle health and possible (relative growth?) herd sizes
- Approximation of different carrying capacities in regard to management practices/grazing plans on certain landscape units (sand-veld, old/new floodplain?) → dynamic trends (rising,declining,?)

Feedbacks: crop production ←→ natural system

- Indicators for decreasing soil fertility/quality/degradation?
- Local agro-system described as shifting-cultivation: Is that so? Rather mixed system?

Future of dryland agriculture for subsistence

- Expected future development – currently sustainable? (mainly in regard to yield & land availability)
- How long will sufficient land for clearing still be available?

Chances for agro-industrial schemes & conservation agriculture

- In regard to cash input, labour, land, legal requirements

Impact of drought relief program on behaviour of farmers

3. Explorative interviews: Smallholder

Section 1:
Farming System overview

- For how long have you been working as a farmer?
- Which crops do you grow and what are the most important ones? Why?
- How do you decide which crops to grow on which field?
- *What tasks need to be done in the fields at which time of the year? Who in the family performs which task?*
- Do farmers in your village always use the same fields or do they, every few years, move to new fields? How often and how much area do they leave behind?
- Which difficulties/problems do farmers face throughout the year when growing crops?
- How do they overcome them?
- Do you keep cattle?
- *What tasks need to be done for the herd throughout the year? Who is responsible for these tasks?*
- Where does your village keep its cattle? Can every farmer let his cattle graze where he wants?
- What do farmers do if there isn't enough fodder on the grazing areas?
- Which other difficulties/problems do farmers face throughout the year when keeping cattle?
- How do they overcome them?
- What do farmers do if there is a food shortage?
- What do farmers do if there is a labour shortage?
- What do farmers do if there is a cash shortage?
- Why do many farmers use improved seeds?

Section 2:
Fertility management

- How long can sandy soils / soils near the river be used for crop production before yields decline? (specify which crop)
- How do farmers keep their fields healthy?
- How often do they clear new fields? Why?
- How do they get new fields? Is land easy to obtain? Is there enough new land?
- How many farmers use fallow periods? (to let the field rest)
- How long do they generally let it rest? Is it the same for all crops? How much of their planted area? For how many years do farmers generally use fields before putting them to fallow?
- Can farmers use land which was covered with virgin forest longer than land which has been in fallow? How much longer?
- Do farmers use fertilizer or manure?
- Many farmers burn their crop residues or plough them into the soil. What do you think that farmers do most often with their crop residue? (Burning = sensitive topic)
- Is there a difference in regard to cattle forage between virgin forest and fallow areas, that is areas which have been used for crop production before?
- Do farmers use the grazing areas all the time or do they let them recover/rest? How often, how long?

Annex II – Interviewer guidelines for conducting “fuzzy pair wise comparison” interviews

Before you start the interview, don’t forget to note down the full name of the farmer:
____

Introduction:
Hello Sir/Madam,
my name is _______ and I work for the Future Okavango project. My supervisor is called Ben, he is from Germany and doing research on agriculture.
With his research, he tries to find out if *and how* it is impossible to improve local farming methods. This includes, for example, strategies to improve the strength of the soil. He also tries to find out if *or if not* it makes sense to adopt new farming methods like Conservation Agriculture.
I am here today, because we would like to better understand your needs and wishes as a farmer. Therefore, I would kindly like to ask you some questions about the importance of different activities. Those activities are some of the most important or relevant activities here in the village. I will explain them later in some detail.
We ask for this information, because if we as researchers do not understand what for people here in the villages is important and what not, our research results will not help anyone.
[Wait and see if the farmer has any questions. Try to answer them or, if they will be explained later in this text, tell him that you are going to explain that in the next sentences]

Would you be willing to take part in this interview?
[If yes, go on. If not, please find out why and then leave the farmer]

I will present to you now 6 different activities. Later, I would like to kindly ask you to tell me which of these activities you think of as more important than the others.
But first, before I ask you any questions, I am going to explain to you what I mean when I talk about these 6 different activities.

Activity 1 is called “Livestock production”.
This includes everything you do to keep your livestock herd healthy and strong, but also growing your herd or slaughtering your own animals to get food or cash. If you do not own any animals at the moment, you can still say how important it is for you to spent time or money on livestock activities with the aim to one day in the future grow a livestock herd of your own. We want to understand how important you think livestock keeping is compared to other activities. When we talk about livestock, we don’t mean poultry. Rather, we talk about cattle or goats.
[wait for questions]

Activity 2 is called “Crop Production”.

This includes everything you do on your fields with the aim to grow crops of your own. It therefore also means that you are able to a harvest your own crops and consume your staple food.
[wait for questions]

Activity 3 is called "Activities using natural resources"
This includes the hunting or gathering or fishing of natural resources in your surroundings. This could be the collection of reeds, firewood, nuts or fruits but also fishing. It does not include BUYING these resources, it just includes you or your household going out to gather or collect them for sales or home consumption.
[wait for questions]

Activity 4 is called "Participating in off-farm labour"
This includes all activities for which you get cash, for example formal wage labour, e.g. in a company, but also having a own non-farm business. This also includes casual labour, or so-called piece work you do on others peoples fields. That means, getting paid in cash to do agricultural work on the fields another farmer is included here, too.
[wait for questions]

Activity 5 is called "Having time for other activities (social, leisure)
This includes relaxing, having time for yourself, but also having time for attending social activities like marriages or funerals.
[wait for questions]

Activity 5 is called "Maintain and conserve the land you use for growing crops"
As a farmer, you also take care of the land on which you grow your crops. This activity shows how important it is for you to keep your land strong and healthy, both for the sake of the land as well as for you and your children and children's children. That means you work hard to keep the soil strong, e.g. by putting manure on the field or by clearing a new field every two years to leave the old one in fallow a bit earlier. However, by working to keep the land healthy, you are willing to accept that you may have a lower harvest in this specific year.
[wait for questions]

Did you understand what I mean with the mentioned activities?
[If yes, go on. If not, explain again]

Interview starts:
[show farmer the first paper]
I will now show you some papers on which you always find one activity written on the left side and another activity written on the other side. *[show them]*
They are connected by this line *[show thick line]*
The exact middle is shown by this thin line here *[show thin line]*
I would like to ask you now to compare the different activities connected by the thick line.
If both are of the same importance for you, please make a mark directly in the middle on the thin line *[show them]*

If you put a mark on one far side of the thick line … *[show them]*
…it means you would always prefer to do this activity instead of the other.

The farer away from the middle you place your mark, the more important you think one activity is compared to the other. That means you can tell me how much more you prefer to do one activity than the other.

..

[Give example of Spaghetti and Maize Meal – **if they understood this, explain how their preference statement is connected to the consumption of each product – that means that the more time they spent on the activity of preparing the product and the more they eat of it, the less time they use on the other and can eat the other*]***

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[Show all papers and ask questions now]

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.

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Thank you very much for taking part in this interview. This information is very helpful for us because it will allow us to produce research results that can actually help the people here in the region.

Do you have any questions or comments which you would like me to note down?

____

____

____

____

____

Thank you and goodbye!

Erklärung gemäß der Promotionsordnung des Fachbereichs 09 vom 07. Juli 2004 § 17 (2)

„Ich erkläre: Ich habe die vorgelegte Dissertation selbständig und ohne unerlaubte fremde Hilfe und nur mit den Hilfen angefertigt, die ich in der Dissertation angegeben habe.
Alle Textstellen, die wörtlich oder sinngemäß aus veröffentlichten Schriften entnommen sind, und alle Angaben, die auf mündlichen Auskünften beruhen, sind als solche kenntlich gemacht.
Bei den von mir durchgeführten und in der Dissertation erwähnten Untersuchungen habe ich die Grundsätze guter wissenschaftlicher Praxis, wie sie in der „Satzung der Justus-Liebig-Universität Gießen zur Sicherung guter wissenschaftlicher Praxis“ niedergelegt sind, eingehalten.“

[I declare: this dissertation submitted is a work of my own, written without any illegitimate help by any third party and only with materials indicated in the dissertation. I have indicated in the text where I have used texts from already published sources, either word for word or in substance, and where I have made statements based on oral information given to me. At any time during the investigations carried out by me and described in the dissertation, I followed the principles of good scientific practice as defined in the “Statutes of the Justus Liebig University Giessen for the Safeguarding of Good Scientific Practice”.]

Benjamin Kowalski