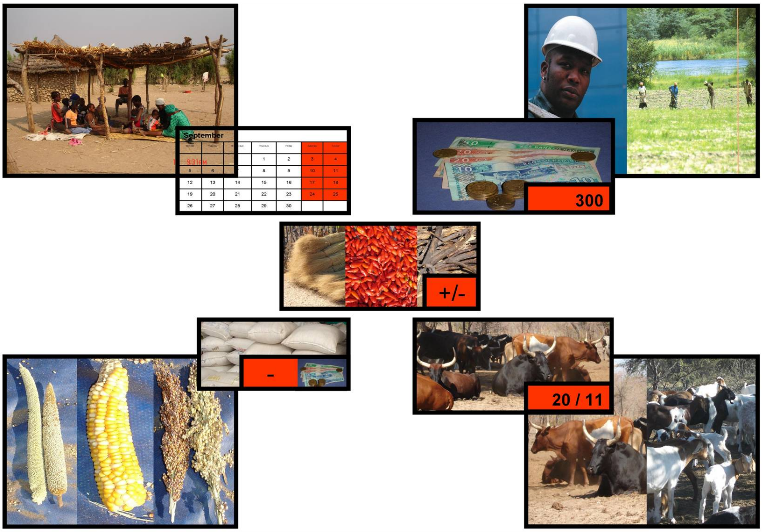
Judith Hecht

Decision Making of Rural Farm Households in Namibia:

Lessons Learned From Multi-Annual Programming Optimisation Models



Cuvillier Verlag Göttingen
Internationaler wissenschaftlicher Fachverlag

Justus-Liebig-Universität Giessen

Fachbereich Agrarwissenschaften, Ökotrophologie und Umweltmanagement

Institut für Agrarpolitik und Markforschung

Professur für Agrarpolitik und Umweltpolitik

Decision Making of Rural Farm Households in Namibia: Lessons Learned From Multi-Annual Programming Optimisation Models

Dissertation

von

Judith Hecht

Bibliografische Information der Deutschen Nationalbibliothek
Die Deutsche Nationalbibliothek verzeichnet diese Publikation in der Deutschen Nationalbibliografie; detaillierte bibliografische Daten sind im Internet über http://dnb.d-nb.de abrufbar.
1. Aufl. - Göttingen : Cuvillier, 2010
Zugl.: Giessen, Diss., Univ., 2010

978-3-86955-505-8

Nonnenstieg 8, 37075 Göttingen
Telefon: 0551-54724-0
Telefax: 0551-54724-21
www.cuvillier.de

1. Auflage, 2010
Gedruckt auf säurefreiem Papier

978-3-86955-505-8

Acknowledgements

Foremost, I would like to express my sincere appreciation and gratitude to Prof. Nuppenau for his scientific guidance, constructive criticism, and his encouragement. I would like to thank him particularly for his valuable ideas and visions which will continue to influence my scientific career. I would like to extend my gratitude to Prof. Schmitz who made fruitful contributions at various stages of this thesis. I am as well thankful to the BIOTA-Africa South Project for their financial support.

Several acquaintances, colleagues and friends were contributing their invaluable support throughout the entire research process. I will bring out my gratitude to them according to their affiliation to several locations and institutions.

First of all, my thanks go to all members of the BIOTA-Africa South Project team. Especially I would like to point-out Dr. Ingo Homburg, Dr. Ute Schmiedel, Bertchen Kohors, Stephanie Domptail, Dr. Michael Pröpper, Bernadett Bock and Dr. Björn Vollan.

Throughout my several stays in Namibia I got in touch with different institutions and their members. For enriching this thesis my appreciations go to all employees of the Ministry of Agriculture, Water and Forestry in Rundu and Windhoek, as well as to staff-members of their out-sourced research stations in Masharey and Mile 46. A lot of the empirical data collection was based on the support of various invaluable translators, field assistants and authorities of the research villages as well as their community members. In this context I would like to express my exceptional thank to Raffa, Robert, Selma, Karl, the Hompa of the Kapako constituency, the village headwomen of Mutompo and Epigiro, the headman of Cove and Donatus -thank you, for all enjoyable talks even without translation-. During my field work I could spend my weekends in Rundu at a camping lodge with all necessary facilities which made my stay very pleasant -thank you Ursula for providing this place of relaxation and peace-. I remember how grateful I was to buy my first fridge-cold soft-drink in Rundu after a tough week of interviews in the rural areas. For several times I enjoyed such a drink at Smittis place -thank you for giving me this opportunity-.

Further, I would like to express my thanks to the scientific and technical staff of the Justus-Liebig University in Giessen. Particularly, I would like to mention Dr. Hans-Jürgen Buß and Ute Schneiderat. Both were helpful advisors for preparing my first field-trip.

Throughout the last quarter of writing this thesis I worked simultaneously in an EU research project for which I was employed at the vTI in Braunschweig. All its staff members contributed to varying degrees their honourable supports, thank you. In this context I would like to show my deepest appreciation to the scientific and technical personnel of the *Institute of Farm Economics*, the *Institute of Market Analysis* and the *Institute of Rural Development.* Especially I would like to mention Dr. Frank Offermann and Dr. Hiltrud Nieberg -who never stopped asking me about the progress of my thesis-, Dr. Claus Deblitz -an excellent e-mail advisor-, Kerstin Martens, Kati Böttger and Annerose Gillner -the best word design performer-, Kubi -who could solve every computer problem-, Klaus Nehring –a brilliant car-caretaker and work-husband-, Birthe Lassen –an excellent cake-baker-, Markus Lutter –an admirable non-sense talker-, Markus Ehrmann -a highly appreciated GAMS fellow-, Thomas De-Witte -an almost tennis star-, Dr. Aida Gonzalez and Gitta Schnaut –with whom I spent the most enjoyable and honest evenings-, Andrea Rothe, Steffi Wille, Heiko Hansen and all fellows of the 'Kafferunde'-who provided a regular location of amusements-.

I finished my thesis while working at the Research Institute for Organic Agriculture in Frick, Switzerland. In this regard I would like to express my special thanks to the socio-economic research group.

This study could not have been completed without empathies, understandings and patience of good friends. During my stay in Gießen I met two brilliant neighbours, thank you Slavi and Petra for your supports. Additionally, my deep appreciations go to all friends in Munich, Stuttgart, Braunschweig and Berlin. Specifically, I would like to point-out Maren, Lisa, Kris, Sandra, Kirstin, Dirk, Cordula and Bert. For his scientific discussions and his never ending moral support I would like to particularly thank Daniel –thank you, for who you are-.

My last but for sure deepest gratitude I would like to express to my entire family which supported and encouraged me my entire life and who made me forget at least for some time my working tasks.

Table of Contents

List of Figures

List of Tables

List of Abbreviations and Acronyms

APA	Animal production activities
AWFHH	Average weighting farm household
BIOTA	Biodiversity Monitoring Transect Analysis in Africa
BEM	Bio-economic models
BL	Baseline Scenario
CPA	Crop production activities
CGE	Computable general equilibrium
CSFS	Case study on farming systems
DAP	Draught animal power
EWFHH	Equal weighting farm households
FAO	Food and Agricultural Organisation of the United Nations
FHH	Farm Household
FHHM	Farm Household Model
FHFHH	Female headed farm household
FSCA	Family, social and cultural activities
GAMS	General algebraic modelling system
HOMPA	Traditional authority, e.g. King
KCAL	Kilo calories
MAPOM	Multi-annual programming optimisation model
MHFHH	Male headed farm household
OAUNR	Other activities using natural resources
OLA	Off-farm labour activities
RRSP	Review of region specific publications
SC2	Scenario 2
SC3	Sceanrio 3
SC4	Scenario 4

TCA	Traditional conjoint analysis
WHO	World Health Organisation

1 Introduction

1.1 Relevance and problem

Ecological functions and related species of savannah systems are important in a world-wide context of biodiversity and ecological complexity, which currently face degradation. In Africa, more than half of the landscape is shaped by savannah eco-systems. Most rural societies within Africa depend highly on the use of such systems to secure at least their minimal nutritional requirements. Human utilisation of fragile savannahs often puts tremendous pressures on natural resources (Teer, 1996: 1). Apart from natural factors, driving forces of globally observable 'desertification' processes are anthropocentric activities, such as over-exploitation of land, overgrazing, illegal and excessive logging, bush and forest fires and deforestation due to population increases (Holtz, 2003: 5). According to Holtz (2003: 5), such manifold causes of desertification processes need to be addressed by a wide variety of measures. These combating or conserving measures need to address a different dimension in the context of developing countries, since survival is often of higher importance than quality of life (Teer, 1996: 1).

In this context, the political relevance of addressing threats related to natural resources and food security is recognised by a) the United Nations Convention on Biodiversity, b) the United Nations Convention to Combat Desertification, c) the United Nations Millennium Development Goal to eradicate extreme poverty and hunger and d) recently signed agreements to tackle the mounting challenge of environmentally induced migration processes. Generally, incentives for converting prevalent land use practices into 'more' sustainable practices that simultaneously prevent famine have to consider both economic and environmental indicators.

In the Kavango Region of Northern Namibia, several driving forces lead to continuous deterioration processes of tree and bush savannahs. In general, agro-forestry activities of peasant farmers using communal land resources are assumed to cause a) deforestation either by clearing land for crop production (Yaron et al., 1992: 10; Ashley, 1996: 3) or by exploiting valuable timber trees (Pröpper, 2009: 204), b) soil degradation (Ashley, 1996: 3) and c) in part, over-grazing (Yaron et al., 1992: 10).

Since 1992, the number of undernourished people in Namibia has been reduced; however, considerable portions of the population are still affected by malnutrition today (FAO, 2006: 24). While population growth is obvious (World Bank, 2008: 2), the effective number of family labourers in general, and particularly in peasant farm households, is expected to drop because of declining health caused by the HIV/AIDS endemic (Fuller and Van Zyl, 2006: 2; Hange et al., 1999: 5; World Bank, 2001: 4). These developments have the potential to cause a collapse in daily calorie intakes and thus threaten food security, particularly in rural areas (Hange et al., 1999: 12/13; Fuller and Van Zyl, 2006: 3/4).

1.2 Objectives and organisation

Following the outlines of the previous section, an immediate concern is assessing long-term effects of peasant household farming strategies on deterioration processes and food security. Finding possible solutions to reduce environmental threats and simultaneously increase daily calorie intakes is a challenge for economists, ecologists and policy makers. Towards this end, the present study tries to simulate human impacts on fragile environments as a cause of seeking food security.

So far, several studies have investigated economic-environmental interactions by different modelling approaches, in Namibia (Buß, 2006; Domptail et al., 2009). However, they concentrate on commercial farmers and hence are calibrated to other objectives than food security.

Bearing in mind the described environmental and socio-economic threats in the Kavango Region, this study aims to:

1. Empirically identify objectives of peasant farm households,
2. Quantify their most frequent activities and other possible on-farm and off-farm activities;
3. Identify optimal farming strategies under important system constraints and their impacts on environmental and socio-economic aspects;
4. Identify policy-based changes to identified optimal farming strategies.

While objectives 1 and 2 are predominantly addressed by two empirical data collection and analysis methods, objectives 3 and 4 are tackled by developing a multi-annual programming optimisation model of a typical village that includes relevant bio-physical features. The results of this study are intended to a) serve as a solution point for similar problems in underlying and related ecological or economic systems and b) be relevant for policy makers to investigate policy impacts on peasant farming strategies.

In order to achieve the aforementioned objectives, this study is organised as follows:

- Chapter 2 gives an overview of general economic and specifically agricultural conditions in Namibia and the Kavango Region with associated socio-economic and environmental threats.

- Chapter 3 covers the theoretical background of farm household and bio-economic modelling and qualitatively describes the applied modelling approach.
- Chapter 4 summarises results of empirical surveys and literature reviews in order to quantify farming activities and objectives of peasant farm households.
- Chapter 5 gives a mathematical outline of the applied modelling approach.
- Chapter 6 presents optimal farming strategies under important system constraints in a baseline scenario, two scenarios which are linked to changes in the objective function and a scenario which is linked to changes in policy conditions with respect to natural resource conservation. It ends with conclusions, policy recommendations and future research topics.

2 Namibia and Its Kavango Region

As an overall goal, this study aims to construct a bio-economic model of northeastern Namibia to analyse optimal land use strategies. Hence, this chapter commences with a rough description of geographic and socioeconomic aspects in Namibia. Subsequently, a lucid picture is drawn of the Kavango Region. Its livelihood and farming system is addressed in a third part. Within the Kavango Region, peasant farmers' rather risk-averse behaviour leads to a high differentiation in farming activities. These activities are one building block of optimal land use strategies. Hence, a first sketch of the farming system helps to understand a) the applied theoretical modelling approach (Chapter 3) and b) the scaling of parameter levels used in the model (Chapter 4). Finally, this chapter closes with an outline of major environmental and socioeconomic threats.

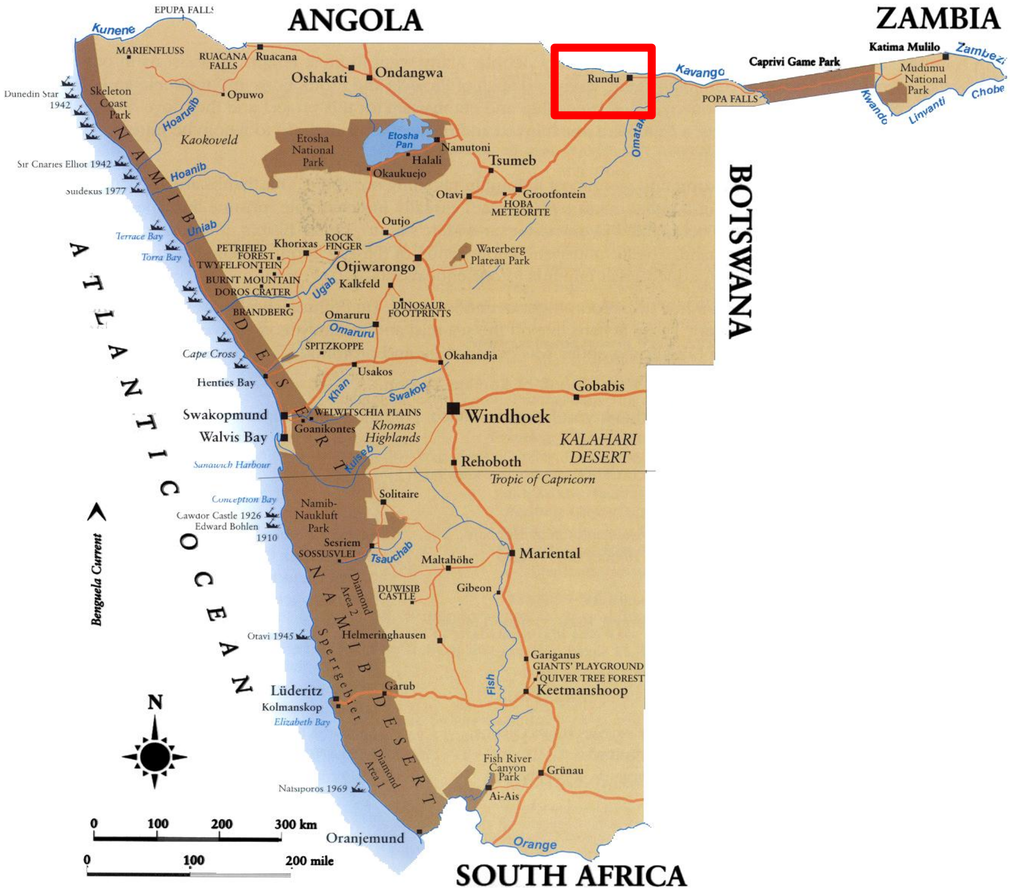
2.1 Namibia

At the end of the 19th century, Namibia was colonised by German settlers. In 1915, colonial power was transferred from Germany to South Africa (Matsaert, 1996: 3), and in 1990, Namibia became independent (Matsaert, 1996: 5). Generally, Namibia is known as one of the driest countries in southern Africa. Rains show regional variation (Schneiderat, 2008: 1) with a mean annual rainfall of 270 mm (Kojwang, 2000: 5). Nonetheless, Namibia produces considerable amounts of woody biomass (FAO, 2000: 1).

2.1.1 Location, land cover and land distribution

Namibia is located in the southern section of the African continent, on the Atlantic coast. It is bordered by Angola to the north, South Africa to the south, Botswana to the east and the South Atlantic Ocean to the west (Figure 2.1). Namibia has five important geographical areas: the Central Plateau, the Namib Desert, the Kalahari Desert, the Caprivi Strip and the Kaokoveld. With the Caprivi Strip, it also borders Zambia and is in touch with Zimbabwe.

Principal vegetation types of Namibia can be divided into savannahs, desert vegetation and dry woodlands (Sweet and Bruke, 2001: 4.1). This indicates that most of Namibia's land resources are suitable for only extensive use (Ashley, 1996: 2). As can be seen in Figure 2.2, cultivation of land is limited to about 6.4 % of the total area. Savannahs and forests are dominant land cover types. Forest resources, which cover more than 20 % of Namibia's area, support the majority of Namibians by supplying energy and building materials. Further, wooded environments provide browsing and grazing, which underpin livestock farming (Kojwang, 2000: 3).

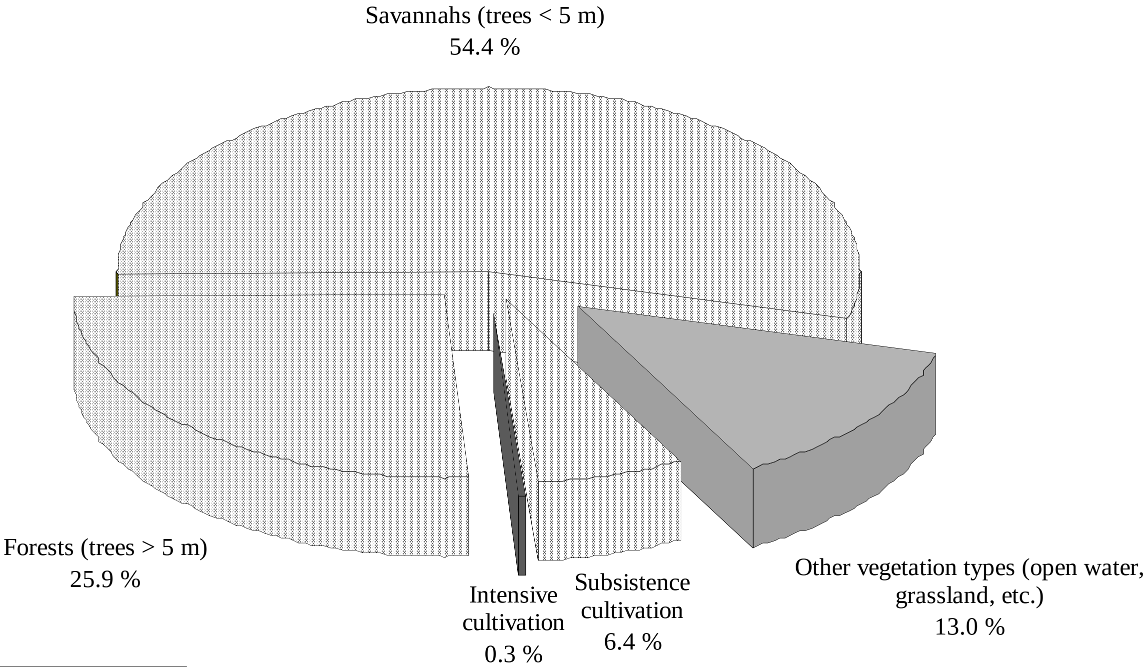


Source: Modified from FAO (2009).

Figure 2.1: Map of Namibia

Namibia is in general one of the most sparsely populated countries on the African continent. Its population of about 1.7 million people lives on an area of 830,000 km². However, land allocation is unevenly distributed within the country. The majority of Namibians are confined to the North on communally owned land that has to be shared by 60 – 70 % of the entire population (Kojwang, 2000: 14).

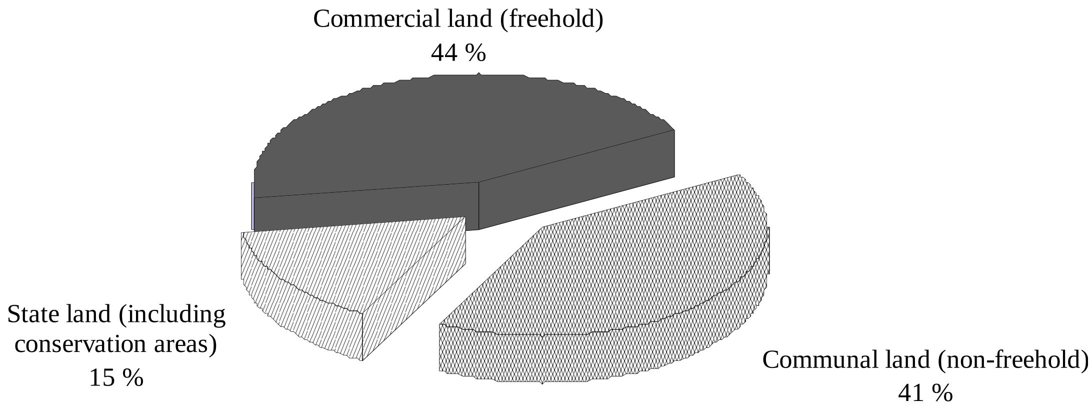
Figure 2.3 shows land cover shares under different property rights regimes in Namibia. Approximately 36.5 million hectares, representing 44 % of the total land, continues to be held under freehold title by approximately 6,500 farmers (Kojwang, 2000: 10). Together they shape the commercial farming sector (Ashley, 1996: 2). Non-freehold areas and communal land areas cover slightly less land – 33.4 million hectares, or 41 % of the total land area (Sweet and Burke, 2002). Though owned by the state, communal communities allow for user rights (Ashley, 1996: 2). The remaining 15 % is state-owned land, including conservation areas (Sweet and Burke: 2002). The latter represent about 8 % of the total land area and can be divided into terrestrial parks like wildlife parks, nature reserves and marine parks. Recent initiatives propose establishing community-based forest reserves that might increase the combined share of protected areas to about 10 % (Kojwang, 2000: 3.9).



Source: Own design based on figures in Kojwang (2000: 3.1).

Figure 2.2: Land cover shares by vegetation and cultivation type

Unsurprisingly, land redistribution is a big political issue with an observable ethnic dimension, since the minority white population controls the major part of the freehold areas. Redistribution should be promoted in a manner that minimizes the economic and political costs at the national level. It is therefore important that agricultural development in the northern communal parts is made more profitable (Kojwang, 2000: 14).



Source: Own design based on figures in Sweet and Burke (2002).

Figure 2.3: Land cover shares under different property rights regimes

2.1.2 Economy and agriculture

According to the World Bank classification, Namibia is a middle-income country (World Bank, 2007: 1). About 15 years ago, Namibia gained independence from previous colonial powers (Matsaert, 1996: 5) and inherited a well-functioning physical infrastructure and market economy coupled with rich mineral resources and relatively strong public administration (World Bank, 2007: 1). Namibia has experienced steady growth, moderate inflation, strong external surpluses and low indebtedness over the past several years. This is a result of a stable political environment with strong legal and regulatory conditions, a prudent fiscal policy and a fairly developed infrastructure (World Bank, 2007: 2). Nevertheless, social and economic imbalances of the apartheid system caused a highly dualistic society that is still present today. Job creation and poverty reduction are recent challenges (World Bank, 2007: 1).

Namibia’s economy is dominated by the service sector, which contributes about 60 % to GDP, followed by industries with about 30 %. A remaining share of 10 % is assigned to agriculture (World Bank, 2008: 1). Since independence, economic growth has averaged 4.3 % per annum (World Bank, 2007: 3). During the last century, this growth was predominated by the service (4.8 %) and industry (4.9 %) sectors. For the agricultural sector, growth rates averaged 2.2 % (World Bank, 2008: 1).

Historically, Namibia has been well-known for its mining industry, which has thrived for over thousand years. Mining concentrates on diamonds, one of the country’s many natural resources, and constitutes the largest foreign exchange earning activity. Other natural resource-based economic activities and primary industries include a commercial fishing industry and commercial livestock ranching (Kojwang, 2000: 5). For a long time, the commercial agriculture sector was exclusively characterized by beef ranching for a traditional export market. Recently, lucrative commercial table grape farming has been introduced (Kojwang, 2000: 3, 10). Between 1996 and 1999, agriculture contributed an average of 8.7 % to GDP, though it employed 70 % of the population. This figure includes an average decrease of about 2 % caused by a decline in production by livestock ranches. Other potential causes were shifts to non-traditional activities such as game farming linked to trophy hunting tourism (Kojwang, 2000: 5, 10, 11). However, agriculture is expected to recover from the recent declines that had predominantly natural causes. In particular, commercial agriculture is anticipated to increase partly because of a) short-term recovery from drought, b) commercialization of existing subsistence farming and c) participation in new production opportunities, such as grape growing for export. Growth in both agriculture as a whole and fishing in particular is expected to be slightly faster than in the overall economy (Kojwang, 2000: 8).

Livestock husbandry is also widespread in the subsistence-oriented economy of northern Namibia. However, as this area is not a disease-free zone, it does not have the same access to export markets that the commercial zone enjoys (Kojwang, 2000: 10). Between 1996 and 1999, small-holder agriculture increased animal production at a rate of about 7.1 % per annum (Kojwang, 2000: 5, 10, 11). It can be expected that such a growth rate coupled with higher population densities puts pressure on this arid to semi-arid environment. Additionally, rain-fed crops are grown on small holdings to supplement incomes and to meet subsistence needs. However, the scale of cropping is rather limited, and Namibia remains a net importer of grains to feed its rural and urban populations (Kojwang, 2000: 10). Despite these agricultural activities, the northern communal parts still rely on remittance from migrant labour and direct employment for much-needed cash income, as livestock and crop sales remain insufficient (Kojwang, 2000: 11).

2.1.3 Socioeconomic developments and future challenges

It is notable that Namibia's population, which counted 0.74 million people in 1970, grew at an annual rate of 3.1 % to 1.03 million in 1981. About ten years later, 1.41 million people were living in Namibia, which indicated a slightly increased growth rate of 3.2 % (Kojwang, 2000: 2). However, between 2001 and 2007 the population growth rate declined to 1.3 % (World Bank, 2008: 2). Projections expect that in 2010 about 2.25 million people will live in Namibia. This number is anticipated to increase to 2.63 million in 2020. These projections must take into consideration the effects of HIV/AIDS and international migration (Kojwang, 2000: 2). Internal population movements can be observed from rural to urban areas and between regions. In general, the rate of migration into urban areas is about 5 % per year, based on estimates from 1996. Males constitute 52 % of the migrants. At the same time, the working, adult generation, those between the ages of 15 and 59, predominantly migrate to urban areas and between regions (Kojwang, 2000: 5).

Namibia's human development and social spending is one of the highest in the world. Spending on social services exceeds that of South Africa, which faces similar poverty and inequity threats. Health and education continue to receive an increasing share of the budget, from 38 % in 1996/97 to 42 % in 1997/98. There is a significant improvement in human development indicators, especially increases in enrolments at all levels of the education system. Basic education has become more equitable and primary health care coverage is more widespread. The Namibian government has improved access to safe water and sanitation (World Bank, 2007: 1). Other current improvements include the development of a social safety net for the elderly, the disabled, war veterans, orphans and vulnerable children. A social security act provides for maternity leave, sick leave and medical benefits (World Bank, 2007: 2).

One of Namibia's Millennium Development Goals has been to halve the proportion of people who suffer from hunger between 1990 and 2015. In 2000, the percentage of children under the age of five who suffered from malnutrition was 13 %. This could be reduced to 7 % by 2007 (World Bank, 2007b: 1, 5). According to the United Nations' Food and Agriculture Organization (FAO) (2006: 12, Table 10), food intake in kcal per person and day increased continuously in developing countries from 1969 to 2001. In contrast, figures for Sub-Saharan Africa stagnated in the same period. Projections for the year 2015 expect that Sub-Saharan Africa will still have an average daily per capita calorie intake of only 2,420 kcal. Similar trends with slight differentiations are proposed by the World Health Organization (WHO) and FAO (2003: Chapter 3.2, Table 1). According to FAO (2006: 24), it will be especially difficult to reduce hunger in countries which had a low food consumption (under 2,200 kcal per person and day) in 1999 to 2001. However, in Namibia the number of undernourished people could be reduced, and the country is approaching the World Food Summit target (FAO, 2006: 24).

In summary, the generally good macroeconomic picture and the reliable vision of meeting some of the Millennium Development Goals are overshadowed by three major socio-economic threats (World Bank, 2007: 2, 3):

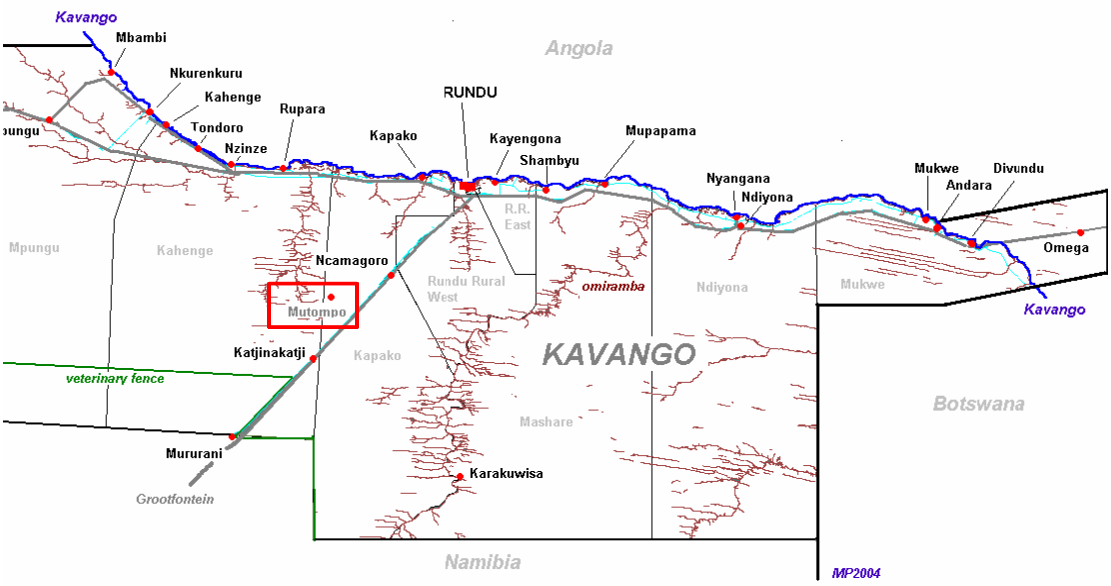
1. Though poverty declined and GDP grew (World Bank, 2007: 3), many Namibians can be classified as poor (expenditures on food exceed 60 % of income). Poverty is concentrated in northern parts of the country.
2. Unequal distribution of wealth and income has led to the highest inequality rate in the world and an unemployment level of about 30 % (World Bank, 2007: 3).
3. HIV/AIDS prevalence has shown a welcome decline (22 % of adult population in 2003 to 19.7 % in 2005) but remains a serious threat to development (World Bank, 2007: 3).

2.2 Kavango Region

Namibia consists of 13 administrative and political regions; the Kavango Region is one of them (Jones and Cownie, 2001: 1). The modelling approach developed by this study is parameterised for a research area in the centre of the Kavango Region.

2.2.1 Location

Geographically, the Kavango Region is located in northeastern Namibia and borders Botswana to the east, Ovamboland to the west and Angola to the north, separated by the Okavango River (Yaron et al., 1992: 7). However, the whole Kavango Region can be further broken down into eight different constituencies (Jones and Cownie, 2001: 2). The research area is located in the Kapako constituency (grey rectangle) (Figure 2.4).



Source: Pröpper (2009: 14).

Figure 2.4: Map of Kavango Region and the research area

The Kavango Region covers 48,500 km^2, which amounts to roughly 5.5 % of Namibia's total area (Jones and Cownie, 2001: 2). The area is flat and broken by low, sandy hills.

Economically, this region seems to be dislocated from the rest of Namibia (Yaron et al., 1992: 6, 7). In this context, Yaron et al., (1992: 6) estimates that 40 % of the population in the Kavango Region are food insecure. The main causes are manifold and can be summarised under the following four points:

1. Population growth, which is leading to over-utilisation of forest resources and scarcity of fertile agricultural land.
2. Increased dependence on crop production only, which limits natural resource areas and with them forest-based food sources.
3. Transition from a subsistence to a cash-based economy, which is leading to outmigration of the male labour force.
4. Breakdown of extended families, which is leading to reduced support systems (Yaron et al., 1992: 6)

2.2.2 From Colonisation via apartheid to independence

In the last century, the population in Kavango has gone through a total cultural and economic transformation. This process was initiated by colonisation and conversion to Christianity. Major milestones were apartheid policies, labour migration and military occupations, as well as the achievement of independence (Matsaert, 1996: 5).

At the end of the 19^{th} century, Namibia was colonised by German settlers. Though the colonial immigrants did not settle in the northern parts of the country, they significantly shaped life in Kavango with missionaries. Even today, Christianity has a profound impact on the Kavango culture (Matsaert, 1996: 2, 3). In 1915, colonial power transferred from Germany to South Africa. In terms of local affairs and infrastructural development, colonial authorities encouraged only minor improvements. Contract labour opportunities for young men in the south of the country did, however, have a major impact (Matsaert, 1996: 3).

Apartheid policies were introduced throughout Namibia after the election of the Nationalist Party in South Africa. Such policies suggested free access to higher education, employment and free movement to members of decision making bodies. However, the only major change was that afterwards, traditional leaders of Kavango received salaries but were still required to work for South Africa (Matsaert, 1996: 3). As the Namibians' protest grew, the South African government responded with an attempt to win their hearts and minds. This strategy involved developing infrastructure and social services (Matsaert, 1996: 3).

After the Portuguese colonialists withdrew from Angola, the South African defence force moved into Namibia's northern regions. The Kavango Region was then under military rule for almost 20 years. Many men were recruited into the army and the police force (Matsaert, 1996: 2).Namibia finally became independent in 1990, but the legacy of colonialism in Kavango still remains (Matsaert, 1996: 5).

In terms of agriculture, the most important impact of colonial time was the introduction of a) the plough, which allowed crop production to become more intensive, and b) new seed varieties. Drilled boreholes facilitated inland movements and permanent settlements along the tar road to Grootfontein (Matsaert, 1996: 4, 5). In the 1980s, a number of large farms were established along the Kavango River with the intention of increasing food production and acting as energy centres for agricultural development. However, impacts on surrounding farms were minor. Later, a farmer support scheme with the aim of transforming a number of communal farmers to commercial farmers had a stronger impact on farming systems. This was achieved by providing advice, inputs and credit (Matsaert, 1996: 4). One positive effect of the military occupation was a sufficient supply of formal employment opportunities for men and thus even rural farmers. Such employments were reduced by the withdrawal of military services. Even after independence, this decrease could not be reversed by local industries (Matsaert, 1996: 6).

Inland movement continued after independence, initiated by large-scale farmers who had access to transportation. Initially, they brought water inland from the river. After these farmers cleared land and settled, authorities agreed to construct additional boreholes. Then other households were able to follow. However, such large-scale farmers often exhausted already high-quality land and were about to move on. This behaviour kicked off large-scale destruction of forest resources (Matsaert, 1996: 5). Agricultural improvements since independence were a) the establishment of the Meatco which is the Namibian public meat trader, b) expansions of agricultural support activities, c) the establishment of a number of farmer organisations and d) a first attempt to introduce credit schemes for small-scale farmers (Matsaert, 1996: 6).

2.2.3 Population, population growth and movements

Today, about 10 % of Namibia's population lives in the Kavango Region (Jones and Cownie, 2001: 2). Figures on population growth showed significant increases of the total population between 1951 and 1981. Specifically in the decade of 1971 and 1981, annual growth rates amounted to 6 respectively 7.5 % (Jones and Cownie, 2001: 17). Between 1991 and 2001, levels of annual growth decreased slightly to 3.97 % and averaged 4.5 % over the complete time frame of 1951 to 2001 (Pröpper, 2009: 98). However, projections assume that the rate of population growth might relax at 1.5 % or might even drop to below 1 % because of the increasing effects of AIDS mortality (Jones and Cownie, 2001: 17).

The research site chosen for the empirical data collection belongs to the Kapako constituency. In 2000, slightly more than 20,000 people were residents of this district (Jones and Cownie, 2001: 2). Generally, population densities can be clustered into three classes:

1. Densely populated zones within a ribbon along the Kavango River with 40 to 100 people per km^2.
2. Small settlements clustered along some of the dry drainage lines with densities varying from one to ten people per km^2
3. Sparsely populated zones that show densities of less than one person per km^2 (Jones and Cownie, 2001: 18).

Based on the age and sex structure of the population, three major trends can be formulated:

1. 75 % of residents are younger than 30 and 43 % are younger than 15.
2. Children under the age of four are fewer than children aged five to ten; this might be due to HIV/AIDS infections or a decline in fertility. Yaron et al., (1992: 16) discovered a similar trend. He explained this phenomenon by the fact that children of primary school age are often being cared for by members of their extended families who live in villages with primary schools.
3. Adult males and females are approximately equal in number (Jones and Cownie, 2001: 19).

Moreover, migration and emigration are important population movements, but urbanisation and movement from rural areas to Rundu, the main urban centre in Kavango, make up the most considerable share. A third movement is the inland-directed migration from homes along the river (Jones and Cownie, 2001: 20).

2.2.4 Ethnicity, political structure and land tenure

Six ethnic groups can be distinguished within the Kavango Region. Generally, each group occupies a specific district and speaks its own language. They are the a) Mbunza, b) Kwangali, c) Shambyu, d) Gciriku, e) Mbukushu and f) Caprivi (Yaron et al., 1992: 17). Traditionally, all ethnic groups had a matrilineal society (Yaron et al., 1992: 21). Today such linkages are still important. Colonisation initiated a transformation of such systems to become more patrilineal or based on the nuclear family system as is favoured in Europe. At the present time, the kinship situation and support systems are still in a state of change, and the level at which such systems operate is not completely clear (Matsaert, 1996: 9).

Political organisations today combine elements of the New Democratic Namibian System and the traditional tribal structures. Elected councillors and members of Parliament represent interests of Kavango inhabitants at the regional and national level. Though their power is much reduced, today tribal chiefs and traditional authorities still exist (Matsaert, 1996: 7). The traditional leader of each ethnic group is the chief, or 'hompa', who is elected from a royal family. This position can held for life but can be changed if a significant proportion of the local community demands it. A 'hompa' is assisted by advisors who control smaller sub-regions (mainly villages) and are called headmen and headwomen (Yaron et al., 1992: 21). Today, headmen and headwomen are elected by the community, rather than being appointed by a chief (Matsaert, 1996: 7). They are closely linked to the day-to-day running of the village and are responsible (Yaron et al., 1992: 21), together with the village committee (Matsaert, 1996: 7), for:

- Land allocation
- Dispute resolution concerning land usage and allocation
- Coordination of cooperative activities for the village (Yaron et al., 1992: 21).

Communal areas in Kavango Region are formally owned by the state, which usually concedes user rights to local inhabitants. Though many aspects of life continued to be governed by laws enacted by the colonial government (Yaron et al., 1992: 6), customary law has recently been reformed. The new version intends to involve local leaders more effectively in resource management and conservation activities (Matsaert, 1996: 7).

One major reform is considered in the communal land act of 2000. This states that the primary power to allocate or cancel any customary land right located in a traditional community is given to a) the chief of that traditional community or b) where the chief determines, the traditional authority of that community. In general, customary land rights are allocated in respect to a farming unit or a residential unit (RoN, 2003). An application for a customary land right must be submitted to the chief and furnished with any information necessary for considerations. The chief has the power to refuse the application or allocate the right by determining the size and the boundaries of the portion of land. A limit of 20 ha is set on the maximum land holding size. However, any allocation of a customary land right made by a chief has no legal effect unless the allocation is ratified by a relevant board. Respective land boards must determine a proper allocation in accordance with the act. By ratifying, a board issues a certificate and registers the portion of land in the name of the applicant (RoN, 2003). Similar proceedings are needed to cancel a customary land right. Unless a user right is relinquished by a holder or cancelled by the chief, a customary land right endures for the natural life of a person. Upon the death of a holder, this right reverts to the chief for re-allocation to the surviving spouse or children by following specific rules (RoN, 2003). Any person who contravenes any provision of customary land rights is guilty of an offence and liable to be fined (RoN, 2003).

Additionally, commonage is available for residents to graze their livestock. However, all residents need to respect specific rules related to a) the species and numbers of livestock, b) the sections that will be used and c) the system of rotational grazing on different sections. Any lawful resident, for instance, may not allow more than 300 large livestock or more than 1,800 small livestock to graze on the commonage. Generally, the state has the right to withdraw and reserve any portion of the commonage for any purpose in the public interest (RoN, 2003).

2.2.5 Infrastructure

For the whole Kavango Region, the numbers of primary (250), secondary (9) and combined schools (41) seem to be rather low (Jones and Cownie, 2001: 4), though Namibia is investing to a considerable degree in its social development (World Bank, 2001: 1). Besides a lack of physical facilities, one major problem is the lack of qualified teachers, which leads to a more or less deficient educational system (Jones and Cownie, 2001: 23). In 1996, only 4 % of men and 1.5 % of women had completed grade 11 or any higher level of education (Jones and Cownie, 2001: 24). Drop-out rates from secondary schools are high and predominantly caused by increasing school fees and teenage pregnancy (Matsaert, 1996: 10).

Generally, health care is given to residents of the Kavango Region by hospitals (4), health centres (6) and clinics (44) (Jones and Cownie, 2001: 4). In rural areas, traditional healers, who are experts in a number of herbal remedies, also continue to practice. They are highly respected and charge high fees for their services (Matsaert, 1996: 10). The most prevalent infections are those associated with a poor, rural and subtropical environment. Diseases like malaria, tuberculosis and malnutrition are most prominent. In 2000 between 15 and 20 % of pregnant women had been infected by HIV/AIDS. This dramatic development can be seen as an indicator for infection rates among all sexually active adults (Jones and Cownie, 2001: 21).

Communication facilities are poor, especially for rural inland communities. Phone lines exist only along the riverside zone and in Rundu. A major source of information and communication is the radio (Matsaer, 1996: 11). According to Pröpper, (2009: 151), about 62 % of households directly in the research area, owned at least one radio (n = 120).

Electricity is supplied to schools, health facilities and even some private users. However, it is limited to residents along the Kavango River, along some main roads and in the urban centre of Rundu. In 1991, only 1 % of all rural households used electricity for lighting (Jones and Cownie, 2001: 4). Generally, energy demands in households are satisfied by wood fuel.

Tarmac or gravel roads serve the riverside zone of Kavango Region. A good tar road runs from Rundu southwest to Grootfontein. Inland communities are served by poor sandy tracks that are only accessible by four-wheel-drive vehicles (Matsaert, 1996: 9). A bus runs daily along the riverside road, and there are frequent minibuses on the road to Grootfontein. However, no public transport serves the inland communities (Matsaert, 1996: 9). Directly in the research area, means of transport are limited.

Permanent or temporal ‘cuca shops’, located in rural communities, act as market outlets for crop surpluses and traditional alcohol. Rundu has a large number of market facilities for agricultural produce and inputs (seeds, fertilisers, etc.). Meatco purchases livestock directly from rural communities (Matsaert, 1996: 10).

A commercial banking service in Kavango is based in Rundu. Since communal land cannot be held as collateral, it is difficult for peasant farmers to obtain loans from a bank for agricultural purposes. Agricultural loan schemes are offered by the government from time to time. According to Matsaert (1996: 11), even Agribank (Agricultural Bank of Namibia) granted loans to farmers in communal areas.

2.2.6 Biophysical conditions and native vegetation

Though the Kavango Region receives more rain than many areas in the south and west of Namibia, its climatic condition is generally dry. This is caused by high rates of solar radiation and evaporation as well as comparatively little cloud cover. Most of the rain falls from November to March, but there are fluctuations in the total amount of rainfall related to a) the location, b) the year and c) the season (Jones and Cownie, 2001: 5). While amounts of rainfall are higher in the east and along the Kavango River, they are lower in the west and south of the river. Records of rainfall in Rundu over 60 years show less than 300 mm in the driest years to over 1,000 mm in exceptionally wet years. On average, 566 mm is recorded (Jones and Cownie, 2001: 10). Seasonal variation in rainfall is significant. About 80 % of rain falls between December and March. January receives the highest amount on average. Another 15 % is allocated to November and April. Almost no rain of any significance is recorded between May and September (Jones and Cownie, 2001: 12).

Temperatures are relatively high. With some exceptions, average maximum temperatures are above 30°C. Minimum temperatures in the winter months of June, July and August fall slightly below 10 °C. Evaporation is a critical issue. The highest rates of evaporation can be observed between September and October (dry season) (Jones and Cownie, 2001: 13).

The native vegetation consists of broad-leafed, deciduous woodlands and occasional shrub lands (Strohbach, Strohbach, 2004: 58) that vary according to topography and soil types (Jones and Cownie, 2001: 14). Aeolian Kalahari sand is the major soil element. It allows very little water retention and is sensitive to wind erosion (Yaron et al., 1992: 7). Dune ridge soils can be classified as Dystri-ferralic Arenosols. Though being nutrient poor, these soils build the habitat of dry forests (Peterson, 2008; Vogel, 2008). Thickly wooded areas consist of a large variety of very valuable tress such as Rhodesian Teak, Leadwood and Marula (Yaron et al., 1992: 7) (Jones and Cownie, 2001: 15). Eutric Arenosols, which are slightly more nutrient-rich, can be found in inter-dune valleys (Peterson, 2008; Vogel, 2006). Hence, these areas are often more open and covered with grassland (Jones and Cownie, 2001: 15).

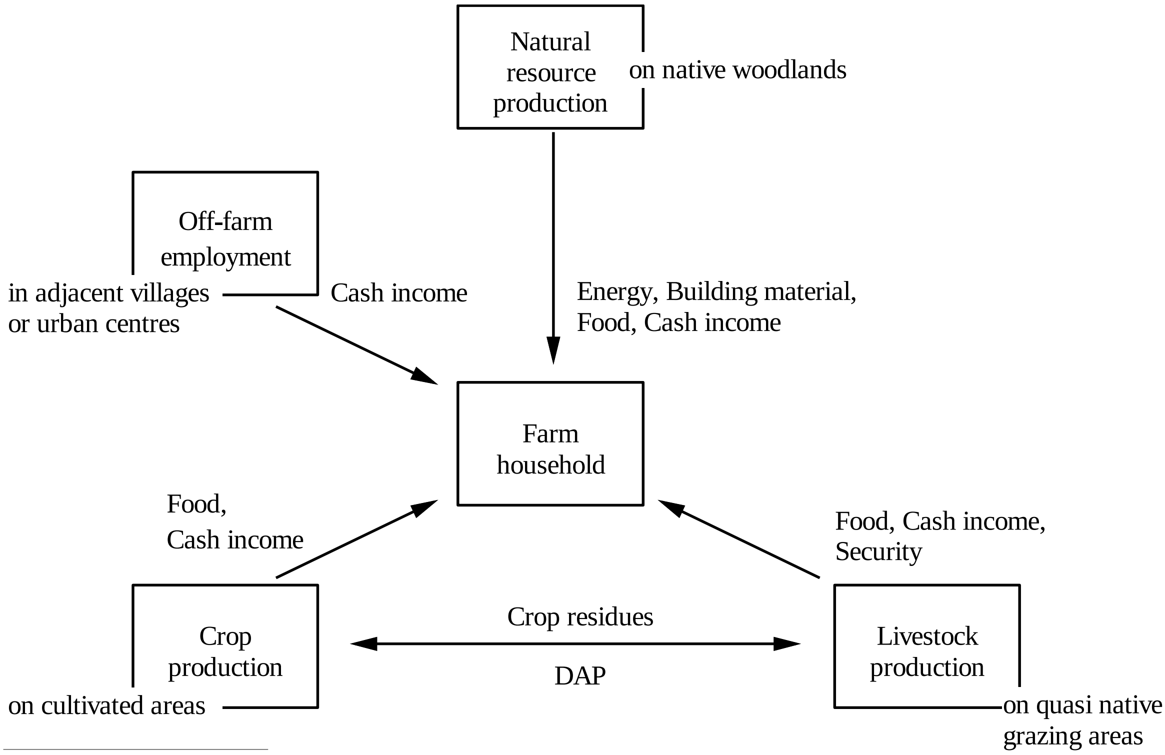
As a result of the biophysical conditions, crop growth is often limited. Similarly, productive potential of natural pastures can be restricted (Jones and Cownie, 2001: 12). Specifically during the dry season, natural resources are additionally threatened by considerable bush fires. The vast majority occur as surface fires that spread in the grass and shrub layer. Fires occur most frequently and intensely in the north and particularly in the northeast (FAO, 2001: 1).

2.3 Livelihoods and farming systems

Subsistence-oriented livelihood systems dominate the Kavango Region. They are generally based on a broad variety of activities. In addition to farming activities, like crop and livestock production, off-farm employment and use of natural resources play a key role (Matsaert et al., 1998: 1, 45). Figure 2.5 shows important elements of the prevailing farming system in the Kavango Region with their locations, deliveries, and major linkages.

Livestock farming and off-farm employment are the most important cash income sources of inland villages. To a varying degree, crop production and natural resource use can also deliver cash income, depending on household characteristics and environmental conditions (Matsaert et al., 1998: 27, 28) (Figure 2.5). For some households, earnings from crop sales exceed even those from off-farm employment (Matsaert et al., 1998: 45).

Cash income can be used to make day-to-day food purchases and to invest in farming activities. In this context, hired labour and draught animal power (DAP) reflect the most important investments within the crop production process (Matsaert et al., 1998: 45; Mutwamwezi, Matsaert, 1998: 7).



Source: Modified from Matsaert et al. (1998:1).

Figure 2.5: Major elements of the prevailing farming system

Food sources predominantly encompass domestic crop and livestock products as well as purchases of the same from retail shops. Specifically in years with poor rainfall, local markets play a key role in ensuring food security (Matsaert et al., 1998: 29, 30, 34, 35, 40, 41). Additionally, wild fruits from forest trees count as a nutritional source for some inhabitants. Together with livestock products, they play a central role, particularly during the hungry period (December to April), when crop production stocks run short (Figure 2.5). Though poorer households are more dependent on native natural resource usage, richer ones generally reap a higher profit from them (Matsaert et al., 1998: 46).

Apart from food purchases, major expenditures that need to be served by cash incomes are school fees and health care (Matsaert et al., 1998: 27, 28). Monthly spending on food and education make up about 50 % of total expenditures of a typical household. Other important purchases include clothing, farming inputs and transport (Matsaert 1996: 23). Linkages between all considered sectors are imperative and need to be kept in mind when developing new management practices or policy directions (Mutwamwezi, Matsaert, 1998: 14). By providing residues and DAP, crop and livestock production are directly linked.

2.3.1 Resource endowments

Besides land, all encountered livelihood system elements demand, as a major resource, family labour. Additionally, family labour pools are sometimes furnished by hiring external workers. Principally, household members can be divided into producers and dependents. Children under the age of 15 and household members above the age of 59 are considered dependents. They are physically not able to contribute to a household's income and food security. On the other hand, producers are household members between the ages of 15 and 59. They constitute the family labour pool.

Figures on the average number of producers and dependents per household vary slightly among different studies. On average, a typical household in the Kavango Region is equipped with between one and five producers who contribute to the family labour pool (Mawrd, 1996: 10; Mawrd, 2003: 29; Deniau et al., 1997: 115; Matsaert, 1996: 20). According to Mawrd (1996: 10), households with more dependents than producers are less common than those with the same number or fewer dependents. Contrarily, Matsaert (1996: 20) observed a high dependency level in the Kavango Region. Less than 40 % of the population is potentially able to work. With respect to agricultural work tasks, this figure needs to be reduced by 12 %, since this share of potential workers is employed in formal off-farm labour. Another 22 % of households are additionally involved in casual labour, which may limit their potential to work on their own farms (Matsaert, 1996: 20).

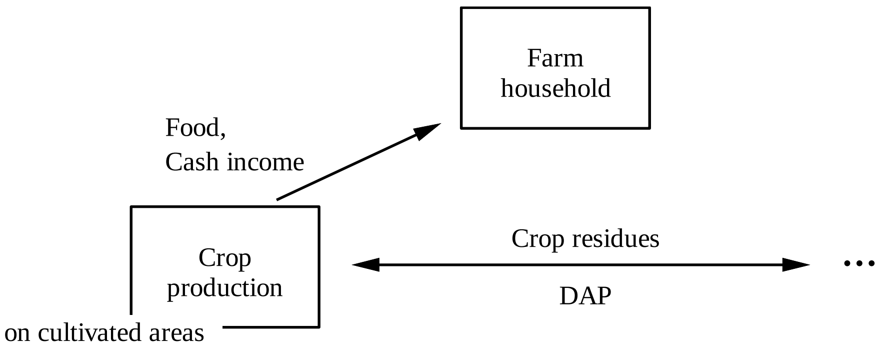
As an addition to the household labour pool, the ability to hire labour plays a key role in meeting labour needs (Mutwamwezi, Matsaert, 1998: 8). Either individual workers or bigger groups of workers are hired (Mawrd, 1996: 10; Matsaert et al., 1995: 18; Jones and Cownie, 2001: 31). Working in groups is called 'nzambi'. This term describes a specific process: first a group of people work together, and afterwards the initiating household provides millet, meat or traditional alcohol (Matsaert et al., 1995: 18; Jones and Cownie, 2001: 31). According to Mawrd (2003: 29), a significant number of households regularly hires labour to help with farm work. This matches with figures found by Matsaert (1996: 21). However, the latter differentiates between a) hired labour, especially during the cropping season for the task of weeding, and b) non-cash labour exchange by organising 'nzambi'.

Though casual labour tasks are carried out by both genders (Matsaert et al., 1995: 25), most hired labour is provided by women (Jones and Cownie, 2001: 31). Households with no means to hire labour seek technologies to reduce labour needs, especially during the weeding season (Matsaert, 1996: 21).

2.3.2 Crop production

Rain-fed crop production plays one of the crucial roles in the livelihood system of the Kavango Region, as almost all households cultivate land. While some households cultivate their land to meet subsistence needs only, some see crop production as an additional cash income source (Mutwamwezi, Matsaert, 1998: 5) (Figure 2.6).

Since pearl millet is known for demanding little in terms of soil quality and rainfall, it is the main staple crop (Yaron et al., 1992: 49; Jones and Cownie, 2001: 29; Mawrd, 1996: 27; Mawrd, 2003: 15; Mutwamwezi, Matsaert, 1998: 5). According to different surveys, pearl millet accounts for approximately 74 % of total crop production (Yaron, et al., 1992: 49), 75 % of cultivated areas (Jones and Cownie, 2001: 29) or even 93 % of cultivated fields (Mawrd, 1996: 27). Millet is grown in distant fields while gardens closer to homesteads are used to cultivate legumes and cucurbits. These are often intercropped with maize and sorghum (Jones and Cownie, 2001: 29; Mawrd, 2003: 15; Mutwamwezi, Matsaert, 1998: 10). Prominent cash crops include cotton, oriental tobacco and groundnuts (Pröpper, 2009: 169). However, directly in the research area, specifically non-food cash crops (cotton and tobacco) are not cultivated (Pröpper, 2009: 169).



Source: Own design based on Matsaert et al. (1998: 1).

Figure 2.6: Crop production as one element of the prevailing farming system

A major factor affecting yields is rainfall. Good years are those during which rainfall is both sufficient in quantity and well-timed.

Usually, however, there are irregular falls of productive rain throughout the growing period. Rain often starts relatively late in the season, and in many years, long periods of hot and dry weather occur (Jones and Cownie, 2001: 32). Besides the influence on yield levels, rainfall seems to be one key factor that determines sizes of cultivated areas.

According to a study by Jones and Cownie (2001: 32), a bad rain season meant that only 50 % of the households that intended to cultivate more than one plot ended up doing so. Among other factors that show an impact on field size, the following two are most prominent:

1. Location of the household. Inland households cultivate about 30 % more land than those along the river.
2. The household's assets and wealth. Households with cash incomes cultivate areas 25 % bigger than those lacking any cash income. Families possessing a plough and oxen cultivate double the area of those having no draught animal power or equipment (Jones and Cownie, 2001: 31; Mutwamwezi, Matsaert, 1998: 5).

2.3.2.1 Field sizes and yield levels

As a matter of fact, specifications on average sizes of land holdings differ considerably among and within secondary data sources. Ranges indicate that land holding sizes of about 1.7 ha to 6.7 ha (Jones and Cownie, 2001: 31), 1 to 7 ha (69 % of respondents) (Mawrd, 2003: 34) or 2.7 ha to 4.5 ha (Mutwamwezi, Matsaert, 1998: 17) exist. The average amounts to 4.2 ha – or 4.7 ha for richer and 3.7 ha for poorer households (Yaron et al., 1992: 49). In general, fields are located in inter-dune valleys (Jones and Cownie, 2001: 31). Households seem to have a preference for sandy loam soil over less fertile sandy soils (Mutwamwezi, Matsaert, 1998: 8).

Yields in region-specific publications are rarely mentioned, but when they are, they vary considerably, just as field sizes do. Yield levels per ha mentioned in different publications range from 60 kg to 625 kg (Mutwamwezi, Matsaert, 1998: 10; Yaron et al., 1992: 49; Mutwamwezi, Matsaert, 1998: 17; Jones and Cownie, 2001: 32). A more plausible span is provided by Jones and Cownie (2001: 32) resulting in 100 to 300 kg/ha.

Generally, yield records are assumed to underestimate the reality (Mutwamwezi, Matsaert, 1998: 10). This was confirmed by Jones and Cownie (2001: 32), who compared farmer estimates of yield levels to data obtained from crop cuttings. While farmer estimates were assumed to represent yields of crops if they are grown in association with other crops, the crop cutting estimates were assumed to represent yields under pure cropping. Farmers estimated their millet yields to amount to 120 kg/ha. At a village level, these estimates ranged from 94 kg/ha to 151 kg/ha. This implies, as expected, a considerable variation in yields per plot within a village. Crop cutting yields indicate an average millet yield of 300 kg/ha, which was more than twice farmer estimates (Jones and Cownie, 2001: 32).

2.3.2.2 Variable inputs

A key element connecting crop and livestock production is draught animal power (DAP) (Mutwamwezi, Matsaert, 1998: 5). According to Mawrd (2003: 62), a majority of households (83 % in a survey) use DAP for ploughing. Non-cattle owners have the possibility of obtaining access to DAP via what are called ‘usita’ systems, an exchange of animals. However, these non-cattle owners are forced to plough later or even interrupt ploughing if the owners are in need of their livestock. Another use of DAP is to transport crops or crop products from fields to the homestead (Mutwamwezi, Matsaert, 1998: 5). DAP use for weeding is not as prominent, since some weeds provide a nutritious and palatable food source in the hungry period before the main crops are harvested (Mutwamwezi, Matsaert, 1998: 12).

Though it can maintain soil fertility, manure is used more in small gardens than in distant fields (Mutwamwezi, Matsaert, 1998: 5). Similarly, the use of chemical fertilizers is very limited (Jones and Cownie, 2001: 32), and pest control plays only a minor role (Mawrd, 2003: 60; Mawrd, 1996: 35). According to Pröpper (2009: 170, 171), manure use and pest control are avoided by households because a) the transportation of such inputs to distant fields requires too much effort and b) transaction costs for buying herbicides and pesticides are not affordable. Consequently, minor dung collection occurs. Another significant non-labour input for crop production is seed. Predominantly, seeds are retained from the previous harvest (Mawrd, 1996: 35; Jones and Cownie, 2001: 32).

2.3.2.3 Domestic and commercial utilisation patterns

For some households, crop production is the major food source; for others, it is cash income which plays a key role (Matsaert et al., 1998: 31). Hence, it can be assumed that the majority of households use crop production for food production and marketing (Mutwamwezi, Matsaert, 1998: 5). Nevertheless, the main portion of the harvest is consumed domestically (Jones and Cownie, 2001: 29; Mawrd, 2003: 62).

Crop residues serve as an additional fodder source for cattle and are therefore an important input for livestock production activities. Estimations of the amount of crop residues are provided in Chapter 4.3.1.5. They needed to be based on different publications.

After the harvest, millet can be stored in different types of containers for up to two years. In general, households report no significant losses during storage (Jones and Cownie, 2001: 32). Sales of crops are used to meet day-to-day cash or exchange needs (Mutwamwezi, Matsaert, 1998: 5), but information on crop prices seems to be poorly provided to rural farmers (Mawrd, 2003: 61). While some farmers may sell surpluses in some years, it seems likely that domestic production is often too low to meet the cereal needs of a household (Jones and Cownie, 2001: 32).

2.3.2.4 Labour

Except for field clearing, all tasks of a cropping season follow the onset of rains. Fields are predominantly cleared before the first rains. Batches of crops are often planted at different times so each planting session follows a period of good rainfall. This improves the chances that at least some crops will grow successfully. Planting at different times means that crops can be harvested gradually over a longer time period. This is how labour peaks can be avoided. In addition, the threat of pests' spreading over all crops simultaneously is reduced (Jones and Cownie, 2001: 29).

Though variation in rainfall between years does not permit agricultural activities to be tied to individual months with certainty (Yaron et al., 1992: 42), some general rules can be outlined at this point:

- Land clearing is carried out from July to October (Matsaert et al., 1995: 18) but seems to peak in September and October (Pröpper, 2009: 164). In this process, trees and shrubs are cut with axes, heaped and burnt. Larger trees are mainly left in the field (Matsaert et al., 1995: 18; Pröpper, 2009: 164). Clearing material is either used as fencing or firewood (Matsaert et al., 1995: 18; Pröpper, 2009: 164). Land clearing is carried out by both genders (Matsaert et al., 1995: 18) but seems to be predominantly performed by men (Pröpper, 2009: 164).
- From November to February, ploughing and planting take place. Ploughing can be carried out by steel ploughs and DAP, typically with two to four oxen, or by manual hoeing. Usually, villagers begin to plough with DAP after the first rains, while the manual ploughing process can start before the commencement of rains. Land preparation starts on sandy soils and continues on black soils, because they need more rain to be workable (Matsaert et al., 1995: 19). A predominant technique of the ploughing process is described in more detail by Pröpper (2009: 165). Older women are especially responsible for seed selection and storage. Planting is carried out by women (Matsaert et al., 1995: 19; Mawrd, 1996: 30; Pröpper, 2009: 165).
- Weeding, as the most labour- and time-consuming component of crop production, is mainly carried out with hand tools (hoes). There can be up to three weeding sessions in a season (Matsaert et al., 1995: 20). The use of DAP for weeding in the research area is rather uncommon, since some weeds provide a nutritious and palatable food source before the main crops are harvested (Mutwamwezi, Matsaert,

1998: 12; Jones and Cownie, 2001: 31). Men and women do the weeding. After school, even children must help (Matsaert et al., 1995: 20).

- From June to mid-August, fields of the main crop are harvested (Matsaert et al., 1995: 21). Harvesting is done manually by cutting the crops with knives or digging with hoes (Pröpper, 2009: 173). The main crops are harvested by both men and women (Matsaert et al., 1995: 21).
- Threshing can be further separated into a male- and a female-specific task. Male household members take care of the ‘main’ threshing process, while females are responsible for separating the grain from its husk (Jones and Cownie, 2001: 31).

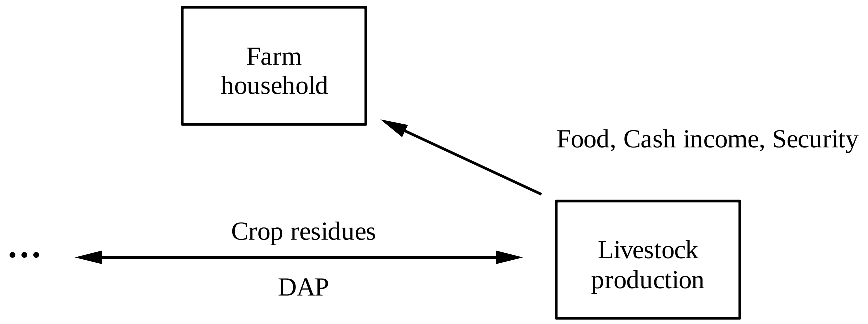
Generally, one of the eldest male household members takes over the decision-making within a household. In case of the household head’s absence, however, much of the day-to-day management and decision-making with regard to crop production is carried out by women (Mutwamwezi, Matsaert, 1998: 9). Though labour is commonly pooled in a household, internal labour shortages appear as soon as all male producers are absent during the ploughing period in search of off-farm employment (Mutwamwezi, Matsaert, 1998: 8, 9). Then, ploughing activities have to be carried out by women as well (Matsaert et al., 1998: 51). As more men are observed to leave the household after ploughing, this fact might be another reason for not using DAP in the weeding process (Mutwamwezi, Matsaert, 1998: 8).

2.3.3 Livestock production

Livestock farming is of key importance to farmers in the Kavango Region (Mawrd, 2003: 46). Though some households own donkeys, horses, pigs and sheep, livestock farming is based primarily on cattle, goats and chicken (Jones and Cownie, 2001: 32; Yaron et al., 1992: 88; Deniau et al, 1997: 113). This study concentrates on cattle production.

As can be seen in Figure 2.7, products obtained from animal husbandry add to the diet of their owners. Further, cattle deliver draught animal power (DAP), which can then be used for ploughing activities. As an exchange crop-residues left standing on fields after the harvest serve as an additional fodder source for livestock.

However, ownership of livestock, mainly cattle, can be particularly interpreted as a sign of wealth. Cattle ownership is used to accumulate capital and functions as an insurance against all sorts of risks (Pröpper, 2009: 188). Cattle herds are predominantly regarded as a bank account from which cash income can be effortlessly generated, if needed (Mawrd, 2003: 15).



Source: Own design based on Matsaert et al. (1998: 1).

Figure 2.7: Livestock production as one element of the prevailing farming system

2.3.3.1 Cattle numbers

In 1998, a total of 125,000 cattle were estimated in the Kavango Region. This number increased at an annual rate of 4 % (Jones and Cownie, 2001: 32). This matches with figures reported by Mawrd (2003: 32) for the year 2000, in which cattle numbers were estimated to amount to 137,000 heads. However, recently numbers of cattle, have decreased to 120,168 (Mawrd, 2003: 32). This change in livestock numbers can be partly attributed to the end of the war in Angola, when many Angolans moved back to their homesteads and certainly took their livestock with them (Mawrd, 2003: 15).

According to Jones and Cownie, (2001: 33) and Mawrd (2003: 32), almost half (40 or 45 %, respectively) of all households in the Kavango Region possess no cattle. Yaron et al., (1992: 88) mentioned that more than one third of households reported having no cattle at all. Pröpper (2009: 187) stated that little more than 50 % of the households he interviewed directly in the research area owned cattle.

This indicates that cattle ownership is skewed and, consequently, even numbers of cattle seem to vary within the region. According to Jones and Cownie (2001: 33), this variation relates to a number of factors. First, patterns of ownership vary in the different zones of the Kavango Region. Following population densities exclusively, 23 % of inland households do not possess cattle, compared to about 50 % of those along the Kavango River. Second, livestock ownership is related to the main source of cash income of the household. Households with wage earners have about twice as much livestock as those that have no cash income. Third, large households are more likely to be cattle owners than those with fewer family members. In fact, bigger households have higher overall livestock numbers. Finally, ownership varies in relation to the gender of the household head. Male-headed homes have about 30 % more cattle than those headed by females. Surprisingly, there is only a little difference in cattle numbers between male- and female-headed households that possess livestock. Consequently, the 30 % difference is largely because more female-headed households do not own any livestock at all (Jones and Cownie, 2001: 33).

Between 15 and 25 heads of cattle are owned by one household on average. These figures are reported by different region-specific publications. Households who own cattle have an average herd size of 25.6 (the median figure is 13) (Yaron et al., 1992: 88). Jones and Cownie (2001: 33) specified that the number of cattle kept per household is 15. This average includes the 40 % of those households that possess no cattle. Further, they indicated that the average cattle herd size along the river is nine cattle, compared with 26 cattle in western inland households. Many farmers in the western interior have large herds of more than 30 cattle, and there are a fair number of farmers with herds of 100 or more cattle. For the region as a whole, 12 % of all households have 30 or more cattle, and these farmers jointly possess about 65 % of all cattle (Jones and Cownie, 2001: 33). About 45 % of households interviewed in a study by Mawrd (2003: 32) owned fewer than 30 cattle, with only 2 % of the households having cattle in excess of 50 heads (Mawrd, 2003: 32). In this context, Yaron et al., (1992: 88) recommended that sustainable commercial cattle farming requires herd sizes of approximately 35 heads. However, fewer than 10 % of farmers meet this criterion (Yaron et al., 1992: 88).

2.3.3.2 Cattle management and performance

Generally, livestock can stroll freely around the wider village bush area and are herded by male household members during the cropping season. The starting and end points of a herding season are determined by traditional authorities and announced informally or via radio (Pröpper, 2009: 188). At night, livestock return to the water points to drink. All through the year, they are then corralled to reduce disappearances due to predators and thefts (Deniau et al., 1997: 116, 118; Pröpper, 2009: 188). Bulls are only occasionally separated from cows. Some farmers keep their calves and sick animals at their homesteads to provide them with better care under closer supervision (Deniau et al., 1997: 116). Dehorning cattle is quite common, especially compared to deworming. According to Mawrd (2003: 46, 48), 37 % of cattle owners dehorn their cattle, while only 1 % deworm them. However, the most important management practice seems to be castration. A large number of cattle owners seem to castrate their cattle in order to gain animal draught power or to control breeding (Mawrd, 2003: 47).

Deniau et al., (1997: 118) indicated that cattle mortality seems to be fairly high (14 % average over 21 years) and increases considerably in drought years (24 % in 1996). Drought is by far the main cause of cattle mortality (Deniau et al., 1997: 118).

However, sometimes mortality is also caused by heavy rains. Heavy rainfall induces a sudden growth of grass, which is rich in non-protein nitrogen. Animals weakened by deprivation and used to a fibrous feeding can suddenly consume large quantities of grass without sufficient feeding transition and finally die (Deniau et al., 1997: 123). Unlike mortality, off-take rates are fairly low (6 % over 1995 – 1997). In general, off-take concentrates on old and male cattle (Deniau et al., 1997: 122). Off-take rates of all cattle classes amount to about 7 % per year (Pröpper, 2009: 201). Of the total number of cattle sold, only one quarter is assumed to reach the formal market (Pröpper, 2009: 201).

Calving rates of Sanga cows, the predominant breed in the Kavango Region, allow one calf per cow every three years. This is a lower limit for drought years. Average rates of delivery can be assumed to be a little bit higher (Deniau et al., 1997: 118). However, at research stations within Namibia, Sanga cows prove considerably higher calving and weaning rates (Mawrd, 1997: 2). Sanga cows are known to have low milk production. Still, in some northern areas, cows are milked throughout the year (Deniau et al., 1997: 124). However, directly in the research area no systematic milk production exists (Pröpper, 2009: 189).

2.3.3.3 Forage and grazing reserves

In general, the provision of supplementary feed for livestock is quite uncommon (Mawrd, 2003: 49). If supplementary forage is provided, this comprises of crop residues (Deniau et al., 1997: 116).

Grazing management is commonly based on a seasonal transhumance. At the beginning of the rainy season, cattle stay around homesteads and crop fields to be fed on residues and inter-household pastures. As soon as fodder resources become scarce, cattle are sent to cattle posts outside village areas. These posts seem to be associated with villages in a strict and precise way and are managed by the village headman (Deniau et al., 1997: 117). However, pasture management varies within communities. Some cattle owners do not have access to cattle posts; their livestock graze freely during the dry season within the village and are herded for the whole day in the rainy season to avoid crop damage (Deniau et al., 1997: 117; Mawrd, 2003: 53). Other, mainly richer, farmers leave their cattle at the cattle post throughout the year.

Though erecting fences on communal land is not allowed, some farmers enclose a pasture reserve of about two to three ha. Farmers without this reserve face more difficulties in feeding their animals during the dry season. These difficulties are sometimes increased when village-internal pastures are used by livestock from neighbouring communities.

Usually, feeding stress periods may last two months if the rains come early in November, but can also last up to December or even January. Though boreholes drilled by the colonial or present government provide water in the envisaged pasture areas, water is the most limiting factor (Deniau et al., 1997: 117; Mawrd, 2003: 53).

During a survey initiated by Mawrd (2003: 53), farmers were asked whether they perceived that their communities have enough grazing throughout the year and if not, what can be done to maintain good grazing (Mawrd, 2003: 53). A large number of farmers revealed that their communities have enough grazing. Farmers who were aware of grazing shortcomings recommended a) resettling strong farmers on commercial farms, b) drilling more boreholes and c) giving the grazing areas rest periods (Mawrd, 2003: 54).

2.3.3.4 Domestic and commercial utilisation patterns

Peasant farmers in the Kavango Region cannot be assumed to keep livestock for the purpose of intensive meat consumption or commercial meat marketing (Pröpper, 2009: 200). For many households, livestock and particularly cattle are a major store of capital (Hengua, Bovell, 1997: 12). The functions of cattle are manifold. According to Pröpper (2009: 202), the following functions can be seen directly in the research area: a) capital investments, b) savings, c) hedging insurance, d) source of wealth (large bank account), e) commercial distribution and f) meat consumption. A large herd of livestock is additionally a cultural symbol of status and a successful life. Livestock births are a dominant source of increases in numbers (Mawrd, 1996: 25) and thus of great interest. Nevertheless, cattle require care and investment in the form of herding and breeding-related labour. The herd might grow eventually but is also constantly at risk of disease, theft and predators (Pröpper, 2009: 202).

According to Mawrd (1996: 38), the proportion of households in the Kavango Region consuming their own cattle products is rather small and varies over the year. Slaughtering cattle is for either a) domestic consumption to improve the daily diet, b) domestic consumption on special occasions, such as Christmas, or c) selling meat and purchasing millet afterwards to face some pressing food need (Deniau et al., 1997: 122 and Mawrd, 1996: 25). Additionally, emergency slaughtering allows consuming meat from the killed animal (Deniau et al., 1997: 122). Gifts of living cattle or meat are given to family members on special occasions, such as weddings (Deniau et al., 1997: 122).

Similarly to meat, the consumption of milk products produced by the household is not significant (Mawrd, 1996: 38). This can be confirmed by information provided by

Pröpper (2009: 209). He stated that households do not consume milk regularly (Pröpper, 2009: 209).

Mawrd (2003: 52) also writes that a large number of cattle owners do not sell any of their cattle. Others sell one to five animals each year, either at any age or between the ages of four and seven (Mawrd, 2003: 53). Predominant selling facilities are a) traders, b) bush-markets (slaughtering and selling under a tree in communities), c) Meatco, d) village cuca shops, e) auctions and f) commercial farmers (Mawrd, 2003: 52; Deniau et al., 1997: 122). Generally, the Kavango Region is separated from the southern parts of Namibia by a veterinary cordon fence. This fence prevents livestock from travelling north unless they have been quarantined and declared free of infestation (Pröpper, 2009: 201). Implied costs and the inconvenience of prolonged quarantine requirements might be one factor why cattle sales are rather sporadic (Deniau et al., 1997: 115; Mawrd, 2003: 15).

2.3.3.5 Labour

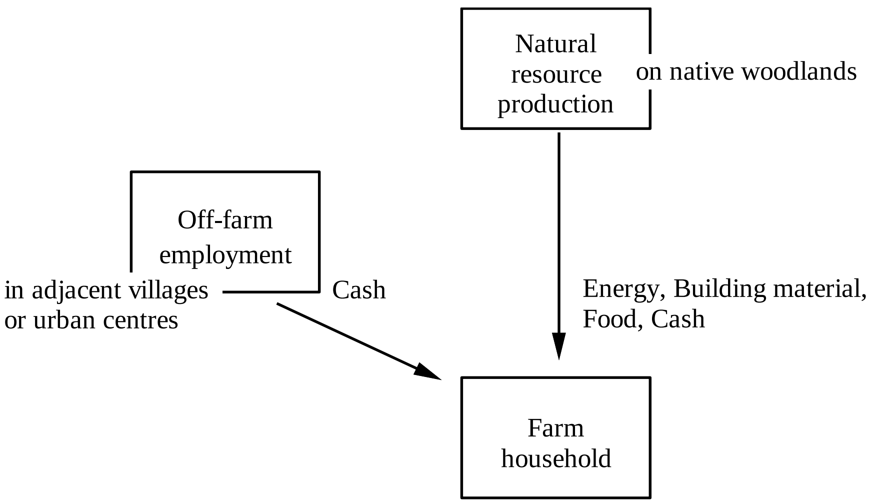
Apart from crop production and domestic purposes, labour is primarily needed for live-stock production. Seasonal calendars for livestock management illustrate a diverse range of tasks. To avoid damage to crops during the cropping season, herding is compulsory. For this reason, this is the most labour-intensive task.

There is a strong division of labour, and adult men are mainly in charge of cattle (Deniau et al., 1997: 115). In the past, but still observable today, even children and young men played an important role in herding. However, as children spend increasing amounts of time at school and young men find formal employment in urban centres, labour becomes a growing problem for livestock management (Matsaert et al., 1998: 51). Generally, women are not allowed to manage cattle without their husbands' authorisation (Deniau et al., 1997: 115). If they are authorised, women must care for livestock on top of their al-ready substantial workloads. Because they are compulsory during the cropping season, herding tasks correlate with peak labour demands for crop production (Matsaert et al., 1998: 51). To prevent potential labour shortcomings, livestock owners often group their cattle under the care of a young man, known as the 'herdsman' (Deniau et al., 1997: 115).

2.3.4 Natural resource production and off-farm employment

Usage of forest products and participation in off-farm employment also play central roles in livelihoods, particularly for inland villages of the Kavango Region (Kakukuru, Mat-saert, Mutwamwezi, 1998: 6) (Figure 2.8). In rural settings, wood fuel is harvested by villagers from communal lands using their access rights for the gathering of various for-est products. Usually, some wood fuel is also traded and sold to the urban areas in the north. A significant portion, about 50 %, of wood fuel is harvested illegally without the required permit (FAO, 2000: 2). A majority of households rely on locally available natural resources for building. About 92 % of inhabitants have made the walls of their houses out of wood or mud. Roofs are often made of grass (Jones and Cownie, 2001: 21).

Generally, the functions of woodlands and natural resource areas are manifold. However, their main functions are supplying a) food, b) building material, c) energy and d) cash income (Figure 2.8). For instance, the Manketti tree, which is a key forest resource, provides a) fruit, which can be used to produce liquor, b) wood, which is used to build sledges for transport, and c) nuts, which are popular food products and are sometimes even sold (Kakukuru, Matsaert, Mutwamwezi, 1998: 10).



Source: Own design based on Matsaert et al. (1998: 1).

Figure 2.8: Natural resource production and off-farm employment as elements of the prevailing farming system

Legal ownership and management of forests is in the hands of the government rather than the local authorities. Often, forestry staff faces extreme shortcomings, i.e. to become actively involved in forest management. Sustainable management of forests becomes even more complicated with a) non-physical and non-fixed boundaries for forest areas used by specific villages and b) misuse of forest areas by burning considerable portions (Kakukuru, Matsaert, Mutwamwezi, 1998: 15).

2.3.4.1 Domestic and commercial utilisation patterns

The four utilisation patterns – food, building material, energy and income – can be observed in the Kavango Region and are briefly discussed in the following paragraphs. Fruits, nuts, wild vegetables, edible roots, tubers and tree caterpillars are valuable food sources, especially during the hungry period (Kakukuru, Matsaert, Mutwamwezi, 1998: 6). Another use of forest products is the production of medicines (Kakukuru, Matsaert, Mutwamwezi, 1998: 11).

Trees and grasses provide material for house-building. Pröpper (2009: 150) found that for housing, a combination of timber and corrugated iron roofs seems to be associated with wealth and status. State legislation, statutes and traditional institutions control the cutting of young trees. To use smaller trees for domestic building purposes is generally permitted (Pröpper, 2009: 193). Another main building material is grass (Kakukuru, Matsaert, Mutwamwezi, 1998: 10), which is used predominantly for roof-making.

A large number of households depend on firewood as a source of energy (Mmopelwa, 2006: 118). Generally, firewood is freely accessible for the production and consumption of domestic energy. It is either manually collected or cut with axes in the form of dead wood (Pröpper, 2009: 193).

Rural farmers are engaged in a subsistence-dominated household economy (Pröpper, 2009: 210), which can also provide some cash-income. Forest products often contribute to food security even if they are not actually consumed but sold. Profits are then used to buy food on the market (Kakukuru, Matsaert, Mutwamwezi, 1998: 8). In this context, roots and shrubs play an important role for basket production and carpentry, such as making furniture, tool handles and pestles, (Kakukuru, Matsaert, Mutwamwezi, 1998: 9). Commonly produced items are yokes, cooking sticks, sledges and ropes (Pröpper, 2009: 149; Kakukuru, Matsaert, Mutwamwezi, 1998: 11). However, even semi-professional tree-logging is prominent in the research area. Target species for logging are a) Uguva (Pterocarpus angolensis), b) Uhahe (Baikiaea plurijuga), also known as teak, and c) Usivi (Guibourtia coleosperma) (Pröpper, 2009: 194). After the harvest, planks of wood can be sold to traders or directly at markets in urban centres (Pröpper, Gruber, 2007). However, the extraction of timber trees for market-oriented production is regulated by a permit system and payment of certain statutory fees (Pröpper, 2009: 193). Additionally, grass species can be sold to provide cash income (Kakukuru, Matsaert, Mutwamwezi, 1998: 10).

2.3.4.2 Labour and off-farm employment

With regard to natural resource production, family labour is needed for harvesting and collecting. In terms of grasses, the harvesting season and the amount of family labour required depend on the grass species. Mmopelwa (2006: 115) indicated that, for instance, three bundles of a specific grass species can be harvested in ten hours twice a week. At the same time, eight bundles of another grass species can be exploited six times per week (Mmopelwa, 2006: 115). Hence, total collecting labour for grass harvesting per household and year can vary considerably (Mmopelwa, 2006: 116). Firewood or fuel wood is collected throughout the year. Twine et al. (2003: 470) found a declining availability of fuel wood in their investigated research area over the past five to ten years. This caused an increase in family labour requirements for collecting. For example, a head load of fuel wood that previously took about two hours to be collected now had a mean collection time of four hours (Twine et. al., 2003: 470). As for firewood, timber tree harvesting is not tied to specific months of a year. Harvesting involves felling and processing the trunk into planks of wood of a specific diameter (Pröpper, Gruber, 2007).

According to Matsaert (1996: 17), more than 10 % of Kavango adults have formal employment. About one third of households have one or more wage earners (Mawrd, 1996: 10). The most common occupation after farming is teaching and then employment by NGOs or cooperatives (Mawrd, 1996: 10). Usually, the adult working generation find off-farm employment either close to their locality, in other areas of Kavango, or even outside the region (Matsaert, 1996: 17). It can then be observed that within households, grandparents increasingly take responsibility for farm activities and child care (Matsaert et al., 1998: 49, 50). Formal education can be more easily received by men. This in turn impacts opportunities for formal off-farm employment opportunities. However, even unskilled labour opportunities are often available to men (Matsaert et al., 1998: 50).

2.4 Major environmental and socioeconomic threats

According to Ashley (1996: 1), it is possible to generally distinguish two causes of biodiversity loss. First, an overuse of one or more specific species can occur, for instance by selective grazing of cattle. Second, a loss of habitats can threaten many species or resources (Ashley, 1996: 1). According to Myers (2002: 56), habitat losses induced by cultivation are the main threats worldwide to forests, accounting for two thirds of the annual losses. Threats to biodiversity in the Kavango Region are based on human land use. This predominantly causes a) deforestation and soil degradation and b) grazing area depletion (Yaron et al., 1992: 10).

Apart from poverty and malnutrition, one major socioeconomic threat originates from HIV/AIDS, which also has the potential to increase poverty and malnutrition. Generally, the impacts of HIV/AIDS are manifold. This study focuses on impacts at the household level and the demographic structure of the economy.

2.4.1 Environmental threats and driving forces

Namibia has a National Biological Diversity Task Force in which several directorates in charge of parks, wildlife, forestry and environmental affairs are involved (Kojwang, 2000: 3.5). Still, deforestation is a major environmental threat in the Kavango Region (Yaron et al., 1992: 10). Deforestation causes a change in biodiversity with a decrease in wildlife numbers and species due to habitat losses (Ashley, 1996: 3). Apart from population growth, the following two driving forces which support deforestation can be distinguished: a) losses of soil nutrients and b) misleading incentives. These driving forces lead to a higher frequency of clearing new fields for cropping.

Aerial photographs indicate that the land cleared for crops increased more than seven times, from 0.5 % to 4 %, in the Kavango Region between 1943 and 1996 (Mendelsohn, el Obeid, 2003: 114). For other northern areas in Namibia, for instance, the Ohagwena Region, an annual decrease of forest areas of 0.5 % is reported by Kojwang (2000: 3.1). The predominantly sandy soil texture prevalent in Kavango Region holds few nutrients and allows water to drain away rapidly (Mendelsohn, el Obeid, 2003: 14, 62, 93; Yaron et al., 1992: 41). A loss of soil nutrients also arises from a lack of crop rotation, manure applications and intercropping. This is often referred to as unsustainable use of agricultural areas (Ashley, 1996: 3) coupled with a reduction of fallow periods. Sometimes misleading incentives also strengthen deforestation processes. Kakukuru, Matsaert and Mutwamwezi (1998: 13) detected that awareness of benefits provided by trees left in fields is low. Often trees are judged as hindrances to efficient crop production. In the past, removing trees from cropping fields was supported by the government and Agribank policies. They linked a credit program to complete tree removal (Mutwamwezi, Matsaert, 1998: 1). Overgrazing, especially around water points in inland regions due to poor livestock management, is another threat to local biodiversity (Yaron et al., 1992: 10).

Threats are likely to include losses of edible and perennial grass species (Ashley, 1996: 3). In addition, the expansion of cleared land can be expected to cause an intensification of grazing pressures on the remaining grazing areas (Mendelsohn, el Obeid, 2003: 114). Generally, a degradation of rangelands is rather subjected to how livestock is managed and not exclusively to how much livestock is managed (Ashley, 1996: 3).

Because of higher population pressures along the riverside, farm households there experience the impact of degradation of communal resources more directly (Matsaert et al., 1998: 46).

Some results of these potential threats can already be directly observed in the research area. In this context, Pröpper (2009: 172) stated that ongoing expansions of fields, along with new clearings, are a potential threat to biodiversity. In his survey, he found that about 20 % of respondents counteract declining soil fertility by clearing a new field or by expanding their field boundaries. Extracting selective valuable timber tree species can also be observed within the research area. Pröpper (2009: 204) indicated that global tourism and trade provides an incentive for local inhabitants to participate in semi-commercial production of carved artefacts and crafts.

However, for grazing reserves directly in the research area, degradation is not yet a cause for alarm. Stocking numbers seem to still be in the rage of conserving pastures and sustainable rangeland management (Schneiderat, 2008: 120). While Pröpper (2009: 190) calculated stocking densities, Schneiderat (2008: 120) calculated carrying capacities for pastures located in the research area. Calculations by Pröpper (2009: 190) resulted in a stocking density of 19.17 kg/ha for cattle. Schneiderat (2008: 120) estimated a corrected possible carrying capacity based on actual rainfall patterns of a) 75.9 kg/ha for sandy soils and b) 35.7 kg/ha for the moderate stony range. Both figures indicate that stocking densities have not yet reached critical limits. They can still be increased by a factor of 1.86 for the stony range or even 3.96 for sandy soils. In summary, the grazing area is not yet endangered by overgrazing (Pröpper, 2009:190).

Bearing above paragraphs in mind, driving forces for the destruction of biodiversity are manifold and predominantly based on human land uses. Ashley (1996: 2) assumes that the non-ownership of main agricultural resources discourages a process of investment in natural resource conservation. Thus, interest in biodiversity conservation is low because of a) the few benefits of wildlife conservation and b) comparably high returns for agricultural activities (Ashley, 1996: 7).

2.4.2 Socioeconomic threats and their impacts on farm households

Impacts of HIV/AIDS on the demographic structure have several implications. One major effect is a decrease in life expectancy and increase in mortality rates. The population will grow at a slower rate than otherwise, and there will be a smaller labour force (World Bank, 2001: 4). Given that the economy can barely keep up with the growth in the labour force, which is resulting in high levels of unemployment, a shrinking labour force would not affect the economy directly, but it would increasingly lead to a shortage in skills.

Since prevalence of the virus among the skilled and the educated is likely, sufficient labour resources can become a problem (World Bank, 2001: 21).

In general, significant differences in prevalence rates can be observed which are representative for Namibia's population to different degrees. Therefore, this paragraph gives a brief overview of some statistical evidence. HIV prevalence rates observed among pregnant women indicate that the simple mean has significantly increased from 4.2 % to 17.4 % between 1992 and 1998 (World Bank, 2001: 7). There is a wide variation among regions. In Rundu, the urban centre of the Kavango Region, prevalence rates increased from 8 % in 1994 to 14 % in 1998 (World Bank, 2001: 8). Statistical surveys from STD clinics show higher figures for 1998. In Rundu, approximately 46 % of STD patients were HIV positive (World Bank, 2001: 9). However, as STD patients carry a higher risk of infection, prevalence among the STD population is likely to be higher than prevalence among the total population (World Bank, 2001: 10). National estimates from the UNAIDS/WHO working group estimate that about 20 % of adults in Namibia were living with HIV (excluding those with AIDS) in 1999 (World Bank, 2001: 11). Results of projection models indicate that the prevalence will grow in proportion to HIV-positive cases reported by the Directorate of Health and will reach 25 % by 2015 (World Bank, 2001: 19). Generally, all indications show that the epidemic is widespread in the country (World Bank, 2001: 11).

At the household level, an HIV/AIDS infection may result in a dramatic decrease in income, consumption and savings because of a loss of income earners (World Bank, 2001: 3). The availability of family workers per household will decrease (Hange et al., 1999: 5). Additionally, poverty could be accentuated due to substantial medical expenses and may lead to food insecurity. To save some cash resources, children might be taken out of school to instead care for ailing parents. Finally, the elderly population may be burdened with bringing up children orphaned by the epidemic (World Bank, 2001: 3). Often, impacts on women are more significant (Hange et al., 1999: 4; World Bank, 2001: 4). This causes a specific problem because of their usually higher work burdens (Hange et al., 1999: 5). Because of their inferior status, they are less able to take precautions, as they have less control over decisions and are often pressured into sexual relations that offer them economic security. They are likely to have sexual relations with older men who have had more exposure to infection in the past. Even if they are not infected, they shoulder the burden of caring for the sick (World Bank, 2001: 4).

One major input of the farming system in the Kavango Region is family labour. Family members comprise 90 % of total farm work input. The effect of HIV/AIDS on the reduction of this family work force is complex (Hange et al., 1999: 5). Generally, households with fewer workers can cultivate less land and produce less crop output for their own consumption. Moreover, they become more subsistence-oriented (Hange et al., 1999: 13).

2.4.3 Possible coping strategies

Partly ignoring the dependence of local inhabitants on land use, strategies for biodiversity conservation could be linked to a) increasing awareness of the benefits of wildlife or b) increasing costs of land use (Ashley, 1996: 8). Increasing costs of unsustainable land use can be generally induced by charging inhabitants for the use of natural resources (predominantly land). Since cash inflows of local inhabitants can be assumed to be rather small, it is questionable whether such a strategy would result in a desired outcome. However, the applied modelling approach of this study can be used to detect land use changes induced by such cost increases.

Investments in biodiversity conservation (Ashley, 1996: 7) and in productive assets (land) for crop production are rather low in the research area (Pröpper, 2009: 155). To stimulate both, another strategy could be to increase investments in already cultivated areas. This could be done by promoting the use of variable inputs for crop production, like manure or fertilisers. Unfortunately, these investment activities are linked to higher labour and cash efforts.

Therefore, a promising trigger strategy could be promoting labour-saving techniques. This would match with strategies recommended for dealing with the threat of increasing HIV/AIDS prevalence. Hange et al. (1999: 14) suggested that public money needs to be used to develop and promote labour- and cash-saving technologies. Technologies which can reduce labour pressures on women are of especially high interest, since they take over most of the health care (Hange et al., 1999: 14).

To this end, a first step could be to promote row-planting technologies for millet. Though this technique consumes more time during the actual planting process, it saves time and work during the weeding stage. This will have a positive effect on women’s workloads, as they are responsible for several cropping tasks. However, it needs to be kept in mind that random-scatter planting is quicker during the actual planting process, which is important when all crops sown should have the chance to take maximum advantage of available soil moisture (Hange et al., 1999: 14). In addition, labour-saving devices can be applied to daily maintenance activities carried out by women. For water fetching and firewood collecting, women often have to walk long distances. Thus, more effective stoves using less firewood or more water pumps for inland villages can reduce workloads. Some millet varieties are much easier to thresh, pound or cook faster than others. Introducing and promoting such millet varieties would also result in savings in labour hours (Hang et al., 1999: 15).

3 Theoretical Foundation and Modelling Approach

A major goal of this study is to identify optimal farming strategies of peasant farm households which take both economic and environmental aspects into account simultaneously. In order to accomplish this task, obviously different concepts and disciplines need to be considered.

By analysing peasant farm households in the context of developing countries, this study addresses a vast domain of neoclassical theory - farm household economics. A peculiarity of models related to farm household economics is that they consider production and consumption decisions simultaneously, which is further discussed in Chapter 3.1. Subsequently, this chapter includes a description of different farm household models (FHHM) with their major implications and aspects relevant to this study.

As indicated by the aim to find 'optimal' farming strategies, the wide range of mathematical optimisation plays another important role. Generally, optimisation models describe the evolution of a system over a period of time and determine optimal levels of decision variables under specific constraints. However, in many cases, optimisation of farming strategies should be determined by considering environmental and economic aspects at the same time. In this context, applied mathematical optimisation with respect to the field of bio-economics can be addressed by designing specific tools, e.g. bio-economic models (BEMs). Chapter 3.2 describes classification characteristics of BEMs and illustrates several characteristics of the model used in this study.

The above-mentioned research directions are combined in Chapter 3.3, which describes the modelling exercise by considering different aspects and dimensions relevant for the Kavango Region. After a brief outline of the combined modelling approaches that inspired this study, the first section addresses the decision-making unit. Subsequently, a theoretical dimension is outlined, where some dimensions of FHHMs are modified to match empirical findings in the research area. Important assumptions relevant to the theoretical base are discussed afterwards. In the end, the overall model structure and a qualitative description of the most important linkages are outlined.

3.1 Farm household models

Under the assumption of perfect markets, the simple neoclassical theory distinguishes between a) producers (firms, farmers, etc.), which are assumed to maximise profits under specific resource constraints by selling their products, and b) consumers (households), which are assumed to maximise utility under a budget constraint by purchasing products.

Inputs for the production activities of a producer and products for consumers can be obtained at prevailing market prices. Following this concept, in terms of agricultural economics a farmer may then be regarded as a producer of farm products. In this case, production theory provides a framework for explaining a farmer's decision on how to allocate resources to different economic activities in order to maximise profits. Production decisions are not influenced by any consumption preferences and vice versa. Based on these settings, farmers' behaviour patterns and their adaptations as induced by policy changes can be modelled by using a 'pure producer' model (Holden, 2004: 14; Taylor, Adelman, 2002: 3).

In contrast to the simple concept, rural peasant farmers in developing countries, where market failures can occur, often act simultaneously as producers (farmers) and consumers (households) for the same product (Taylor, Adelman, 2002: 4; Holden, 2004: 14; De Janvry et al., 1992: 1; Ellis, 1998: 106). In this case, a 'pure producer' model and a 'pure consumer' model would both fail to capture important aspects and might misinterpret reactions to policy changes (Holden, 2004: 14). For instance, if the price of a good (staple crop) increases, the consumption level of the good in a household, as a consumer, would drop. However, if the same household is also marketing the good as a producer, it would gain higher cash income. Finally, a negative price effect might be balanced out by a positive profit effect (Taylor, Adelman, 2002: 6; Low, 1986: 31). Generally, market imperfections, a major cause of non-separability (De Janvry et al., 1992: 1), often occur because of a) high transaction costs (Taylor, Adelman, 2002: 1), b) information asymmetries or c) the scarcity of, for instance, labour or credit markets (Holden, 2004: 3). As shown by Singh et al. (1986: 52 – 59), applications and justifications of non-separability in farm household modelling are manifold. They address, for instance, differences in sale and purchase prices for commodities or resources such as labour. Other typical hints for non-separability are incomplete and interlinked markets, risk, or household production activities. Taylor and Adelman (2002: 5), noted that empirical models quantitatively confirmed non-separability in various country settings.

As indicated in Chapter 2, farm households in the research area are semi-commercial, or rather subsistence-oriented, and they face market imperfections. Hence, simulating decision making must be based on non-separability. To emphasise this aspect, the present study refers to the term farm household (FHH) rather than simply 'household' or 'farmer'. Over time, different non-separable theoretical models have been developed in order to explain the behaviour and reactions of peasant FHHs to changing policy or technological conditions. In the following chapters, the most relevant concepts, implications and differences of these models are discussed. Following a chronological sequence, this study starts with the model of *Chayanov*, touches the major developments incorporated by *Barnum-Squire* and ends with adaptations initiated by *Low*. Intermediate development steps like the models of *Nakajima* and *Kirshna* or the *New Home Economics Model* are not explicitly described because a) important features are also considered by the advanced models discussed here or b) their character is only partly non-separable.

3.1.1 Chayanov's model of farm households

One of the earliest attempts to combine FHHs' production and consumption decisions was initiated by *Chayanov* in the first quarter of the last century. *Chayanov* basically followed the theory of utility maximisation. However, he incorporated two opposing objectives in the utility function (U) of a peasant FHH: income (Y) and leisure (H) maximisation (Ellis, 1998: 106).

$$MaxU = f(Y,H)$$ **(3.1)** (Ellis, 1998: 108, 109)

According to consumer theory, convex indifference curves are used to describe the level of utility obtained by the consumption of two conflicting goods (Ellis, 1992: 103). In *Chayanov's* theory, the income objective requires work on the farm, whereas the leisure objective conflicts with income generation. Hence, the slope of a utility function describes the amount of utility obtained by leisure which would be foregone for a certain amount of utility obtained from additional income (Ellis, 1992: 108). This trade-off is mainly influenced by the size, composition and structure of a household (Ellis, 1992: 106). In order to combine utility maximisation from consumer theory with production theory, *Chayanov* included a production function in his model, which depends on varying levels of labour input. Market prices of outputs (p) and labour input to produce the outputs f(L) determine a FHH's cash income (Y) (Ellis, 1992: 108).

$$Y = py \times f(L)$$ **(3.2)** (Ellis, 1992: 108)

In the end, utility of a FHH is maximised subject to such a production function, the need to secure a minimum standard of living and a time constraint (Ellis, 1992: 109). A minimum standard of living (Ymin) is mainly determined by the family size, e.g. the number of all consumers, dependents and producers. This non-fixed constraint points out that, after consumption needs have been satisfied, the utility of additional income is relatively low compared to the utility of additional leisure time (Ellis, 1992: 110).

$$Y \geq Y\min$$ **(3.3)** (Ellis, 1992: 109)

Further, a FHH is constrained by a maximum number of working days (Lmax), which is determined by the family structure (number of producers) (Ellis, 1992: 109).

$$L \leq L\max$$ **(3.4)** (Ellis, 1992: 109)

Ellis (1992: 107) imposes the following core assumptions on *Chayanov´s* model:

- Access to land is not fixed but flexible for a peasant FHH
- Farm output is valued at market prices and either domestically consumed or sold
- An acceptable minimal consumption level of a FHH needs to be met
- Labour markets are absent (no hiring in or out of labour)

One proposition is that the marginal product of labour will vary significantly between FFHs according to their demographic structure. For example, the number of days devoted to farm work will vary directly with the consumer/producer (c/p) ratio; the size of the area cultivated will vary directly with family size. The lower the c/p ratio, the higher the average income per person, since a low c/p ratio means a higher subjective wage with high marginal returns of labour (Ellis, 1992: 113) (large families reduce income).

The power of *Chayanov's* model is shown by its capacity to predict effects on the slope and position of indifference curves by changes in FHH size and composition (Ellis, 1992: 113). Low (1986: 29) further stresses the importance of incorporating complex cooperations. This implies that production efficiency increases as more producers become available. This phenomenon can be empirically observed especially in rural FHHs: shifting producers from daily maintenance tasks to productive farm work increases productivity (Low, 1986: 30). Though some peculiarities might not be empirically observed, the *Chayanov* model is fairly suitable for describing FHH behaviour under conditions in African countries (Ellis, 1992: 113).

According to Ellis (1992: 110), *Chayanov's* model is weak in predicting responses of FHHs to changes which affect the production function; for instance, changes of exogenous variables like market prices of agricultural outputs are badly predicted. With respect to Low (1986: 28), additional deficits are negligence of comparative advantages of household members in specific tasks over others and the assumption of non-existing labour markets. In accordance with empirical observations in an African context, *Chayanov's* model indicates flexible access to land. Indeed, the predominant land-tenure systems of many African countries enable FFHs to increase the area cultivated simultaneously with its household members (Low, 1986: 32). However, applying this phenomenon strictly would off-set the assumption of diminishing returns to labour for farm production

(Ellis, 1992: 108). This makes it difficult to explain participation of household members in off-farm labour, in case labour markets exist (Low, 1986: 32).

Neglecting the mentioned shortcomings, the following implications of *Chayanov's* model are relevant for reflecting FHHs' behaviour in the Kavango Region:

1. A utility function can consist of several opposing objectives.
2. A FHH has flexible access to land. Though local inhabitants need to go through an application process (RoN, 2003) to obtain user rights, land access at the FHH level is generally flexible (Chapter 2.2.4).
3. Outputs are valued at market prices; they are either domestically consumed or sold. In the research area, farm products are primarily consumed domestically (Jones and Cownie, 2001: 29). However, if surpluses can be generated, FHHs are familiar with selling them (Mutwamwezi, Matsaert, 1998: 5) (Chapter 2.3.2.3).
4. A FHH's acceptable minimal standard of living needs to be met. Since malnutrition and poverty are still shaping life in Namibia (World Bank, 2007b: 1, 5; World Bank, 2001: v), this minimal consumption constraint is of high importance.

3.1.2 Barnum and Squire's model of farm households

In general, the *Barnum and Squire* model follows the thoughts of *New Home Economics* (Ellis, 1992: 128). *New Home Economics* developed the concept that goods, as such, are not the immediate objects of utility anymore; rather, they are associated with characteristics which are directly relevant to consumers. Such desired characteristics need to be produced within a household, using physical goods as inputs (Low, 1986: 14). A FHH therefore transforms its own production and purchased goods and services (with the help of the respective resource endowment: time) into a set of desired products (referenced as z-goods) which deliver utility (Ellis, 1992: 124). An example of such a z-good is a prepared meal, where purchased ingredients, firewood and equipment are combined with respective household members' time and skills (Chen, Dunn, 1996: 14).

Utility, aggregated over all FHH members and the agricultural cycle, can be derived from four elements; consumption of z-goods (Z), leisure (L), own consumption of agricultural output (C), and consumption of market-purchased goods (M) (Barnum, Squire, 1979: 27).

$$MaxU = f(Z, L, C, M)$$ **(3.5)** (Barnum, Squire, 1979: 27)

Again, the utility function is being maximised subject to the production function of the household, the availability of time and cash income (Ellis, 1992: 128). A FHH's input and output relationships are described by a production function with 'A' being the land under cultivation (presumed fixed) and 'L' being the total labour including hired labour.

'V' is a vector of other inputs for the production of outputs (Ellis, 1992: 128, 29).

$Y = f(A, L, V)$ **(3.6)** (Ellis, 1992: 128, 129)

In the equilibrium situation, the FHH's total time endowment (T), needs to equal the sum of time spent on farm work (Tf), time spent on off-farm labour (Tw), time spent on the production of z-goods (Tz) (Ellis, 1992: 129) and time spent on leisure (Tl) (Barnum and Squire, 1979: 28). By hiring non-family workers, the total time which can be devoted to farm production can be increased and vice versa (Ellis, 1992: 129).

$T = Tf + Tw + Tz + Tl$ **(3.7)** (Ellis, 1992: 129) (Barnum, Squire, 1979: 28)

The cash income constraint states that a FHH's net earnings, obtained by sales of output (p (Q - C)) and wage labour (wTw), have to equal expenditures on market goods (output mM and input vV) (Ellis, 1992: 129).

$p`(Q - C) + wTw - vV = mM$ **(3.8)** (Ellis, 1992: 129)

As core assumptions, *Barnum and Squire* impose that:

- Access to land is fixed
- Farm output is either domestically consumed (C) or sold to purchase non-farm consumption needs (M)
- There is a single food price which is equal for purchases and sales (Ellis, 1992: 134)
- Labour markets exist (with labour being hired in or out) (Ellis, 1992: 128)
- Credit markets exist (Chen, Dunn, 1996: 16).

For optimisation, equilibrium conditions for consumption and production are fulfilled, i.e. if a) the marginal rates of substitution between each pair of items in the utility function equal the price ratios between them and b) the marginal product of labour equals the market wage rate while the marginal product of other variable inputs equals their average prices (Ellis, 1992: 129).

According to Ellis (1992: 125), the *New Home Economics Theory* is not systematically different from others. Its power is rooted in the possibility of including many different aspects in the z-good utility function (Ellis, 1992: 125). According to Low (1986: 15), the z-good approach expands the applicability of the neoclassical economics theory of choice into a non-market sector and hence makes this theory more useful in analysing FHH behaviour with its many dimensions. However, Low (1986: 15) sees even more useful implications of the *New Home Economics Theory*. For instance, it recognises that a FHH's time can be transformed into market-purchasable goods.

Thus, FHHs may not only sell their leisure time in labour markets but may also buy time in the form of purchasing certain consumer goods. Further, this model considers the resource constraints a FHH faces in its production and optimisation decisions. These are generally taken to be the time of FHH members and non-wage income, e.g. property income (Low, 1986: 15). Both authors respect the effort to analyse impacts of changes in exogenous variables (such as prices of inputs) on a FHH's decision making (Ellis, 1992: 125; Low, 1986: 15).

Generally, the *Barnum and Squire* model of a FHH allows analysis of interactions between various activities of a FHH, such as production for markets, production for home domestic consumption, wage labour and consumption of purchased goods (Chen and Dunn, 1996: 16). One of the major implications of the *Barnum and Squire* approach is their proof that signs of response elasticity for a) own consumption of farm production, b) consumption of market goods and c) consumption of leisure might change when consumption is examined alone. This stresses the importance of considering production and consumption aspects simultaneously (Low, 1986: 31). According to Ellis (1992: 128), the *Barnum and Squire* model of a FHH gets its power by generating predictions about responses to changes in both household and market-specific variables. Household modifications might include changes in FHH size and structure, whereas adaptations in terms of market variables cover changes in a) prices (input + output), b) wage rates and c) technologies (Ellis, 1992: 12).

Limitations of the model are based on some underlying assumptions. For one, it neglects to consider risk and uncertainty, which might be essential elements of the FHH's decision making (Chen, Dunn, 1996: 16). According to Low (1986: 31, 32), the model is not entirely appropriate to explain the behaviour of indigenous farming in South Africa, especially when it comes to food-deficit FHHs.

Leaving aside some shortcomings, the following implications of the *New Home Economics Theory* considered by the *Barnum and Squire* model of FHHs are relevant for the present study:

1. A utility function comprises of a) the consumption of z-goods, b) leisure, c) own consumption of agricultural output and d) consumption of market-purchased goods. These elements significantly match empirical findings in the research area (Chapter 4.7.2.1).

2. Labour markets do exist. By this assumption, family labour pools can be extended or reduced. Though highly imperfect, there are labour markets in the research area. Hiring labour (Mutwamwezi, Matsaert, 1998: 8; Mawrd, 1996: 10; Matsaert et al., 1995: 18; Jones and Cownie, 2001: 31) and participating in off-farm employment (Matsaert, 1996: 17; Mawrd, 1996: 10) are important aspects of the livelihood system in Kavango Region (Chapter 2.3.1 and 2.3.4.2).

3.1.3 Low's model of farm households

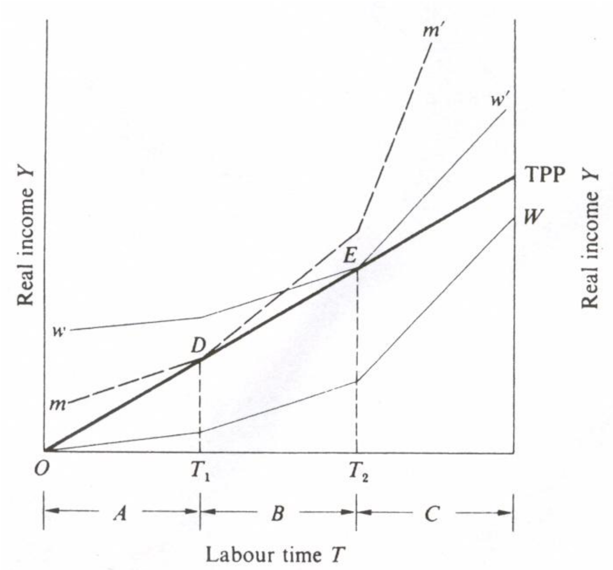
As an alternative or extension, *Low* developed his model of a FHH partly on the theories of *Chayanov* and the *New Home Economics*. He analyses rural FHHs in African countries with a focus on South Africa. Rural communities in these countries are characterised by a more or less developed market for wage labour (Ellis, 1992: 134).

Low's model encompasses the following assumptions:

- According to Singh et al. (1986: 58) one of the principal messages of the *New Home Economics Theory* is to incorporate different wage rates for male and female household members into the production activities. This is especially important when policies on z-good production and off-farm activities are analysed. Low pays attention to this aspect by considering a labour market in which wage rates vary for different categories of labour, especially for men and women. This implies comparative advantages of FHH members not only in specific farm tasks but also in earning cash income (no single wage as in the Barnum and Squire model) (Ellis, 1992: 134).
- An indigenous land tenure system which permits flexible access to land according to family size -equal to Chayanov and different to Barnum and Squire- is also suggested (Ellis, 1992: 134). This implies that areas under cultivation can be increased in parallel to the labour availabilities, off-setting the assumption of diminishing returns to labour (Ellis, 1992: 135).
- A semi-subsistence FHH for which the farm gate price of food differs from the retail price is engaged -no single food price as in Barnum and Squire- (Ellis, 1992: 134).
- Widespread occurrence of food-deficit FHHs which mainly hire out family labour is acknowledged -no food-surplus FHHs which mainly hire in labour as in Barnum and Squire- (Ellis, 1992: 134).

Low assumes that some subsistence crops can be also categorised as z-goods. However, FHHs have the additional possibility of obtaining subsistence goods through a direct purchase from markets. Therefore, the household may save time, but faces market input costs (prices) (Low, 1986: 36). All in all, a FHH has three possibilities: a) to be employed in wage labour, b) to purchase staple food crops or c) to produce staple food crops on its farm. Additionally, decisions made by a FHH are manifold. For instance, it can be assumed that FHH members with the greatest comparative disadvantages in wage employment will not be allocated to subsistence crop production. This will occur until either the requirement for the subsistence z-good is satisfied or the wage rate of a following FHH member will be greater than the opportunity cost of purchase (Low, 1986: 36).

Hence, for food-deficit FHHs, the amount of labour to commit to subsistence food production depends not on the farm gate price of output but on the ratio of wages to the retail price of purchased food (Ellis, 1992: 135). A graphical representation of a food-deficit household according to *Low's* assumption can be seen in Figure 3.1.



Source: Ellis (1992: 135).

Figure 3.1: Simplification of *Low's* farm household model

Real income is illustrated on the vertical axis and time on the horizontal axis. The following assumptions can be formulated:

- Three producers are permanent members of a FHH with the working times 'A', 'B' and 'C'. They add to the total working time available (T).
- All producers have a similar productivity in farm subsistence production.
- For subsistence production, the total production curve (TPP) is linear and the marginal product of labour is constant.
- Each producer would earn different wage rates in the labour market.

- Total wage income is defined by the line OW (or opportunity cost of labour), which represents labour time of each member. It is valued by the real wage that they could earn.
- Real wages w/p are given by the nominal wage rates (w) divided by retail prices of food (p). For a food-deficit FHH, the purchasing power of wages over the retail prices of food is of relevance (Ellis, 1992: 135).
- Parallel to the segmented OW line is the opportunity cost of labour line (ww'), which meets the total production curve at point E. This point defines the profit maximisation level of labour input for this FHH.
- Relevant for this analysis is the slope of the real wage line w/p, compared to the slope of the production function (MPP). FHH members whose $w/p < MPP$ engage in subsistence production and vice versa.

After a decrease in retail prices or an increase in wage rates, the following observations can be made:

- The point 'mm' is the switched opportunity wage cost line, which becomes steeper throughout.
- Under such conditions, it is advisable for producer 'B' to also engage in off-farm labour, leaving only producer 'A' to take part in subsistence production (Ellis, 1992: 136).

Given the relationship between wage levels and retail food prices in southern Africa, the model seemed to provide a plausible explanation of agricultural stagnation. This is due to a wage/price mechanism which is not favourable. Those family members who have comparative advantages in wage work tend to be able-bodied males, so subsistence production is carried out by women, children and other dependents. Even if labour productivity of females may be as high as that of men, women have innumerable other tasks to perform, which limits the time they can spend on farm work (Ellis, 1992: 136).

Low (1986: 41) further continues to involve the possibility of a FHH engaging in income-earning activities on its farm by growing a crop not for own consumption but for sale. This implies that one and the same activity can supply a z-good for own consumption and income through sales (Low, 1986: 41). Decisions on the allocation of a FHH member to wage labour or crop production depend on the level of that member's wage rate and the opportunity cost of purchase until subsistence requirements are secured. Subsequently, a FHH decides upon the level of a member's wage rate and the net commercial return to crop production (sale price – input costs) simultaneously. It can be assumed that such net commercial returns are less than the opportunity costs of purchase. Thus, after satisfying subsistence needs, the minimum wage rate above which FHH members will be assigned to wage employment is reduced (Low, 1986: 41). Decisions to produce for own consumption or for the market deeply depend on three factors:

1. Costs of purchasing the amount which is not grown to meet subsistence needs and the value of the labour time of producing this amount.
2. Market values of produced crops in excess of domestic requirements and the value of labour time of producing this excess.
3. Any risks in terms of a) finding reliable food suppliers, b) changes in prices (for retail or sales), c) finding reliable employers and d) natural events (diseases, rainfall) (Low, 1986: 41).

A special issue occurs with livestock. Cattle provide several goods and functions like milk, meat, hides, security and prestige. These are obtained by allocating time and other market or non-market inputs. In this case, cattle can also be considered as z-goods. For other z-goods, like semi-subsistence crops, the marginal value in consumption declines right after basic needs are met. In contrast, cattle z-goods (specifically prestige and security) will continue to have high values. This might be additionally supported by the following two assumptions: a) costs of keeping extra cattle are relatively low (especially if they are reared on communal grazing areas) and b) prestige and security functions can rarely be subsidised by any other commodity (Low, 1986: 40).

To sum up, it can be said that though *Low's* assumptions differ in some aspects from those used by *Barnum and Squire*, the basic idea of an optimal time allocation in a FHH's production function is common to both. This provides a powerful tool for microeconomic analysis (Ellis, 1992: 137). Since the allocation of time between productive activities and leisure is less significant for agricultural development than the allocation of time between farm and non-farm activities, *Low* neglects leisure (Low, 1986: 45). Additionally, though many factors relevant for rural FHHs in developing countries are implied, a seasonal variation in labour requirements on the farm has not been considered. Some imperative assumptions are not needed anymore, for instance to explain the phenomenon of constant returns to wage employment or declining returns to labour on a farm. In general, Low's (1986: 45) FHH model (FHHM) can explain relationships between a) farm production and off-farm labour employment, b) farm production for domestic consumption and sale, c) prices of outputs and inputs (retail prices and off-farm labour employment) as well as d) all mentioned relationships with consumption behaviour of FHHs as a priority (Low, 1986: 45).

Generally, the following implications of *Low's* model are relevant for reflecting FHHs' behaviour in the Kavango Region:

1. Farm gate prices of food differ from retail prices. Since transaction costs can be assumed to exist in the research area, for instance for transport (Pröpper, 2009: 151, 208), different prices for purchasing or selling goods (TPSU, 2006: 6; Vigne and Associates, 2005: 33, 47; Emongor, 2008: 121) are important aspects. As long as they could be determined by using reliable data sources, they are taken into consideration.
2. Wage rates for male and female FHH members are different. This would have been a desirable assumption to include in the underlying model. Because of insufficient data, this could not be achieved. However, as a simplification, this study considers that male and female FHH members have different comparative advantages of becoming engaged in off-farm employment (Matsaert et al., 1998: 50) (Chapter 2.3.4.2).
3. Cattle are considered as z-goods and marginal values in consumption do not decline right after basic needs are met. Cattle in the research area have many functions, including the provision of security and prestige (Mawrd, 2003: 15; Pröpper, 2009: 188). Therefore, considering these two functions as additional z-goods is an important aspect to reflect settings in the research area.

3.1.4 Summary of farm household models

All mentioned FHHMs and their theories predominantly differ according to a) numbers and characters of arguments considered in the utility function, b) numbers and characters of activities that produce cash income and c) some basic assumptions. In terms of the utility function, *Chayanov* considers exclusively income and leisure, while *Barnum and Squire's* FHHM includes consumption of z-goods, leisure, consumption of agricultural output and consumption of market-purchased goods. *Low* modifies the FHHM tailored by *Barnum and Squire* by adapting some assumptions. This improves the theoretical framework by making it more appropriate for conditions in southern Africa. Since labour markets are assumed to be non-existent, only sales of products generate income in the models of *Chayanov* and *Barnum and Squire,* while *Low* agrees with *New Home Economics* and considers that a FHH can generate cash income by sales as well as by engaging in off-farm employment.

Because of their underlying assumptions, all considered FHHMs show some limitations. Their common shortcoming is that utility is always aggregated over both FHH members and the agricultural production cycle (Barnum, Squire, 1979: 27). According to Chen and Dunn (1996: 16), this might, for instance, neglect conditions where FHH members face (seasonally) limited employment opportunities and thus the assumption of labour market participation is seasonally off-set (Chen, Dunn, 1996: 16). Further, there might be trade-offs in the perception of utility between different FHH members or genders (Chen, Dunn, 1996). Combining the important implications in all the models, the following aspects are relevant for this study:

1. A utility function consists of a) the consumption of z-goods, b) leisure, c) own consumption of agricultural output and d) consumption of market-purchased goods.
2. A FHH has flexible access to land.
3. Outputs are valued at market prices and are either domestically consumed or sold.
4. Farm gate prices of food differ from retail prices.
5. Cattle are considered as z-goods for which marginal values in consumption do not decline right after basic needs are met.
6. Labour markets exist.
7. Comparative advantages of becoming engaged in off-farm employment are different for male and female household members.
8. A FHH's acceptable minimal consumption level needs to be met.

3.2 Bio-economic models

Often a combination of knowledge from biophysical and social science is required to evaluate effects of changes in policy-related conditions (Kruseman, 2000: 15). This applies if impacts of natural resource management (NRM) are analysed (Holden, 2004: 1). In this context, the field of bio-economic models (BEM) is quite important. To support policy and decision-making processes, it is imperative to make complex interactions between agro-ecological and socio-economic observations transparent. Such a task can be facilitated by using BEMs (Kruseman, 2000: 15). BEMs have been developed since the 1980s with the motivation of embedding the concept of sustainable development in classical economic models (Araya, 2005: 53; Barbier, Carpentier, 2000: 1).

3.2.1 Definition

According to Kruseman (2000: 16), bio-economic modelling is defined as a quantitative methodology that accounts for biophysical and socio-economic processes and combines knowledge in such a way that results are relevant to both social and biophysical science. BEMs at the micro-economic level generally consist of a biophysical and an economic dimension. The biophysical dimension attempts to describe the behaviour of a living system, whereas the economic dimension relates this system to market prices, resources or institutional constraints (Cacho, 2000: 2). With respect to Holden (2004: 1), BEMs fulfil various functions and provide suitable tools to a) predict adoption and impacts of new NRM technologies, b) predict impacts of projects targeting NRM, c) reveal knowledge gaps, d) offer guidelines for setting research priorities and e) assess the robustness of uncertain assumptions by conducting a sensitivity analysis (Holden, 2004: 1).

At the farm level, one can distinguish a number of separate methodologies: a) BEMs with dynamic programming, b) BEMs with optimal control models and c) BEMs with FHHMs (Kruseman, 2000: 26).

Since this study analyses policy impacts on optimal farming strategies of peasant FHHs, it combines the aspects of BEMs with those of FHHMs. Generally, BEMs can be distinguished according to different dimensions. The following classification principles are most often applied: a) disciplinary focus, b) time scale (including the degree of integrated stochastic) and c) spatial scale.

3.2.2 Disciplinary focus

There is a continuum of BEMs. On the one extreme, biological process models can be found, which encompass economic analysis components, though at a minor scale. On the other extreme, economic optimisation models are located, which include biophysical components at a minimum. Integrated BEMs are positioned in between (Brown, 2000: 1).

Biological processes are often dynamic and include parameters which describe interactions of variables and their changes over time. Such processes are related to plant and animal growth, soil conditions, nutrient flows etc., as well as interspecies interactions, competition and feedback effects (Brown, 2000: 4). Temporal and spatial scales of biological processes are often different from those of economic models. In general, fields, patches, watersheds, habitats, landscapes, villages, households or farms are to be distinguished on a spatial scale and days, weeks, months or years on a time scale (Brown, 2000: 5). Practical uses of predominantly ecological models for evaluating and improving conservation policies are limited, since institutional and political dimensions often have a minimal presence (Drechsler et al., 2005: 3).

By definition, economic optimisation models of agro-ecological systems are BEMs, while decision making is related to biological resource use and agricultural production. The limitations are the agro-ecological processes involved. In general, models can optimise an economic indicator like farm income and include a component that measures biological sustainability. More complex models encompass multiple objectives held by one decision-making unit, i.e. a FHH or a community (Brown, 2000: 2). Barbier and Carpentier (2000: 3) summarise that the most common way to embed environmental components into BEMs is to simulate effects of economic decisions on the natural resource base without considering feedback on production functions of the model. In a reversal of ecological models, highly focused economic models often oversimplify assumptions regarding ecological effects of conservation (Drechsler et al., 2005: 3).

An integrated BEM would include socio-economic features of economic optimisation models and processes simulating features of biological relationships. Many biological process models exist of rule-based routines for modelling animal behaviour depending on particular environmental variables or states. To use rule-based approaches to model human behaviour limits the set of determined responses to environmental circumstances (Brown, 2000: 3).

Ecological expertise to quantitatively capture biological processes of the native vegetation in the Kavango Region in a form appropriate for a BEM was clearly lacking. Therefore, a disciplinary focus in this study needed to be set on the socio-economic component. Though this study predominantly simulates effects of human land use decisions on natural resources, it partly respects feedback on production functions (Chapter 5.3.1, 5.4.1 and 5.5.1).

3.2.3 Time scale

In general, the scale of time is very important, especially for the biophysical components. Soil degradation and biodiversity loss processes, for instance, continue for a long time, and respective conservation measures have effects in the future. Obstacles might occur if processes that are significant in the long term are not important in the short run (Kruseman, 2000: 19). Generally, BEMs may refer to phenomena in the past, present, or near or far future (Kruseman, 2000: 19):

- Postdictive BEMs analyse a system's past performance (Brown, 2000: 7). They describe reality using empirical evidence and are based on theoretical foundations. For specific experimental data, surveys and statistics can be used (Kruseman, 2000: 22).
- Descriptive BEMs characterise the definite system being modelled (Brown, 2000: 7). They can go beyond descriptions and serve a predictive role. They primarily model decision making and agro-ecological response in present circumstances (Brown, 2000: 8).

- Predictive BEMs are used to forecast system behaviour over time. Again, high priority is given to specifying a suitable objective function (Brown, 2000: 8). Usually they build on descriptive models and move towards the future (Kruseman, 2000: 22).
- Explorative BEMs of the far future are built on descriptive models but take them out of the boundaries of conceivable reality. Usually, they take an immeasurable step into the future and start the analysis from there (Kruseman, 2000: 22).

In terms of the length of time considered and the degree to which changes over time are included, models can be 1) static, 2) comparative static or 3) time recursive (multi-annual or sometimes referred to as dynamic):

1. Static models are much simpler and cheaper to construct as time recursive models. They can imply inter-temporal constraints or preferences. In terms of natural resource assessment, such models may predict the potential impact of a new NRM technology but cannot describe the adoption process (Holden, 2004: 12).
2. Comparative static models, represented by two static models, may then for instance analyse a situation with and without access to a new technology (Holden, 2004: 12).
3. Time recursive (multi-annual or sometimes categorised as dynamic) models are formulated as a sequence of static models that are updated from period to period. Such models are run for one year at a time and deliver output for the next period. Every year, the resource stocks are updated and depend on the situation in the previous year. Weather and market conditions may also change over time and affect the development pathway. Such models may have a planning horizon of more than one year based on expectations about the future (Holden, 2004: 18).

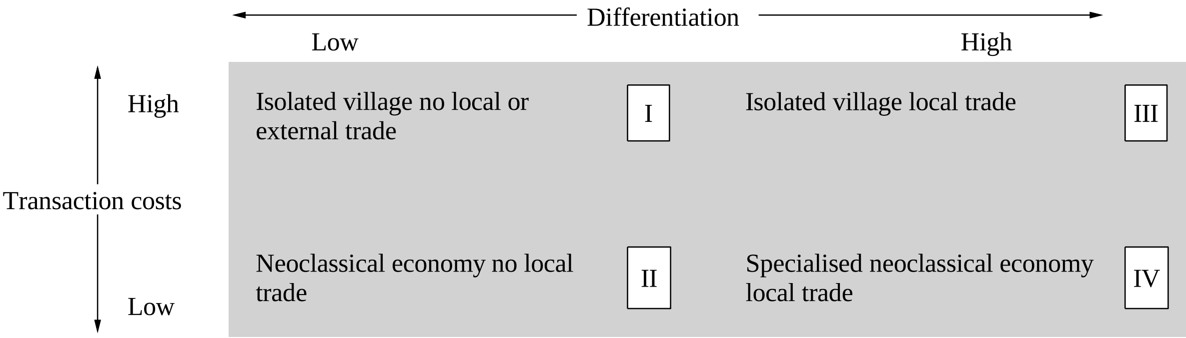
In the end, the objective of the study determines which of the mentioned temporal scales needs to be considered (Araya, 2005: 54). According to Brown (2000: 7), food security and natural resource management are, by nature, inter-temporal concerns which must go beyond an assessment of a situation at one point in time. Since this study aims to identify a) optimal farming strategies which respect food security and natural resource management and b) their modifications induced by policy changes, a predictive model approach was chosen which incorporates multi-annual updates of natural resource stocks.

3.2.4 Spatial scale

A classification of models in terms of spatial scale must recognise the location a study takes place, e.g. field/plot, farm, watershed, village or region. Preference for a particular spatial scale is in some instances science-specific and may therefore depend on the 'focus discipline'. Investigations on a plot level are obviously most important for biophysical science. Socio-economic sciences focus more often on a farm (enterprise), FHH, watershed or village or even higher regional levels to inspect resource allocation, investment and consumption decisions. It works either with one farm or FHH, with respect to different FHH groups, or with interactions between different FHHs or FHH groups (Kruseman, 2000: 20, 21).

Diverse BEMs were developed to analyse policy impacts at the village or watershed level (Kruseman, 2000: 27). However, often the dominant decision-making unit in rural areas of developing countries is the FHH, which is partly integrated into markets (Holden, 2004: 3). According to Okumu et al. (2001: 4), taking the FHH level for assessing conservation strategies might be too restrictive, especially in terms of the biophysical component. Delineation processes of natural resources often need a higher aggregation level, especially if decisions are made with respect to communal resources. In a similar sense, Barbier and Carpentier (2000: 7, 8) mention that in developing countries, larger scales need to be addressed since resources are less individualised. Natural resource management usually includes problems that go beyond farm boundaries (Barbier, Bergeron, 1998: 15). Contrarily, village or watershed-scale models often face weaknesses caused by aggregation. Impacts and issues related to food security or natural resource management on different FHH types are especially masked (Brown, 2000: 8). Nevertheless, applying a BEM to the FHH scale also causes, by definition, aggregation bias, since utility is at least summed up over household members and the agricultural production cycle (Barnum, Squire, 1979: 27).

Obviously, the choice of a correct decision-making unit or scale in BEMs is widely discussed and depends on various aspects. In this context, Holden (2004: 4, 5) constructed a useful two-step approach for choosing an appropriate modelling unit and method according to 'easy' observable characteristics of the empirical research community. First, he developed a typology of village economies resulting in four corner solutions; this is done by focusing on two dimensions: a) transaction costs related to the outside world (market access / market integration) and b) internal differentiation in access to resources and specialisation in activities (Figure 3.2).



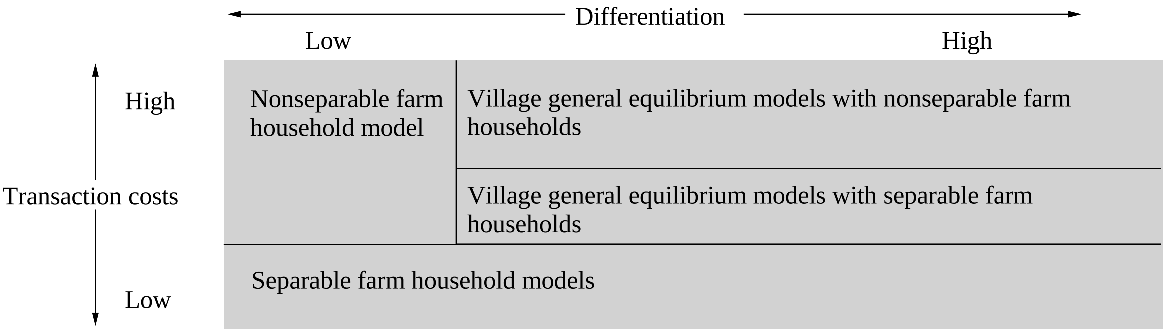
Source: Holden (2004: 4/5)

Figure 3.2: Typology of village economies according to transaction costs and differentiation

Taking both dimensions into consideration, he depicted four corner solutions:

1. Village economy 'I' is characterised by a low level of differentiation and high transaction costs. In general, prices are determined outside the household but inside the village. Such a village is isolated from outside markets with no linkages to external labour markets. Resources are distributed in an egalitarian manner within the village and there is no local trade.
2. Village economy 'II' is characterised by a low level of differentiation and low transaction costs. In general, prices are exogenous. Such a village is well integrated into markets, and there is an egalitarian distribution of resources. There is no local trade.
3. Village economy 'III' is characterised by a high level of differentiation and high transaction costs. In such a village, some prices are determined outside households but inside the village, given local general equilibrium effects. A high level of differentiation causes local trade.
4. Village economy 'IV' is characterised by a high level of differentiation and low transaction costs. In general, prices are exogenous to the household but endogenous to the village. Internal differentiation and isolation combined with low internal transaction costs cause production decisions to be separable from consumption decisions (Holden, 2004: 4, 5).

Note that in reality there is a continuum of villages. Positions of villages may also change over time or because of policy changes. Considering the mentioned characteristics of village economies, Holden (2004: 4, 5) suggested four appropriate modelling units and methods as outlined in Figure 3.3.



Source: Modified from Holden (2004: 4/5)

Figure 3.3: Appropriate modelling method according to transaction costs and differentiation

As indicated in Chapter 3.1, most rural FHHs in developing countries face significant market imperfections (Holden, 2004: 9). This holds true for FHHs in the Kavango Region. Therefore, this study focuses on non-separable modelling approaches depicted in Figure 3.3. Village economies which can be represented by a BEM with one or more non-separable FHHs can be further differentiated into 1) land-abundant remote rural economies and 2) land-scarce remote rural economies (Holden, 2004: 7):

1. In a typical land-abundant remote rural economy, there is little internal trade, which causes land, labour and credit markets to be highly imperfect or lacking entirely (Holden, 2004: 7). A low level of differentiation might occur based on life-cycles of FHHs (Holden, 2004: 8). Outputs may be externally traded with the outside world, but at high transaction costs. These are typically Chayanovian economies (Holden, 2004: 7). A low level of differentiation might occur due to life-cycles of FHHs. In addition, environmental problems that may be of interest to incorporate might include deforestation and a loss of biodiversity (Holden, 2004: 8).
2. A typical land-scarce remote rural economy may be located far from external markets. If there is an egalitarian distribution of local resources, there may be little external or local trade. This causes a stronger subsistence orientation. High population pressure may limit the ability to produce a surplus for sale. The major difference to land-abundant remote economies is land scarcity. Population growths may lead to agricultural intensification if it is technically and economically feasible. This should increase land productivity, although labour productivity may decrease with increasing population pressure. Labour may then turn out to be less important because of its abundance. Land degradation leading to soil erosion and nutrient depletion is the main environmental problem in land-scarce economies (Holden, 2004: 8).

Computable general equilibrium (CGE) models constitute a major discipline in agricultural macro-economic modelling schemes, for example the one initiated by De Janvry and Subbarao (1986) for India. However, this study touches exclusively on some important aspects which need to be considered for choosing an appropriate modelling approach and to show that such a modelling approach is not suitable for the research economy. Village economies represented by a BEM which incorporates a CGE model with non-separable FHHs are commonly characterised by unequal distribution of land, livestock, labour and other resources. In such village economies, isolation creates incentives for local trade unless transaction costs are higher than benefits from trade. Local trade is associated with differentiation and there is no trade with an external world. While prices are exogenous to each FHH, they are endogenous to the village (Holden, 2004: 23). For instance, the distribution of oxen, which are often crucial for land preparation, may, in these economies, be important and skewed.

Unequal distribution of oxen may lead to rental markets for oxen, causing considerable productivity differentials if these markets do not function well. Consequently, BEMs, which incorporate CGE models, are highly desirable if significant local general equilibrium effects occur. If transactions between FHHs represent a rather small portion of total factor or commodity use, these effects might be ignored (Holden, 2004: 8).

From an economic point of view, the research community analysed in this study can be characterised as moving from a land-abundant remote rural economy to a land-scarce remote rural economy (Holden, 2004: 7). This is a result of population growth and movements (Pröpper, 2009: 98, 99; Jones and Cownie, 2001: 20). Differentiation can be assumed to be low (Jones and Cownie 2001: 33; Matsaert et al., 1998: 48) and internal village trade can be neglected. Hence, a BEM with non-separable FHHs is a promising approach. However, to overcome previously discussed shortcomings of ‘purely’ FHH-scale BEMs, this study aims to incorporate both dimensions. This is achieved by designing a BEM at the village scale and calibrating it for two non-separable FHH groups. A detailed specification is outlined in Chapter 3.3.

3.2.5 Summary of bio-economic models

Though fluctuating with respect to the disciplinary focus chosen, optimisation is the core of most modelling approaches where human decision making is included. Often there are trade-offs among various objectives and decision makers subject to a set of basic needs or goals (Brown, 2000: 3).

An important distinguishing factor for various BEM types is the time scale. If the decision process is modelled in a dynamic rather than statistic way, the number of time periods included and the feedback mechanisms are important aspects (Brown, 2000: 4).

In the context of developing countries and their rural communities, decision dimensions are linked to a) production patterns and b) consumption patterns. Both need to be considered (Holden, 2004: 8; Brown, 2000: 4) to account for non-separability. In terms of the spatial scale, the two major economic decision-making units which can be distinguished are the FHH and the village scale (or wider regional scales). Both scales have their shortcomings. With respect to the village scale, weaknesses of BEMs can be limited by differentiating several FHH categories within village boundaries (Brown, 2000: 8). But if interactions between different FHH categories are significant, a CGE model needs to be integrated (Holden, 2004: 8). Bearing shortcomings and benefits of different bio-economic modelling approaches in mind, this study attempts to construct a BEM which:

1. Sets the disciplinary focus on the socio-economic component and partly integrates feedback of natural resource depletion on production functions
2. Predicts and simulates system behaviour over time
3. Is multi-annual and incorporates several time periods
4. Simultaneously addresses the village and the FHH scale by placing two non-interacting groups of non-separable FHHs into village boundaries

3.3 A combined modelling approach

As can be concluded from the previous section about various approaches of theoretical FHHMs, they have already been applied widely for different research tasks (De Janvry et al., 1992; Lopez, 1986; Strauss, 1986; Singh, Subramanian 1986; Taylor, Adelman, 2002). Similarly, BEMs gained importance in the last decade (Drechsler et al., 2005: 3). Recently, two approaches were developed in the Namibian context. Both focused on private farmers and hence were of a separable type (Buß, 2006; Domptail et al., 2009).

As indicated in Chapter 3.2.4, units of scale are important to address in BEMs based on non-separable FHHs. However, recommendations about an appropriate scale to be used are rather ambivalent. This can be illustrated by three studies tackling soil degradation in Ethiopia while respecting non-separablility:

- Shiferaw and Holden (1999: 744) calibrated their BEM for one representative FHH group which reflects the average of three surveyed FHH groups.

- Okumu et al., (2000: 4) calibrated their BEM on the watershed level. They did not acknowledge different FHH categories, since resource availability and decision units for allocating resources were assumed to have a high degree of homogeneity.
- Holden et al., (2004: 377) calibrated their BEM for three different categories of FHHs that were differently equipped with draught animals (oxen).

According to Kruseman (2000: 49), the FHH scale is a suitable level in policy analysis to capture interactions between biophysical and socio-economic behaviour. Several BEM imply different FHHs or FHH groups aggregated at a wider geographical unit in order to a) better confine impacts of land use on natural resources and b) reduce aggregation bias of 'purely' village-scale approaches (Senahoun et al., 2001; Araya, 2005; Kruseman, 2000). Often, a low level of interdependence is exhibited among those FHH groups focused on labour exchanges (Barbier, Carpentier, 2000: 8; Barbier, Bergeron, 1998: 16). Barbier and Carpentier (2000: 8) analysed, among others, four applications of different BEMs at village scale which were calibrated to farming systems in Africa. All approaches distinguished characteristics of different social groups and took into consideration the exchange of labour within the community. This outline shows that it is important to clarify the decision-making unit first.

3.3.1 Decision making and its units

As a matter of fact, decision making and its units, in any modelling approach, need to reflect the situation in the research area. In the Kavango Region, land is owned by the government and assigned for allocation to local authorities on the constituency level (*Hompas*) (RoN, 2003). Hompas, assisted by local authorities on the village level, *headmen or headwomen*, hold the power to allocate land for cropping. Grazing and natural resource use areas are not assigned to a specific FHH but used and managed communally (RoN, 2003). Dilapidation processes like deforestation which are apparent in the research area (Yaron et al., 1992: 10; Mendelsohn, el Obeid, 2003; Pröpper, 2009: 172) are known to occur rather at a larger scale than at the FHH level. Bearing above aspects in mind, the present study uses the village level as the overall unit of decision making.

From an economic point of view, the survey village economy is characterised by generally little trade. There is only trade in the case of surplus generation. Then products are marketed (Jones and Cownie, 2001: 29; Mutwamwezi, Matsaert, 1998: 5; Kojwang, 2000: 11). Attributed to a more or less egalitarian distribution of resources (land, family labour, livestock, ploughs – Chapter 4.1.2) (Jones and Cownie 2001: 33; Matsaert et al., 1998: 48), trade is assumed to be external. This means that products and inputs are predominately exchanged outside village boundaries. However, input factors which can be assumed to be even partly traded within village boundaries are draught animal power (DAP) and labour (Mutwamwezi, Matsaert, 1998: 8; Mawrd, 1996: 10; Matsaert et al., 1995: 18; Jones and Cownie, 2001: 31). But, trading degrees are rather small, and for model specifications it was assumed that these factors are rather traded with other adjacent communities. Hence, internal trade is not considered.

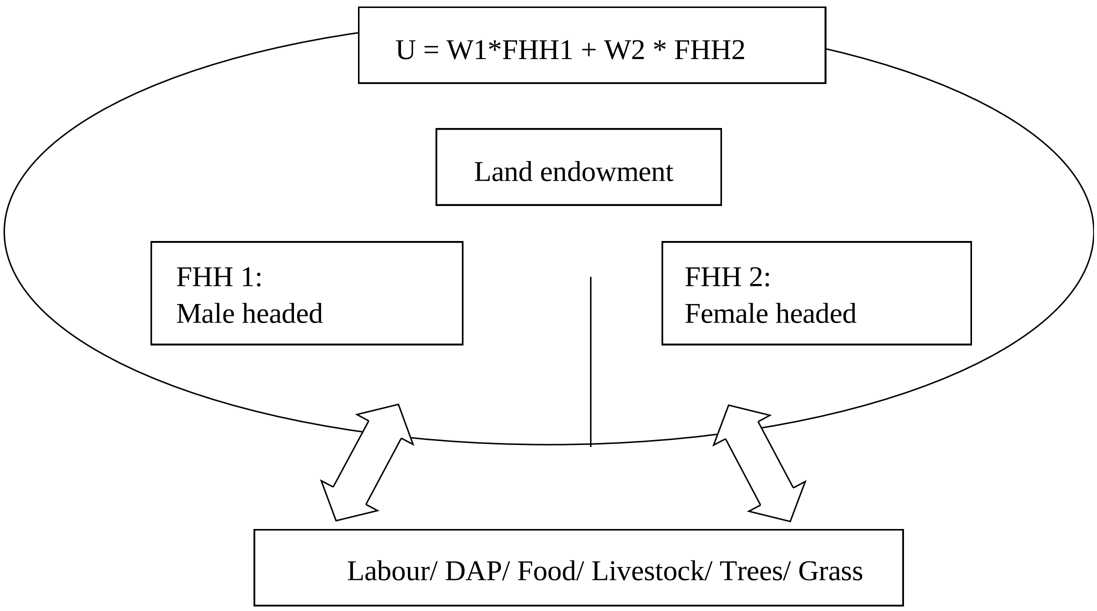
In the last century, population pressure increased in the research area, though the area is not densely populated yet (Jones and Cownie, 2001: 17, 18; Pröpper, 2009: 98). In contrast to credit markets (Pröpper, 2009: 155; Mutwamwezi, Matsaert, 1998: 1; Yaron et al., 1992: 202), labour markets exist (Mawrd, 1996: 10) but can be assumed to be more or less imperfect (Matsaert, 1996: 17). A major environmental threat within this research area is deforestation (Yaron et al., 1992: 10; Mendelsohn, el Obeid, 2003; Pröpper, 2009: 172), which leads to biodiversity loss and some land degradation. With reference to Holden (2004: 8), village economies facing such threats can be described as being in the process of moving from a land-abundant to a land-scarce remote setting.

In order to overcome shortcomings of models that stick exclusively to a village scale (Brown, 2000: 7, 8; Holden, 2004: 3), this study considers that the village is made up of two gender-specific FHH categories, male- and female-headed FHHs.

According to Brown (2000: 3, 4), the process of capturing essential objectives of decision makers is a difficult task. He recommends that more efforts could be made to understand decision makers' objectives and the attached importance of competing and complementary goals. Though addressing competing goals in terms of agro-ecological sustainability and current consumption Kruseman (2000: 29) states that specifications of objective functions have not always received sufficient attention in research. Following Taylor and Adelman (2002: 29), theoretically FHHs are often regarded as one decision-making unit engaged in production and consumption decisions. Obviously, this is a simplification of the real world, in which preferences of individual FHH members may diverge. Matsaert et al., (1998: 2, 51) point out that FHHs in the Kavango Region are often made up of a number of hearth-holds (women and dependents) which have needs and interests that differ from the overall household head. Bearing these arguments in mind, this study respects, as empirically confirmed, diverging consumption objectives of gender-specific FHH groups. This is accomplished by attaching a gender-specific level of importance (weights) to each argument considered in a direct utility function (which respects multiple consumption objectives). The empirical identification of these weights will be addressed in Chapter 4.7.2.

As demonstrated in Figure 3.4, both FHH groups share land endowments summed up at the village scale. Similarly, the village scale is used to aggregate utility (U) derived from consumption applying different weights (W1, W2) to each FHH category. Trade within village boundaries is not considered. Common tradable commodities are sold or purchased at markets in adjacent communities or urban centres.

Because of initial data deficits, both FHH groups are modelled as equipped with similar resource endowments. Though a simplification, this seems to be a plausible assumption for the research area. Empirically, this is evidenced by the Case Study on Farming Systems (CSFS) conducted in 2005 (Chapter 4.1.2). Here, results show that important assets like the number of cattle or FHH members, do not significantly differ between the two FHH groups considered. This matches evidence from region-specific publications. Jones and Cownie (2001: 33) show, for instance, that there is only a slight difference in herd sizes between livestock-owning male- and female-headed FHHs. Matsaert et al., (1998: 48) could detect that differences are less significant for assets and wealth statuses in 'inland villages' of the Kavango Region. They predominantly occur with respect to age and stage in the family cycle.



Source: Own design.

Figure 3.4: Spatial scales and economic characteristics of the village community

Following Kruseman (2000: 6), FHH decisions for resource allocation and production structures are influenced by their resource endowment, their objectives and external factors like socio-economic and biophysical conditions. Thus, keeping the resource endowments equal for both FHH groups and assuming exclusively different objectives might help to show the importance of addressing objectives of peasant FHHs more adequately in a FHHM.

3.3.2 Theoretical foundation and implicit assumptions

Decisions for production and consumption of rural FHHs in developing countries are assumed to be non-separable due to market imperfections (Taylor, Adelman, 2002: 4; Holden, 2004: 14; De Janvry et al., 1992: 1; Ellis, 1998: 106). This assumption seems plausible for rural areas of the Kavango Region. Generally, FHHs' decision making in terms of production (use of inputs, choice of activities, desired production levels) is highly influenced by utilization characteristics (consumption patterns, demographic structure). According to micro-economic theory, such phenomena originate from market failures. Observable market failures in the research area can be predominantly identified as due to non-existent land and credit markets and due to imperfections in the labour market (Pröpper, 2009: 155; Mutwamwezi, Matsaert, 1998: 1; Yaron, et al., 1992: 202; Mawrd, 1996: 10; Matsaert, 1996: 17). Consequently, the applied modelling approach is based on theoretical FHHMs mentioned in Chapter 3.1.

A major part of the theoretical foundation references the *Barnum and Squire* FHHM (Barnum, Squire, 1979; Ellis, 1992). However, an inclusion of a minimum standard of living which needs to be respected is adopted from *Chayanov* (Ellis, 1992). Additionally, some modifications of assumptions in the *Barnum and Squire* FHHM, as suggested by *Low*, are implemented (Low, 1986).

A typical way of addressing non-separability in BEMs, either implemented at the FHH or village scale, is to approximate utility by maximising net earnings and considering other consumption goals (like leisure or self-sufficiency) as constraints. However, there are different lines of thought on how to suitably implement a utility function. The following four approaches could be identified in recent publications:

- Holden et al., (2004: 377) defined FHH utility as a function of full income normalised by a specific poverty line. Hence, utility was zero, positive or negative if full income was equal, higher or lower than the poverty line, respectively.
- Okumu et al., (2000: 5) maximised the margin over variable costs generated by agricultural activities in a watershed. They assumed that this gives a proxy for maximising aggregate utility based on income, leisure and basic food requirements. Their argument was that it becomes possible to treat leisure and calorie intake as fixed and separable from income.

- Shiferaw and Holden (1999: 743, 751) identified as FHH objectives a) a maximisation of net income, b) a self-sufficiency in major stable crops, c) a cash sufficiency to meet various needs and d) an acceptable level of leisure. However, only a maximisation of net income was considered in the utility function, while the other goals were incorporated as constraints. Such an approach assures, in the presence of market failures for food crops, that a FHH meets its minimum consumption requirement with domestic production. However, FHH preferences can be assumed to change as levels of cash income change. Generally, consumption of leisure tends to increase with increasing cash incomes while consumption of staple crops might decrease.
- Kruseman (2000: 106, 107) employed a direct utility function by using data of a budget survey. Utility was derived by consumption of cereals, leguminous grains, meat, milk and other purchased goods. In his BEM, he optimised for consumption utility and afterwards considered, by a tentative function, disutility of resource degradation (Kruseman, 2000: 81). He judged approximations of 'real utility' based on income components of other applied BEMs to be often too simplistic (Kruseman, 2000: 92). Though he also used a certain degree of simplification, his model applied a direct utility function. However, some adjustments which build on empirical evidences were necessary.

As indicated in formula 3.1, the utility of each FHH group can be derived from four elements as described in Barnum and Squire (1979: 27). These are own consumption of agricultural output (C), consumption of market-purchased goods (M), consumption of z-goods (Z), and leisure (L). This study refers to leisure as participation in family, social and cultural obligations (Pf). To respect the empirical evidence of high aspiration for being engaged in formal employment (Chapter 4.7.2.4), the component 'participation in off-farm labour' (Po) is added. Consumption levels of all considered elements are valued at selling prices with the external world. For arguments 'Pf' and 'Po', these prices reflect respective wage rates obtained from empirical data collection (Chapter 4.5.3). Further, 'C' includes all products which can be either a) consumed by a FHH or b) as surpluses, sold at the market. In contrast, 'Z' can exclusively be consumed domestically. To be able to consume market-purchased goods 'M', expenses in terms of cash are necessary.

$$MaxU = f(C, M, Z, Pf, Po) \quad \textbf{(3.1)}$$

Another aspect is the combination of livestock production and cropping. According to Low (1986: 40), cattle deliver several z-goods, namely hides, meat, milk, prestige and security. Apart from milk and hides, these functions also play an important role in the research area (Pröpper, 2009: 188, 189; Mawrd, 2003: 15). In this context, a further categorisation of such cattle z-goods might be a) z-goods obtained from a 'living cattle' (prestige and security) and b) z-goods obtained from a 'post-living cattle' (meat). In the above equation a z-good 'meat' is considered under component C 'own consumption of agricultural output'. Contrarily, the two remaining z-goods 'prestige' and 'security' are considered in the argument Z 'consumption of z-goods'. According to this differentiation, the empirical evidence is acknowledged that FHHs have high aspirations of simply 'keeping' cattle. Based on its non-commercial character, consumption of firewood is also encompassed in argument Z (Chapter 4.5.2.2).

'C' can be further divided into three components: a) output from crop production, b) output from livestock production and c) output from natural resource production. A similar differentiation is possible for 'M'; however, based on common availability of natural resource products and the assumption that they are rather sold than purchased, a differentiation is exclusively necessary for crop and livestock commodities. Differentiation of 'C' and 'M' are needed to implement different empirical importance weights for each production sector. These weights are gender-specific and represent results of a conducted traditional conjoint analysis (Chapter 4.7.2.4). In the end, utility levels of both FHH categories are aggregated at the village level.

Utility is maximised subject to a production function, time and income constraints, (Barnum, Squire, 1979: 27) as well as a food security constraint. Input-output relationships are described by several production functions (Y) of the structure below.

$$Y = f(A, L, V, B) \quad \textbf{(3.2)}$$

'A' is land allocated to different possible economic activities. In contrast to *Barnum and Squire*, land is not assumed to be fixed at the FHH scale. It is rather constrained at the village level as suggested by *Low* (RoN, 2003). Land endowments of the village are further separated into two different soil quality classes with different production potentials (Peterson, 2008; Vogel, 2006; Schneiderat, 2008: 57). Such different soil qualities are due to geographic differentiation (dune and inter-dune valleys) (Jones and Cownie, 2001: 31; Peterson, 2008; Vogel, 2006). In general, FHH members need to decide which portions of land are assigned to the different production sectors (crop production, livestock production and natural resource production). As outlined in Chapter 2.2.4, real rental or sale markets do not exist and land is owned by the Namibian government (RoN, 2003).

'L' is the total labour available and includes hired labour from outside village boundaries. Hence, before FHHs are able to consume domestically produced outputs, effort in terms of labour time is required. Unlike other resource endowments (land, production technology like ploughs and cultivators), labour endowments increase over the time period. This is subject to population growth.

'V' is a vector of variable inputs for the production of outputs. Note that for some production activities, this vector is empty. This happens if capital investments are rather small because of lacking capital stocks (Pröpper, 2009: 155). An example is the traditional cattle production system, which requires only family labour and forage. Forage is generally generated on grazing areas.

Since this study aims to identify farming strategies which take both economic and environmental aspects into account, a vector 'B' is also included in production functions. It describes different biophysical conditions of the research area (rainfall and soil quality).

According to *Barnum and Squire's* FHHM, the total time endowment of a FHH (T) needs to equal the sum of time spent on farm work (Tf), time spent on off-farm labour (Tw), time spent on the production of z-goods (Tz) (Ellis, 1992: 129) and leisure (Tl) (Barnum, Squire, 1979: 28). For the present study, the latter is transformed into time spend for family, social and cultural obligations (Tpf). In case labour is hired, total FHH labour pools are increased and vice versa (Ellis, 1992: 129).

$$T = Tf + Tw + Tz + Tpf \tag{3.3}$$

Leisure or 'time spent on family, social or cultural obligations' is the difference between total available family labour plus hired labour time, reduced by labour time spent on economic activities (on-farm and off-farm). In other words, family labour can be allocated to on-farm production, off-farm production or 'family, social and cultural obligations'. Notably, it is assumed that hired labour is a perfect substitute for family labour. As indicated in Chapter 2.3.2.4, some labour tasks in the research area are gender-specific and partly season-specific (Mutwamwezi, Matsaert, 1998: 9; Matsaert et al., 1995: 21; Jones and Cownie, 2001: 31; Pröpper, 2009; Yaron et al., 1992; Matsaert et al., 1995). Often, the seasonal character of specific labour tasks may lead to peaks which need to be satisfied by hired labour (Mutwamwezi, Matsaert, 1998: 8; Mawrd, 1996: 10; Matsaert et al., 1995: 18; Jones and Cownie, 2001: 31). This is done even though the marginal productivity of hired labour might be lower than the average observed labour wage. Total FHH's labour is the sum of family and hired labour (measured in man-hours equivalents). Consequently, a FHH's labour endowment is equated to the summation of used labour for crop, livestock and natural resource production, daily maintenance tasks, leisure and net labour trade.

Comparative advantages of FHH members in specific farm tasks exist. Though mainly based on traditional responsibilities, this applies specifically to male and female FHH members (Mutwamwezi, Matsaert, 1998: 9; Matsaert et al., 1995: 21; Jones and Cownie, 2001: 31). Because of a lack of data, it is not possible to acknowledge comparative advantages in income-earning activities stemming from different wage rates for male and female off-farm employment. However, as a simplification, this study considers that male and female FHH members have different chances of becoming engaged in off-farm employment (Matsaert et al., 1998: 50). Details are further discussed in Chapter 4.5.3.

Still, in accordance with *Barnum and Squire's* model, a cash income constraint states that net FHH earnings, obtained by sales of output (p (Q - C)), and wage labour (wTw) need to equal expenditures on market goods (mM) and inputs (vV) (Ellis, 1992: 129).

$$p`(Q-C)+wTw-vV=mM+mS \tag{3.4}$$

Hence, domestically produced agricultural output can be sold and is not exclusively consumed. Cash income is especially earned from sales of crop, livestock, partly natural resource products and by doing off-farm labour. At the moment, capital investments for farming activities in the research area are rather minimal. This is based on a lack of capital stocks (Pröpper, 2009: 155). In the traditional cattle production system, capital inputs are almost non-existent. The component 'mS' is also included. In the research area, FHHs pay for different services which are necessary for shaping their lives, such as water fees or transport (Pröpper, 2009: 296, 208, 151). A consumption of such services does not enter the utility function, but needs to be met by FHH cash income allocation.

In the case of existing credit markets, FHHs would theoretically adjust their income-generation strategy to reduce income fluctuations by undertaking less risky activities. Other alternatives would be to a) diversify their activity pattern, b) go for 'safety first' conditions in terms of food security and c) reduce the level of investment tasks. Some of these phenomena can be observed in the research area. The assumption that FHHs do not have any access to formal credit markets is strengthened by the non-existent ownership of land assets (RoN, 2003, Pröpper, 2009: 155; Yaron et al., 1992: 202). Purchased inputs for farm production have to be obtained by cash earned directly by the FHH. Hence, cash outflows need to be balanced by cash inflows.

In the research area, farm gate prices of food differ from retail prices at which food can be purchased from the market (TPSU, 2006: 6; Vigne and Associates, 2005: 33, 47; Emongor, 2008: 121). This matches theoretical foundations of the *Barnum and Squire* and *Low* FHHMs (Ellis, 1992: 134).

However, data series on prices significantly lack agricultural outputs in the Kavango Region. Therefore, this study assumes that certainty in terms of crop and livestock prices exists. Finally, a 'safety first' condition as considered by *Chayanov*, to fulfil a minimum standard of living, is implemented.

$$C, M, Z \geq C\min, M\min, Z\min \quad \textbf{(3.5)}$$

Such a condition is not related to cash income earnings but to a minimum level of nutrition. Minimal nutrition can be served by the consumption of specific domestically produced agricultural output or their marketed goods counterparts. In terms of energy requirements, firewood is an important product (Mmopelwa, 2006: 118). The minimum amount of firewood which needs to be consumed by a FHH is represented by (Z). This amount depends on the size of the FHH.

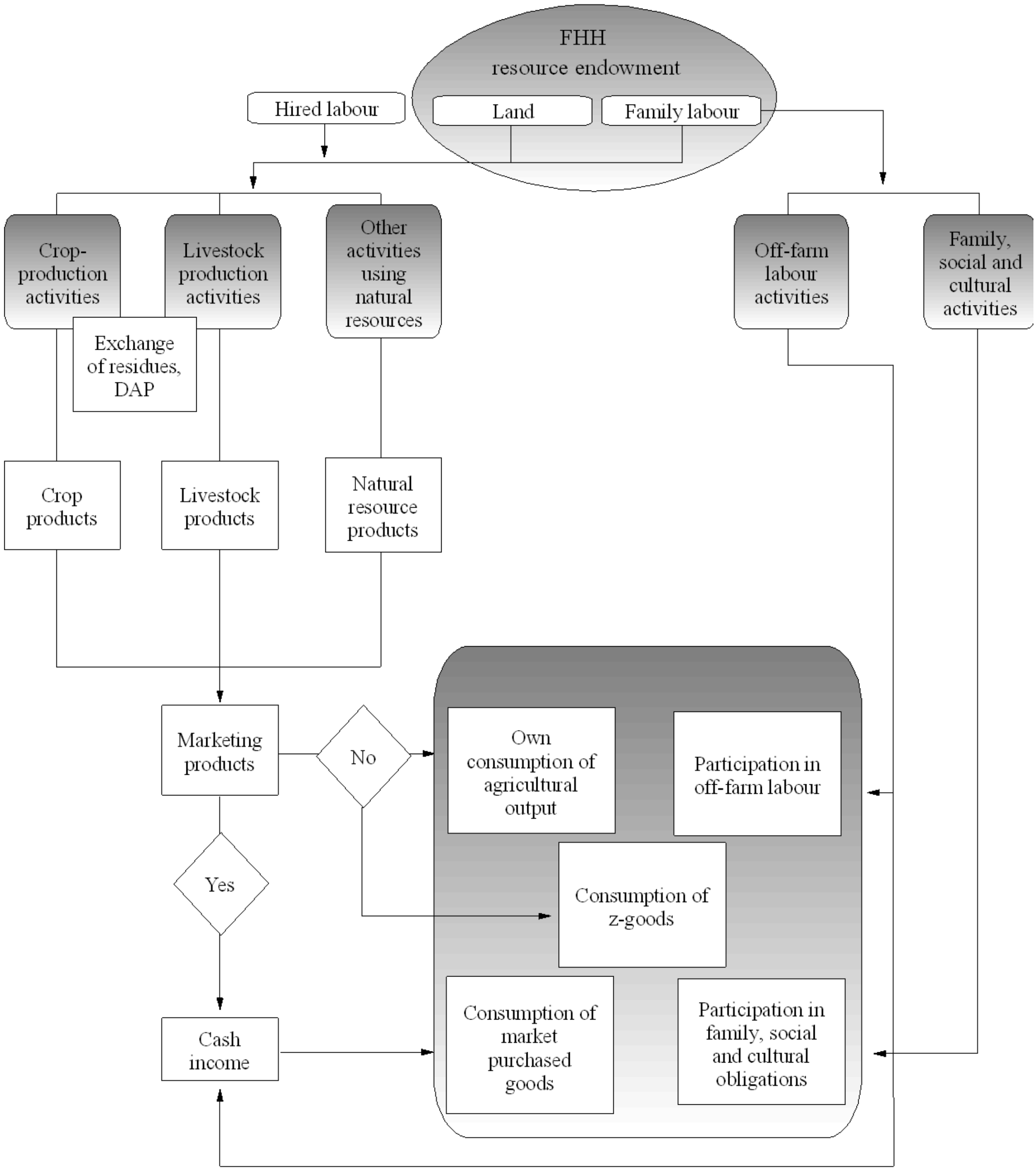
3.3.3 Qualitative model descriptions

In a nutshell, this study designed a multi-annual programming optimisation model (MAPOM) of a virtual village with two non-separable FHH categories (female- and male-headed), including biophysical features. Technical details and mathematical model formulations are discussed in Chapter 5. Here, the model description is based on systematic aspects and inter-linkages of various components.

3.3.3.1 A schematic overview

Based on manifold facets of the Kavango farming system (Matsaert et al., 1998: 1, 45), a central element of the present study is to reflect several activities in which a FHH can be engaged. Figure 3.5 gives an aggregated picture of such economic activities. Special attention is paid to a) activity-specific demands of resource inputs, b) activity-specific deliveries which are considered as arguments in the utility function and c) major interactions of different economic components.

For the analysis, it must be noted that all activities are competing for labour, to support either a) on-farm production processes, b) off-farm labour employment or c) participation in family, social or cultural obligations. Additionally, all on-farm production processes require land, which is allocated in the model. At the village level, land is fixed. FHHs can decide which portion of land can be allocated to each of the three main land use categories (cropping area, grazing area, natural resource area) and thus which portion of land is *used* for one of the three main on-farm production activities. Interactions occur between livestock production and crop production with respect to exchanges in terms of residues (forage for livestock) and traction (DAP for cultivation). Generally, DAP can be used for several crop production activities as a labour-saving technique. In case grazing areas do not deliver enough forage for livestock, a part of livestock forage can be satisfied by crop residues.



Source: Own design.

Figure 3.5: Farm household resource endowments, activities and linkages

In order to acknowledge non-separability, after production processes a FHH decides how much of the output is sold at markets or, alternatively, consumed domestically. As mentioned earlier, an 'own consumption of agricultural output' is delivering utility.

Selling the output generates cash income. Cash is intermediary; it has the power to generate utility by purchasing market goods but is not explicitly considered in the utility function. Contrarily, participation of FHH members in off-farm labour or in family, social or cultural obligations provides utility. Moreover, participation in off-farm labour also generates cash income earnings as an intermediary. With cash income, FHH members can increase the value of their diet with market purchases in food deficit periods. As for own consumption of agricultural output, consumption of such market-purchased goods flows into the utility function.

3.3.3.2 Objectives and decision variables

Peasant FHHs in northern Namibia generally act at subsistence level or marginally above (Kojwang, 2000: 11; Jones and Cownie, 2001: 29; Mutwamwezi, Matsaert, 1998: 5). Consequently, at an aggregated level their major objective is to secure basic needs described by the argument ‘own consumption of agricultural output’. To reflect observed high aspiration for simply ‘keeping cattle’, the argument ‘consumption of z-goods’ needs to be taken into account. Additionally, consumption of firewood is considered as a z-good. During food-deficit periods, some FHHs might need to purchase food at the market to meet their basic needs (Jones and Cownie, 2001: 32). Consumption of such purchased goods is represented in the objective function by the component ‘consumption of market-purchased goods’. To be able to purchase goods at the market or to pay for village internal services (for instance water fees) (Pröpper, 2009: 296, 208, 151), FHHs share the desire to participate in off-farm labour activities (Kojwang, 2000: 11). Nevertheless, farmers are also interested in spending time with their families (‘participation in family, social and cultural obligations).

The two aggregated components of ‘own consumption of agricultural goods’ and ‘consumption of market-purchased goods’ can be broken down according to production sectors:

- Consumption of own produced and market-purchased crop products
- Consumption of own produced and market-purchased livestock products
- Consumption of own produced natural resource products (partly z-goods)

This separation is needed to assign weights of empirically identified importance to each component (Chapter 4.7.2.4). Natural resource products are rarely purchased within the research area. They are more or less freely accessible (Pröpper, 2009: 193). Hence, natural resource products are not considered in the argument ‘consumption of market-purchased goods’. According to Low (1986: 40) and confirmed for the research area by

Pröpper (2009: 188), cattle fulfil, among other purposes, security and prestige functions. These functions keep the marginal value in ‘consumption’ high even after subsistence needs are fulfilled. To emphasise this fact, note that purely ‘keeping’ livestock delivers utility, as a kind of existence value. In accordance with the above descriptions, peasant FHHs will maximise their discounted utility, obtained by a multi-attributive consumption utility function including all above mentioned elements, for a considered time horizon of 30 years.

In general, ‘decision variables’ in terms of resource allocation are known to be influenced by a) FHH preferences, b) FHH resource endowments, c) biophysical conditions and demographic factors (Kruseman, 2000: 6).

First-order decisions are those related to the level of production including all activities. As a following step, a FHH needs to decide how much, in addition to own production, is purchased at the market. This variable is affected by the cash income constraint. A FHH cannot buy products when its cash income is insufficient, especially since credit markets are missing (Pröpper, 2009: 155; Yaron et al., 1992: 202). Market-purchased products and own produced output determine the stock from which FHH members can allocate products to the three utilisation purposes: a) products can be sold to generate cash income, b) products can be consumed to satisfy a nutrition constraint and to deliver utility, or c) products can be stored for future consumption. All these decision are accompanied by logical constraints. As a further constraint, purchased products cannot be re-sold.

3.3.3.3 Farm household activities

As indicated in Chapter 2.3.2, pearl millet is the major crop cultivated in the research area (Yaron et al., 1992: 49; Jones and Cownie, 2001: 29; Mawrd, 1996: 27; Mawrd, 2003: 15; Mutwamwezi, Matsaert, 1998: 5). Sometimes millet is intercropped with other cereals or pulses. In terms of crop production, MAPOM allows production of millet on two different soil qualities. Soil quality ‘a’ provides higher yields than soil quality ‘b’ (Peterson, 2008; Vogel, 2006; Schneiderat, 2008: 57). Based on the component’s rain-fed character (Kojwang, 2000: 11; Jones and Cownie, 2001: 32), a biophysical component, namely rainfall, is considered in the crop production function. Further, a FHH can choose an appropriate cultivation mode from a pool of 16 different millet production activities. Labour is an important input, especially for crop production (Vigne and Associates, 2005: 88). Hence, these 16 activities vary predominantly in applied cultivation techniques and thus according to the ratio of manual labour against DAP input. Another differentiation is made between cultivation of millet as a single crop or under a ‘mixed cropping’ setting. The latter delivers lower yield levels in terms of millet.

Except for millet, data on concrete crop yields is missing. However, to acknowledge the diet delivery function of all other simultaneously cultivated crops, crop products obtained from the 'mixed cropping' activity provide a higher potential to satisfy the minimal nutrition constraint (Chapter 4.3.3). A detailed description of all different yield levels and labour requirements can be found in Chapter 4.3.1.5 and Chapter 4.6.1.4.

Cattle are the most important livestock class in the study area (Jones and Cownie, 2001: 32; Yaron et al., 1992: 88; Deniau et al., 1997: 113). MAPOM determines the composition and herd size of cattle as dictated by a number of considerations like the need for DAP, and the availability of forage, labour and cash. According to such decisions, income flows and nutrition values and utility deliveries are shaped.

In order to simulate livestock population dynamics, cattle are divided into different age and sex groups: cows, bulls, calves and oxen. Cattle herd growth can be attained by natural growth, which is the predominant source of herd increases in the Kavango Region (Mawrd, 1996: 25), or by purchases, which is rare. Outflows are due to cattle sales or domestic consumption by a FHH (Deniau et al., 1997: 122; Mawrd, 1996: 25). Each cattle unit requires labour and forage. Feed requirements are defined in terms of dry matter intakes (Schneiderat, 2008: 119) and can be satisfied by grazing on communal grazing areas or by crop residues (Deniau et al., 1997: 116, 117). Oxen can be used for land preparation and serve as a labour-saving technology for ploughing and weeding (Mawrd, 2003: 62; Mutwamwezi, Matsaert, 1998: 5). Cows are kept for reproduction and calves for herd growth. For simplicity, calves cannot be sold or consumed before they enter the cow or bull population at the age of three years. Animal husbandry practices in Kavango Region are poor and a major area of improvement for the future (van Rooyen, Gartside, 1999: 7). Hence, a FHH in MAPOM has the possibility to select a) an 'improved' cattle farming activity or b) a current practice. The 'improved' production activity is characterised by a higher cattle performance in terms of weaning rates but also higher labour inputs.

In the study area, different ways of using native natural resources are common (Kakukuru, Matsaert, Mutwamwezi, 1998: 6; Pröpper, 2009: 149, 150; Pröpper, Gruber, 2007). They are related to FHHs' labour budgets. Grass cuttings can be used either for homestead construction works (roofs) or for generating cash income by selling it to local traders (Jones and Cownie, 2001: 21; Kakukuru, Matsaert, Mutwamwezi, 1998: 10). Tree logging, which generates timber for sale, is another source of cash income (Pröpper, Gruber, 2007). Further, FHH members need to collect (Pröpper, 2009: 193) a specific minimum amount of firewood (Mmopelwa, 2006: 118) to satisfy their own energy demands. As a matter of fact, all production activities related to natural resource use in MAPOM require only harvesting labour. The volume of thatching grass, trees and bushes is predominantly determined by the area allocated to natural resource uses. This fills into the land budget. As for crop production, the biophysical component of rainfall influences growth rates of native natural resources.

3.3.3.4 Biophysical components

Biophysical conditions such as soil quality and climate determine the suitability of a region for various economic activities and potential production. Hence, in various bio-economic models (BEMs), biophysical information is linked to the production side of the model (Kruseman, 2000: 25). In the research area, rainfall is a major impacting factor (Kojwang, 2000: 11; Jones and Cownie, 2001: 32), since irrigation facilities are not prevalent.

Biophysical components that are of direct importance in this study are climate (represented by rainfall), soil quality and vegetation. As for crop production yield, levels of native biomass predominantly depend on a) amount of rainfall in a respective year and b) the soil quality class (Peterson, 2008; Vogel, 2006; Schneiderat, 2008: 57). According to Pröpper (2009: 172), decreasing soil quality in cropping fields is counteracted with several strategies. One of the most dominant strategies is leaving fields fallow. To include this conservation technique, MAPOM endogenously calculates a ‘fallow coefficient’. This coefficient influences yield levels of a following year by relating the area in use to the area under fallow. Fallow coefficients are additionally calculated for grazing and natural resource use areas.

Deforestation and subsequent biodiversity depletion caused by clearing new fields for cropping are the major environmental threats in this research area (Yaron et al., 1992: 10; Mendelsohn, el Obeid, 2003; Pröpper, 2009: 172). In order to classify land-use strategies according to their ‘deforestation’ or ‘native biomass destruction’ character, a biomass depletion coefficient is calculated. This coefficient measures the amount of potentially grown native biomass in relation to native biomass losses due to human land use. It relates to the whole land endowment of the village and is differentiated for the three production sectors. Though it might be an oversimplification, this indicator can be used to evaluate impacts of the considered policy changes in terms of natural resource conservation which are discussed in Chapter 6.

3.3.3.5 Constraints

In general, FHHs undertake their decisions under various sets of constraints or conditions. MAPOM acknowledges the following categories of constraints:

- Constraints to limited availability of resources: In the research area, few modern agricultural inputs and technologies are used, and family labour continues to be the most important input, especially for crop production (Vigne and Associates, 2005: 88). Labour supply is determined by demographic factors such as the average number of producers in a FHH and its gender composition. Family labour pools can be supplemented with hired labour (Mutwamwezi, Matsaert, 1998: 8; Mawrd, 1996: 10; Matsaert et al., 1995: 18; Jones and Cownie, 2001: 31). Principally, demands for labour vary throughout a year (Mutwamwezi, Matsaert, 1998: 9; Matsaert et al., 1995: 21; Jones and Cownie, 2001: 31). Labour demand is determined by chosen production patterns. Each subgroup of activity has its gender-specific manual labour demands (Pröpper, 2009; Yaron et al., 1992; Matsaert et al., 1995). Land endowments are fixed on the village scale but flexible for the two considered FHH categories. Land allocated to one of the three production sectors – such as crop production, livestock production (grazing) or natural resource production – cannot exceed the total area of land, differentiated by the two soil quality classes. Levels of production factors such as crop residues and DAP are endogenous in MAPOM. They depend on production decisions of the FHH in the corresponding production sectors. However, usage levels of these resources, in any given period, cannot exceed their supply.
- Constraints related to a minimal nutrition level: Rural communities in Namibia are still subject to malnutrition (World Bank, 2007b: 1, 5). Therefore, MAPOM takes into consideration meeting a minimal nutrition level, which is defined as a lower bound on kilocalorie intakes. As respected also for family labour supply, the required minimal nutrition level is increasing with population growth and is related to both FHH producers and dependents. To reflect current consumption patterns in terms of livestock products (Mawrd, 1996: 38; Deniau et al., 1997: 122), only a part of the calorie requirement should be satisfied by livestock products (system constraint).
- Constraints related to market conditions: A FHH in MAPOM needs to respect the budget constraint that cash spent on market-purchased goods cannot exceed cash income levels. This is influenced by prices of outputs, wage rates and prices of market-purchased goods (Emongor, 2008: 121; Deniau et al., 1997: 119; Vigne and Associates, 2005: 33, 47, 51; Pröpper, 2009: 153, 149, 204; Pröpper, Gruber,

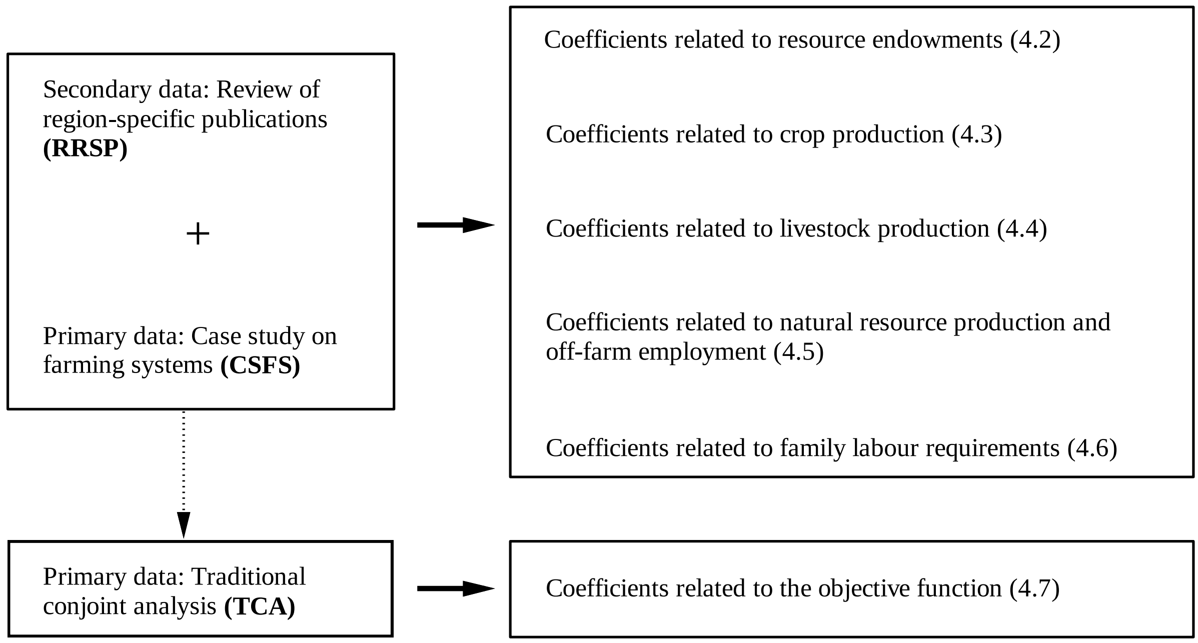
2007). All prices are assumed to be fixed. Because credit markets do not exist (Pröpper, 2009: 155; Yaron, et al., 1992: 202), FHHs do not have access to formal loans. Additionally, cash income can be generated by off-farm employment. Based on imperfect labour markets, FHHs in MAPOM face constraints on participation in off-farm employment. This is even more striking for female producers.

- Constraints on biological conditions: At this point, important relationships are a) between rain and available native biomass in grazing areas, b) between rain and crop yields as well as c) between rain and native biomass production in natural resource areas. Further, yield levels (in terms of previously mentioned production activities) are constrained by the soil quality (Peterson, 2008; Vogel, 2006; Schneiderat, 2008: 57).

4 Empirical Data Collection and Parameter Levels

For MAPOM, different parameter levels are required which determine characteristics of a) different FHH management activities and their production functions, b) different system-related constraints and c) the objective function. Often, it is also recommended to provide 'initial values' of important variables for the first year of the simulation period. This is especially necessary for modelling approaches with non-linear functions. Then, initial values help to improve solution ability and time. This chapter presents relevant parameter levels, initial values and their calculations.

The database for calculating relevant parameter levels and initial values consists of outcomes from literature reviews and two different empirical data collection exercises (Figure 4.1).



Source: Own design.

Figure 4.1: Organisation of Chapter 4

A brief introduction of this chapter describes the research sites and the empirical processes for data collection. Subsequently, a major first part is devoted to a) outcomes of a case study on farming systems (CSFS) and b) outcomes of a literature review on quantitative agro-economic figures which were found in region-specific publications (RRSP). An in-depth review of the socio-economic interdependences of the Kavango Region is provided by the ethnographic study by Pröpper (2009). In one chapter, he tackles economics of the prevailing farming system. However, other publications addressing economic figures of the farming system are largely lacking. Often these are research project reports accomplished by different institutions within Namibia. A smaller second part of this chapter concentrates on the theoretical background and data collection process for a traditional conjoint analysis (TCA). This method was used to identify preferences of peasant farmers. Results of the TCA serve as coefficients in the objective function.

4.1 Research sites and empirical data collection

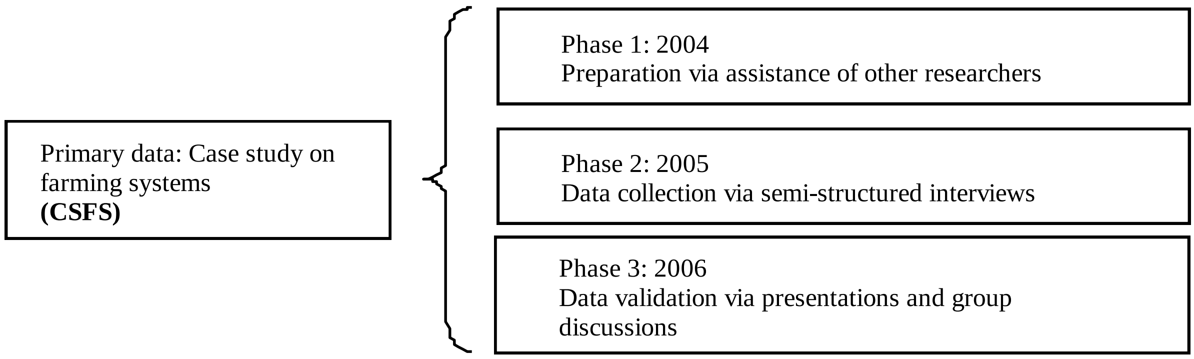
This study was accomplished within the wider project BIOTA South (Biodiversity Monitoring Transect Analysis in Africa). BIOTA conducted biodiversity research along the main rainfall gradient from the winter-rainfall Cape Region in South Africa up to the summer-rainfall regions of northern Namibia. Generally, natural scientists who worked in this project obtained their data from a standardised pair of biodiversity observatories. One main idea of these paired observatories was that they were located in an identical natural environment but exposed to different land use and property rights. This enabled natural scientists to detect the impact of different land-use systems on biodiversity. In the Kavango Region, one of the paired observatories was located at the research station Mile 46 (state-controlled property), and the other one in the neighbouring community Mutompo (communal property). Principally, the socio-economic groups of BIOTA conducted their research among ‘user-cycles’ of these observatories.

Consequently, one important criterion for choosing an appropriate research site was the vicinity to a BIOTA observatory. Since the CSFS was conducted in the second phase of BIOTA, the village Mutompo had already been evaluated as being appropriate for socio-economic research. In accordance with other participants of the socio-economic research group, it was agreed to include two additional villages to increase the data base.

These communal villages -namely Epingiro, Cove and Mutompo- are located in the centre of the Kavango Region. They belong to the Kapako constituency and the ethnic area of the Mbunza group. All villages are located approximately 65 km southwest of Rundu, the rural centre of the Kavango Region. Epingiro and Cove lie directly on the road to Rundu. Mutompo, on the other hand, is situated at the end of a ten-kilometer deep, sandy track. It is exclusively reachable with 4x4 vehicles. In all villages, a borehole and a primary school comprise the village centre. Several inhabitants from all three villages are identified as they are users of the observatory areas. Fields are located either within village boundaries or even further inland in native forest areas. A detailed and comprehensive description of the considered village communities can be found in Pröpper (2009: 53-55, 62-64) and partly Schneiderat (2008: 31-35).

4.1.1 Data collection

As depicted in Figure 4.2, the data collection process for the CSFS can be divided into three phases. In a first phase, the research site was visited and the interviewer assisted with surveys of other BIOTA researchers. Further, preliminary questions on the research topic were discussed with inhabitants whenever this was applicable. Additionally, an introduction to the village communities and their traditional authorities took place.



Source: Own design.

Figure 4.2: Data collection of the case study on farming systems

In a second phase, the main amount of quantitative data was collected by conducting semi-structured interviews with open and closed questions. A mixture of closed and open questions legitimated a) the collection of quantitative data with a focus on the most important topics and b) the inclusion of relevant topics mentioned by the respondents. Focal points of these interviews were FHH activities and structures, namely:

- FHH composition
- Crop production
- Livestock production
- Natural resource production
- Family labour requirements and off-farm labour activities
- Incomes and expenditures
- Objectives

Beforehand, the questionnaire was pre-tested and adapted several times. A random sample of 45 FHHs was chosen in which all three villages were presented to the same degree (15 FHHs each). In general, interviews were carried out with the head of a FHH. Because of language differences, translators assisted with all interviews.

In a third phase, the data validation process was conducted with a) a group discussion on the village scale and b) several group discussions with experts from ministries and research stations. The focal points of these discussions were calculated parameter levels which were obtained from data collection in the previous phase. For the expert discussion cycles, the identified parameter levels were embedded in a presentation referring to MAPOM, and a group discussion about parameter levels was sub-sequenced.

The data collection process for the traditional conjoint analysis (TCA) was completely different from data collection processes for the CSFS. Moreover, this process can be more comprehensively understood after an outline of the general approach. Therefore, it will be discussed in Chapter 4.7.2.3.

4.1.2 Data processing and evaluation

Data from the CSFS were processed with statistical software packages from SPSS. Via descriptive statistics, mean values for corresponding parameter levels were calculated. According to Buß (2006: 87), relevant parameters for optimisation purposes cannot be conditionally determined by averages or mean values of *all* farmers. He could identify ‘best farmers’ in the commercialised parts of Central Namibia. Besides, agricultural extension officers could offer additional information about these farmers. This was not possible for the present study because of a) the remoteness of the investigated villages, b) their rather scarce participation in extension services and c) the high degree of differentiation of the relevant farming activities. Instead, mean values of specific farming activities of the CSFS included exclusively FHHs who participated in these farming activities, rather than *all* interviewed FHHs. Thus, the sample size varies considerably among the parameter levels of different farming activities.

Apart from some exceptions, no further statistical analyses were sub-sequenced. This had several reasons:

1. Data sets were rather small for a higher statistical analysis. Pröpper (2009: 179 ff.) conducted a regression analysis to assess crop productivity functions of FHHs in the research area. He used a mostly complete and reliable data set of nine interviewed FHHs. With regression analysis, he wanted to investigate the relationship between the dependent variable yield and several independent variables. He concludes that results of his analysis ‘remained puzzling and a challenge for further empirical work’ (Pröpper, 2009: 185).
2. Data sets were regarded more as case studies. They were intended to give an indication of the complex reality. In discussions of research methodologies, De Viers (1992: 68 ff.) suggests that a) case study analysis depends on the establishment of logical connections between a number of ‘case-relevant’ variables and b) statistical analysis depends on formal theory and results in statistical significance. In this

context, a case study serves to elaborate the validity of a particular theoretical principal by confronting it with the complexity of empirical reality (Matsaert et al., 1998: 3).

3. Data sets were used to obtain an idea of some relevant parameter levels. These levels were subsequently discussed with other region-specific findings and served exclusively as an input for the applied modelling approach.

Results of the second data collection exercise showed some differences in outcomes between two different FHH categories, namely male- and female-headed FHHs. Therefore, important parameter levels obtained by the CSFS were statistically tested for differences between these two FHH groups (for instance, the number of FHH members and yield levels). However, no significant difference could be found. This can be partly confirmed by region-specific publications. Jones and Cownie (2001: 33) state that there is only a *small* difference in the cattle herd size of male- and female-headed FHHs that own livestock (Jones and Cownie, 2001: 33). Further, Pröpper (2009: 161) found that two thirds of all existing fields are owned by single owners, *equally* divided between men and women. The other third is owned by several owners, predominantly *couples*.

Bearing above statements in mind, MAPOM simulates decision making for a village community which consists of two FHH groups (male- and female-headed). The two groups do not differ in terms of resource endowments or any other parameter level apart from the weight attached to the arguments of the utility function (Chapter 4.7.2.4).

4.2 Resource endowments

Generally, resource endowments of peasant farmers concentrate on land, labour and, in some instances, physical and financial capital. This chapter pays attention to land and labour endowments of peasant farmers in the research villages. A brief last section addresses the endowment of capital and other important assets.

4.2.1 Land

As outlined in more detail in Chapter 2.2.4, land resources in the research area are communal property. But access is not open to just anyone, and user rights for cropping areas are generally allocated to individual FHHs and limited to the members of a village. A more open access regime is assigned to natural resource areas and pastures where villagers share land resources. Sizes of areas assigned to the different FHH activities are ‘decision variables’ in MAPOM. Hence, only land endowments per FHH, differentiated by the two soil quality classes considered, have to be identified in the following sections.

According to Upton (1987: 65), better quality land and better located land is likely to be completely used before production is extended to poorer and more remote land. Generally, the area of more productive land constrains the output. Two different soil quality classes can be distinguished in the research area. A slightly more ‘nutrient-rich’ (darker or redder) soil will subsequently be called soil quality ‘a’. It is concentrated in inter-dune valleys and is used for villagers’ cultivation activities (Jones and Cownie, 2001: 31; Petersen, 2008; Vogel, 2006; Schneiderat, 2008: 57). The other soil, called soil quality ‘b’ from now on, is concentrated in dune ridges and is predominantly the habitat of dry forests (Petersen, 2008; Vogel, 2006). Details of specific soil quality parameters are outlined in Chapter 4.3.1.3.

Land endowments in MAPOM, attached to both soil quality classes, are identified by satellite images for the village Mutompo (presented by Schneiderat, 2008: 182). Table 4.1 shows areas and area shares covered by the different soil quality classes. It can be seen that a larger amount of land is attached to soil quality ‘b’. However, still a share of 41.2 %, representing an area of 1,600 ha, is covered by soil quality ‘a’. These land endowments are constituted for the whole village, which consisted of twelve FHHs in 2001 (Schneiderat, 2008: 3). Hence, land endowments of both soil quality classes need to be divided by the number of FHHs. Note that the number of FHHs in Mutompo have changed since then. In 2004, Pröpper (2009: 55) counted about 16 FHHs. During the data collection process of the CSFS, 15 FHHs could be interviewed. This matches with a FHH counting conducted in Mutompo in 2005 (Pröpper, 2009: 99).

Table 4.1: Areas covered by different soil quality classes

	Mutompo			**MAPOM**
	Covered areas ha	Share of covered areas %	Covered areas ha/FHH	Covered areas ha/FHH
Soil quality class 'a'	1,671	41.2	139.3	27.9
Soil quality class 'b'	2,382	58.8	198.5	39.7
Total	4,053	100.0	337.8	67.6

Source: Own design based on Schneiderat (2008: 181/43).

Still, area endowments per FHH seem to be fairly high. It needs to be kept in mind that figures here only reflect the situation in Mutompo, which is the most remote village. In order to acknowledge population increases and migration of FHHs from river areas to inland villages (Pröpper, 2009: 55), area endowments per FHH in MAPOM are further reduced. They amount to 20 % of the observed area endowments, while the shares of the different soil quality classes are kept constant.

4.2.2 Labour

In many rural communities in Africa, access to labour is the basis of economic power for peasant farmers. This is reflected predominantly in a lack of labour-saving machinery. Then, labour availability for critical tasks can become an effective constraint on production (Upton, 1987: 67). In MAPOM, labour requirements can be served either by family labour endowments or by hiring external labour.

4.2.2.1 Family labour endowments and their developments

In order to calculate family labour endowments of a FHH in the research area, the average number of FHH producers is of key importance. Producers are family members who add to the family labour pool. Contrarily, dependents are FHH members who are younger than 15 or older than 59, e.g. FHH members who are physically not able to contribute to income in terms of labour. Table 4.2 indicates that between one and six producers contribute to the family labour pool in a typical FHH in the Kavango Region. Average numbers vary between 3.4 and 4.7 producers.

The numbers of labour days per year and labour hours per day are also relevant parameter levels for calculating family labour endowments. In MAPOM, the labour amount per year is fixed at a level of 280 days. This rather high level is based on the fact that leisure is included in the objective function of MAPOM and hence participation in leisure is a ‘decision variable’. In general, it is assumed that a labour day consists of 2 sessions, each of 4 hours (morning and evening session). To acknowledge seasonality of some tasks, the available labour hours of female and male producers are equally allocated to the two considered seasons. At the same time, different FHH activities are tied to a specific season (for details see Chapter 4.6.1).

All known human cultures maintain conventions on the division of labour. Many tasks are traditionally the duty of men or women (Upton, 1987: 67; Benson, 1979: 333). Although some tasks of different FHH activities in the Kavango Region are by definition gender-specific, figures in region-specific publications do not acknowledge a division of labour.

Table 4.2: Number of producers per farm household

Source	**Number of producers** per FHH
Mawrd (1996: 10)	4.7 [1)] 3 – 6 (60%) [2)]
Mawrd (2004: 29)	1 – 5 (80%) [3)] >6 (19%) [4)]
Deniau et al. (1997: 115)	<= 4 (60%) [5)] 5 [6)]
Matsaert (1996: 20)	< 40% [7)] 3.4 [1)]
Case study on farming systems (2005)	3.87 [8)]

1) Average. 2) 60% of FHHs have between 3-6 producers. 4) 80% of FHHs having between 1-5 producers. 5) 19% of FHHs have more than 6 producers. 6) 60% of FHHs having 4 or less producers. 7) Including hired labour the number of producers is 5. 8) 40% or less of the population are producers, of which 34% are involved in off-farm employment. 9) n = 45.

Source: Own design based on figures of the CSFS and mentioned publications obtained by the RRSP.

As a first attempt, this study differentiates the average number of producers by male and female FHH members. Further, it acknowledges gender specification even in labour requirements of different agricultural tasks (Chapter 4.6.1). In conducted interviews of the CSFS, heads of FHHs were exclusively asked about a) the total number of FHH members, b) the total number of dependents and c) the number of female and male producers. All other parameters depicted in Table 4.3 are calculated by using these figures. On average, 9.2 permanent members live in a typical FHH in the research area, of which 3.9 are producers. In general, 60 % of producers are females and only 40 % are males, resulting in 2.3 female and 1.5 male producers. These figures match Pröpper’s (2009: 101) findings. He counted 2.1 female and 1.6 male producers per FHH. Slight differences can be found in the number of dependents. Pröpper (2009: 101) estimated 3.8 dependents per FHH, of which 1.7 are females and 2.0 are males. In MAPOM, dependents have a major impact on the nutrition requirements of a FHH. To assure that nutrition is secured even if more dependents are present, this study uses the higher number of dependents calculated in the CSFS.

Table 4.3: Number of farm household members, dependents and producers by gender

	Gender	Mean number persons/FHH
Members		9.2
Dependents		5.3
	Male	2.1
	Female	3.2
Producers		3.9
	Male	1.5
	Female	2.3

Source: Own design based on the CSFS (n = 45), (2005).

As indicated by Pröpper (2009: 98), immigration seems to outweigh emigration directly in the research communities. Hence, the present study does not allow for migration movements. It does, however, consider population growth within FHHs, which is leading to increased numbers of dependents and producers. In comparison to other Sub-Saharan African countries, Namibia's annual population growth rate was relatively low between 2001 and 2007. It amounted to approximately 1.3 % (World Bank, 2008: 2). Within the Kavango Region, Jones and Cownie (2001: 17) proposed an annual population growth of 1.5 %. According to Pröpper (2009: 98, 99), the intrinsic growth rate of the population directly in the research communities amounted to 2.1 % (considering fertility distribution and life expectancy at birth). Including considerations about immigration, fertility and mortality rates, he estimated the actual population growth rate to be slightly lower at 1.5 %. This matches figures outlined by Jones and Cownie (2001: 17). Hence, numbers of producers and dependents in both FHH categories in MAPOM are assumed to grow annually by 1.5 %.

4.2.2.2 Hired external labour

In addition to the family labour endowment, the option to hire external labour seems to be important to meet labour requirements. Often, work peaks occur because critical tasks are closely related to specific seasons (seasonality of tasks: Upton, 1987: 68). Hiring external labour can reduce such pressures for an individual family (Upton, 1987: 69). In fact, FHHs in the Kavango Region are observed to regularly hire labour during the growing season (Matsaert, 1996: 1; Mawrd, 1996: 10; Matsaert et al., 1995: 18; Jones and Cownie, 2001: 1). FHHs with no means to hire external labour often seek technologies to reduce labour requirements (Matsaert, 1996: 21).

To acknowledge the possibility of hiring external labour, the activity ‘labour hiring’ is considered in MAPOM (a decision variable). This activity is related to specific costs. One hour of hired labour causes expenditures of 2.2 Namibian Dollar (N$). However, to prevent MAPOM from focusing on labour hiring, an upper bound limits this activity. Specifications of this upper bound are subject to the assumption that each FHH can hire one labourer for a complete year, not more. As mentioned in the previous chapter, one year consists of 280 labour days, which consist of eight working hours. Hence, an upper bound of 2,240 hours per year is specified, which is equally allocated to the two seasons under consideration.

4.2.3 Capital and other assets

According to Pröpper (2009: 154), productive physical capital (that is, assets related to agricultural production in the research area) of FHHs in the research area mainly includes axes, hoes, sledges and ploughs. For instance, ox-drawn steel ploughs are owned by 60 % of inhabitants (Pröpper, 2009: 164). For MAPOM, it is assumed that both FHH categories are completely equipped with assets related to agricultural production.

Cash capital stocks are generated by balancing cash income with cash expenditure flows. Both cash flows are calculated in MAPOM by multiplying the number of purchased or sold products by the purchasing or selling price, respectively. Numbers of purchased or sold products are ‘decision variables’ in MAPOM. Prices of products and, partly, variable inputs are discussed in more detail in respective chapters on the different production sectors. According to Pröpper (2009: 155), the lack of financial capital, e.g. cash stocks, is a constant problem for FHHs in the research area. As mentioned in Chapter 2.4.1, the Agricultural Bank of Namibia offered credits even to peasant farmers in the past (Mutwamwezi, Matsaert, 1998: 1). But today, very few FHHs have access to formal bank loans (Pröpper, 2009: 155; Yaron et al., 1992: 202-233, 51).

Consequently, borrowing cash from the bank is not considered in MAPOM. Lacking the possibility of borrowing money from a bank does not routinely impede lending money to a bank. For MAPOM, it is assumed that cash income which is not invested into agricultural activities or spent otherwise can be put into a bank account. The aim is to generate interest. In this process, one challenge was determining a reasonable interest rate. When calculating investment efforts of possible ‘development support projects’ for the Kavango Region, Yaron et al. (1992: 202) used a loan interest rate of 6 – 20 %.

Vigne and Associates (2005: 46) assumed a prevailing interest rate of 9.8 % for cost of capital intended for production purposes. Interest rates granted by current bank institutions which have also branches in Rundu are not entirely accessible. The Standard Bank, for instance, offers different interest rates for different types of bank accounts. For a non-complex ‘saving product’ (expecting low amounts of funds), they offer between 3.5 and 4.0 % interest (SB, 2009). It can be assumed that interest rates offered to rural farmers in the research area are rather low. Therefore, MAPOM is calculating with an interest rate for cash income of 4.0 %.

As a general economic rule, future revenues need to be discounted. Particularly in rural areas of developing countries where survival can depend on current revenues, discounting seems to be imperative. According to Buß (2006: 146), the applied discount rate, e.g. the actual time preference of farmers, highly impacts inter-temporal resource use. He suggests that the opportunity to invest in the ecosystem is declining with increasing discount rates. In nine scenarios, Buß (2006: 146) simulated decision making of commercial farmers in Central Namibia with discount rates of 0 to 20 %. For MAPOM, a discount rate of 15 % for future utility levels is assumed to reflect actual time preferences of FHH.

The majority of optimisation models related to agriculture seek to maximise cash incomes. In MAPOM, utility is maximised, and only cash income of the last year of the planning horizon is considered in the objective function (Chapter 5.7). In fact, FHHs in the research area depend to some degree on generating of cash income. They need to pay for important services. Hence, a lump sum of expenditures which is obligatory to be met by each FHH is incorporated in MAPOM. In this context, Table 4.4 shows outcomes of the CSFS in terms of necessary cash expenditure levels per FHH. According to the CSFS, one FHH spends on average more than 1,300 N$ per year for water fees, school fees, medical fees and transport. A major part of these expenditures was related to school fees and medical services.

Table 4.4: Cash expenditures per farm household for important services

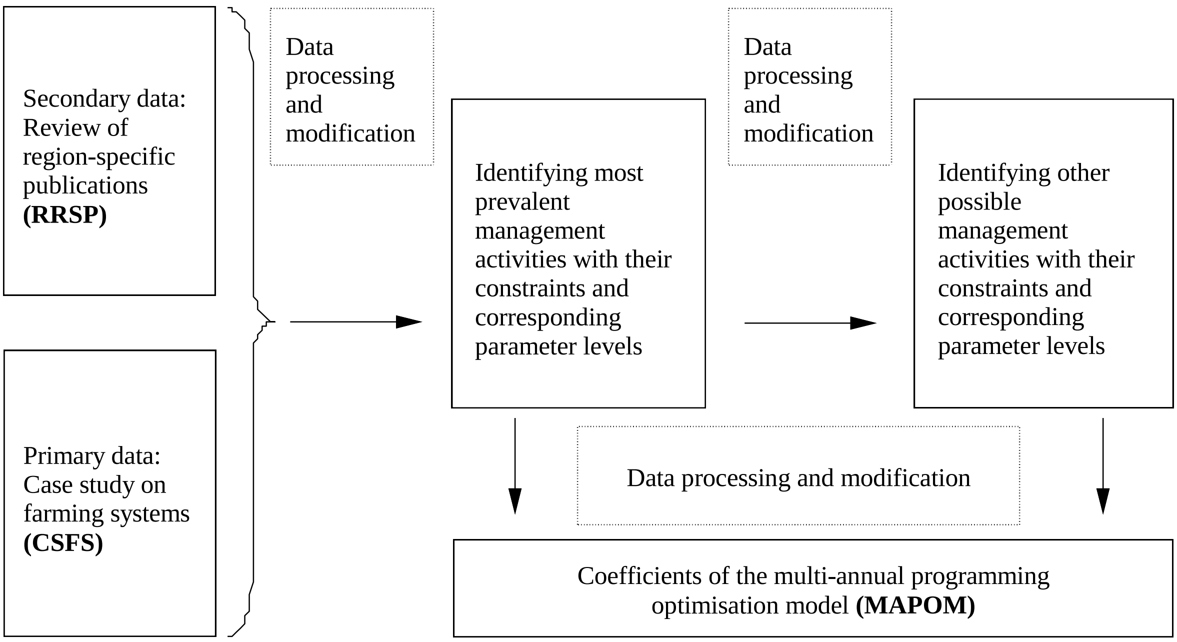
	Important services				
	Water (n = 44)	Health (n = 39)	Transport (n = 43)	School (n = 41)	Total
Cash expenditures (N$/FHH)	290.5	316.9	288.3	486.6	1,351.3

Source: Own design based on the CSFS (2005).

Transaction costs can be assumed to be considerable for rural communities with poor infrastructure (Schneiderat, 2008: 40), but because of data insufficiencies, they could not be entirely considered in the present study. For instance, costs for transport, which are mentioned in Table 4.4, reflect to some degree transaction costs of marketing. At a first glance, the costs of 288 N$ seem to be rather high. However, Pröpper (2009: 208, 151) mentioned that for one car ride to Rundu or other adjacent locations, a lump sum of between 17 N$ and 40 N$ is charged. Under this assumption, only 7 to 17 trips would be manageable per year for each FHH. Expenditures for water fees reflect, to some degree, water fee payments mentioned by Pröpper (2009: 296). They amount to 192 N$ per year for FHHs without livestock and 300 – 540 N$ per year for livestock-owning FHHs. It can be assumed that expenditures might increase if the number of FHH members increases. Hence, each FHH category in MAPOM has to generate a surplus of cash income of at least 147 N$ per year and FHH member.

4.3 Crop production

This chapter discusses relevant information for determining crop production functions (input-output relations, not including labour requirements). Then, a brief monetary evaluation of outputs and variable inputs is outlined. Since rural peasant farmers are known to be producers and consumers, the last section of this chapter addresses FHHs' consumption patterns. Figure 4.3 shows the general procedure of how relevant coefficients are obtained for MAPOM.



Source: Own design.

Figure 4.3: Procedure of coefficient generation

Based on results of the RRSP and CSFS, data processing reveals the most prevalent management activities. Moreover, their constraints and corresponding parameter levels are identified. In order to include other possible management activities which are not prevailing in the research area today, modifications of available data are used to calculate required coefficients. A similar organisation will be applied in Chapter 4.4 and 4.5.

4.3.1 Identifying the most prevalent and other possible management options

As mentioned in Chapter 2.3.2, crop production plays a crucial role in the livelihood system in the Kavango Region. Pearl millet is the main staple crop (Mutwamwezi, Matsaert, 1998: 5; Yaron et al., 1992: 49, Jones and Cownie, 2001: 29; Mawrd, 1996: 27; 2003: 15). Often, millet is cultivated in combination with other crops, like maize, sorghum or legumes (mixed cropping) (Jones and Cownie, 2001: 29; Mawrd, 2003: 15). Fields are concentrated in inter-dune valleys (Jones and Cownie, 2001: 31). Hence, they are often purposefully established by farmers on areas of better soil quality (Schneiderat, 2008: 57). Though there can be up to three weeding sessions (in a season, depending on rain: Matsaert et al., 1995: 20), results of the CSFS revealed that, so far, weeding is typically managed once per cropping season.

In general, different millet production activities are identified which are reflected by different management activities in MAPOM. Among all 32 activities, demand-driven (labour inputs / techniques) and output-driven (yield levels) aspects differ. Concrete differentiation elements are a) the soil quality, b) the cultivation practice, c) the frequency of weeding sessions and d) the techniques for planting, weeding and ploughing. For weeding with draught animal power (DAP), row planting is imperative. After broadcasting, weeding can only be managed with hand tools.

Table 4.5 provides a list of all included crop production management activities. Activity C9 is marked in dark grey. According to outlines in the previous paragraph, this is the most prevalent crop production activity. Consequently, inputs and outputs of Activity C9 are reflected by data obtained by the CSFS. The present study also aims to include other ‘possible’ management options. Hence, several modifications of data are necessary (activities marked grey in Table 4.5). A similar modification process is applied to labour requirements, which are discussed in Chapter 4.6.1. ‘Pure cropping’ techniques are not common in the research area. According to Pröpper (2009: 170), cultivating millet and maize in different fields was done by only 6 % of respondents (n = 120). Another 44 % were planting millet and maize in different blocks of one field. Though intercropped legumes might lead to increasing availability of nitrogen, no detailed knowledge of the nitrogen-fixing properties of locally used millet varieties is found (Pröpper, 2009: 167).

Table 4.5: Crop production management activities

	Soil quality	**Management practice**				
		Cultivation mode	Frequency of weeding	Planting technique	Ploughing technique	Weeding technique
Activity C 1	a	pure	once	broadcasting	DAP	manual
Activity C 2					manual	
Activity C 3				row planting	DAP	DAP
Activity C 4					manual	
Activity C 5			twice	broadcasting	DAP	manual
Activity C 6					manual	
Activity C 7				row planting	DAP	DAP
Activity C 8					manual	
Activity C 9		mixed	once	broadcasting	DAP	manual
Activity C 10					manual	
Activity C 11				row planting	DAP	DAP
Activity C 12					manual	
Activity C 13			twice	broadcasting	DAP	manual
Activity C 14					manual	
Activity C 15				row planting	DAP	DAP
Activity C 16					manual	
Activity C 17	b	pure	once	broadcasting	DAP	manual
Activity C 18					manual	
Activity C 19				row planting	DAP	DAP
Activity C 20					manual	
Activity C 21			twice	broadcasting	DAP	manual
Activity C 22					manual	
Activity C 23				row planting	DAP	DAP
Activity C 24					manual	
Activity C 25		mixed	once	broadcasting	DAP	manual
Activity C 26					manual	
Activity C 27				row planting	DAP	DAP
Activity C 28					manual	
Activity C 29			twice	broadcasting	DAP	manual
Activity C 30					manual	
Activity C 31				row planting	DAP	DAP
Activity C 32					manual	

Source: Own design.

Moreover, ‘mixed cropping’ can expose the millet crop to more risk. Many farmers are not expected to accept additional risks (Vigne and Associates, 2005: 38). Bearing these outlines in mind, for MAPOM, ‘pure cropping’ is related to higher yield levels. Additionally, two weeding sessions influence yield levels positively. Contrarily, lower yield levels are expected on soil quality ‘b’. In a following step-by-step approach, all yield parameters are calculated for the activities highlighted grey in Table 4.5.

4.3.1.1 Millet yields

As indicated in Chapter 2.3.2.1, the specification of field sizes and millet yields per FHH or ha varies considerably in region-specific publications. Table 4.6 shows that field sizes range between one and seven ha. Further, millet yield levels per FHH range between 195 and 343 kg, and millet yields per ha range between 66 and 300 kg. Such a significant variation of considered figures can be attributed to several factors. First, yield levels and field sizes highly depend on rainfall. Second, a FHH's location can play a key role in varying yield levels. A sharp distinction in the Kavango Region can be drawn between river and inland locations. Finally, FHHs' assets and wealth status make it obvious that cash income earners and livestock keepers can generally cultivate more land (Jones and Cownie, 2001: 31) (Mutwamwezi, Matsaert, 1998: 5). Another but not less important factor which increases the difficulty of obtaining comparative data on yield levels is mentioned by Pröpper (2009: 173). Yield data gathered with surveys rely on people's memories. Often, respondents do not remember yield amounts correctly. In the end, yield data might also be distorted by the conversion of locally used metrics (cups or bags) into scientific metrics (kg).

In this study, levels of millet yields per FHH are calculated by using data from the CSFS. Data on crop cuttings are not available. Respondents usually record yield levels in 50 kg bags. The obtained yield levels can be expected to be effective levels, e.g. excluding residues and harvest or threshing losses. Though respondents could easily replicate yield levels, they could not estimate sizes of their fields. Therefore, yields per FHH are divided by the average field size cited in region-specific publications (4.2 ha).

Millet yields in the CSFS amount to 911 kg per FHH and 217 kg per FHH and ha. These figures are positioned in the upper class of yield records cited for the Kavango Region (Table 4.6). In a global context, millet yield levels of the Kavango Region are rather low, as can be seen in Table 4.7. Though already showing the lowest yield levels in the world, the mean millet yield in Africa is more than twice as high as records obtained for the Kavango Region (FAO, 1996). However, neighbouring countries like Angola and Zimbabwe report more or less similar millet yields (FAO, 1996).

Table 4.6: Millet yields and field sizes in the Kavango Region

Source	**Millet yield** kg/FHH	**Field size** ha	**Millet yield** kg/ha $^{-1}$
Jones and Cownie (2001: 31)	-	1.7 – 6.7	100 – 300 [1] 94 – 151(120) [2] 300 [3]
Mutwamwezi, Matsaert (1998: 17)	195 – 300 [4]	2.7 – 4.5	71– 66 [5]
Yaron et al. (1992: 49/50/52)	314 – 343 [6]	4.7 – 3.7 [7] (4.2) [8]	>200 [1] 75 – 82 [6]
Mawrd (2003: 34)	-	1 – 7	-
Vigne and Associates (2005: 16)	-	-	250 - 300
Werner (2002: 17)		1.38	
Pröpper (2009: 173/163)	583 [11] 772 [12] 538 [13] (631) [8]	7.4 [9] (13.4) [10] (9.8) [8]	
Case study on farming systems (2005)	911	-	217

1) Recommendations. 2) Range of farmer estimates and average. 3) Crop cuttings. 4) Range of yield records (1996/97). 5) Yield records (1996/97) with 2.7 ha and 4.5 ha. 6) Yield records (1991 and 1989). 7) For richer FHHs and for poorer FHHs. 8) Average. 9) 15 fields were measured directly in the research area in 2006. 10) 9 additional fields were analysed by aerial photographs. 11) Field survey 2003 (n=25). 12) Field survey 2004 (n = 25). 13) Field survey 2005 (n = 25).

Source: Own design based on mentioned publications and the CSFS (2005).

Table 4.7: Global millet yield levels

Country/ Region	**Millet yield** kg/ha $^{-1}$
Africa	610
Northern Africa and Middle East	270 [1] – 1,830 [2]
Eastern and Southern Africa	260 [3] – 1,570 [4]
Western and Central Africa	270 [5] – 1,010 [6]
Asia	890
Latin America	1,700
North America	1,230
Europe	1,210

1) Sudan. 2) Saudi Arabia. 3) Angola/Zimbabwe. 4) Uganda. 5) Mauritania. 6) Cameroon.

Source: Own design based on FAO (1996).

4.3.1.2 Millet yield differentiation by cultivation modes and rainfall

Millet yields calculated by using data from the CSFS are millet yields of the 'mixed cropping' activity (217 kg/ha). This yield level is obtained if millet is simultaneously cultivated with other food crops. Yield data for the 'intercropped' food crops are assessed as inadequate for advanced calculations. However, the advantage of the 'mixed cropping' alternative is that it delivers calories even with other food crops. Therefore, the present study assumes that outputs obtained by the management alternative 'mixed cropping' provide higher calorie levels. This aspect is further discussed in Chapter 4.3.3. For the production technique 'pure cropping', a millet yield level of 300 kg/ha is assumed. This level is mentioned by Jones and Cownie (2001: 32) and is based on crop cutting estimates. Both considered yield figures serve as a basis for the following calculations.

In order to incorporate yields' dependence on rain, corresponding yield levels per ha are divided by the amount of rainfall in the period under consideration. Rains which most influenced yields in August 2005 were those from June 2004 until May 2005. During this period, rainfall amounted to 400 mm, as measured at the weather station at Mile 46 adjacent to the village of Mutompo. Accordingly, specifications of millet yield levels for the 'mixed cropping' activity amount to 0.54 kg ha^{-1} mm^{-1}. For the 'pure cropping' alternative, a yield level of 0.75 kg ha^{-1} mm^{-1} is considered.

4.3.1.3 Millet yield differentiation by soil quality classes

In the research area and in the Kavango Region in general, crop fields are predominantly concentrated in inter-dune valleys (Jones and Cownie, 2001: 31). Schneiderat (2008: 56) analysed surface soil samples in one-kilometer distances from a watering point and from one crop field in Mutompo. Results of her analysis are summarised in Table 4.8. Generally, the soil parameters indicate a better soil quality for the cropping area than for the other subsoil sampling points (Schneiderat, 2008: 57). The soil sample of the crop field showed higher values for a) clay content, b) pH values (Schneiderat, 2008: 57), c) carbonates, d) organic matter and e) minerals such as potassium, calcium, sodium and nitrogen. The mean difference over all soil parameters between the two soil quality classes is 50 %. P content, measured in parts per million, indicates a difference of 43 % (Schneiderat, 2008: 239 Appendix Table A5). Vigne and Associates (2005: 33) state that soils in the Kavango Region show a highly significant response to phosphates. They assume that grain yields could be increased by 35 % (from 200 kg/ha to 270 kg/ha) with an application of Single Superphosphate (SSP) (97.5 kg per ha SSP with 10.5 % P).

Table 4.8: Soil parameters and calculated differences by soil quality class

	Soil quality class 'a' Crop field	**Soil quality class 'b'** Mean over samples of 1,000 up to 3,000 m from water point	**Difference between soil quality class 'b' and 'a'** Total	**Difference between soil quality class 'b' and 'a'** %
Ph	8.31	5.88	+2.43	+ 29
EC (uS/cm)	95.00	37.43	+57.57	+ 61
OM (%)	4.11	0.68	+1.63	+ 39
P (ppm)	4.33	2.48	+1.85	+ 43
K (ppm)	161.00	30.51	+130.49	+ 81
Ca (ppm)	2,746.00	290.73	+2,455.27	+ 89
Mg (ppm)	105.00	110.85	-5.85	-6
Na (ppm)	15.00	8.08	+6.92	+ 46
N (%)	0.06	0.03	+3.00	+ 52
Carbonate (%)	2.50	0.00	+2.50	+ 100
Sand (%)	91.10	96.60	-5.50	-6
Slit (%)	3.00	1.80	+1.20	+ 40
Clay (%)	5.90	1.68	+4.22	+ 72
Mean difference over all parameters				+ 49
Mean difference over all parameters excluding Mg and Sand				+ 59
Mean difference over soil parameters important for yield (OM, N, Clay)				+ 54

Source: Own design based on Schneiderat (2008: 239, Appendix Table A 5).

According to Upton (1987: 65), better quality land and better located land is likely to be completely used before production is extended to poorer and more remote land. As indicated before, millet yield levels calculated in the previous chapter are assumed to be obtained from fields established on soil quality ‘a’. But as soon as land of good soil quality becomes scarce, villagers are assumed to occupy even dune areas with lower soil qualities. This is an important aspect in MAPOM. Bearing this in mind, the present study suggests that millet yield levels of soil quality ‘b’ are 20 % lower than yield levels obtained on soil quality ‘a’. Corresponding yield specifications for the mixed and pure cropping activities are depicted in Table 4.9.

Table 4.9: Millet net yields per ha and mm of rainfall for different cultivation techniques and soil qualities

Cultivation mode	**Soil quality** class	**Millet crop yield** kg ha^{-1} mm^{-1}
Mixed cropping	a	0.54
	b	0.43
Pure cropping	a	0.75
	b	0.60

Source: Own design based on the CSFS (2005).

4.3.1.4 Millet yield differentiation by weeding frequencies

According to Matsaert et al., (1995: 20), peasant farmers in the Kavango Region may be burdened with up to three weeding sessions in a season. However, interviews in the CSFS revealed that, so far, weeding is typically managed once per cropping season (n = 29). Consequently, calculated yield levels from the CSFS imply the application of one weeding session per year. An inclusion of more weeding sessions is known to have impacts on both weeding labour and yield levels (Upton, 1987: 16). As for the different soil quality classes, a yield difference of 20 % might be an acceptable variation. However, at this point a yield increase is assumed if two weeding sessions are applied. Calculations for mixed and pure cropping alternatives are shown in Table 4.10.

Table 4.10: Millet net yields per ha and mm of rainfall for different cultivation techniques, soil qualities and weeding frequencies

Cultivation mode	Soil quality class	Frequency of weeding	Millet crop yield kg ha^{-1} mm^{-1}
Mixed cropping	a	once	0.54
		twice	0.65
	b	once	0.43
		twice	0.52
Pure cropping	a	once	0.75
		twice	0.90
	b	once	0.60
		twice	0.72

Source: Own design based on the CSFS (2005).

4.3.1.5 Millet yields resulting from different management options

As mentioned before, millet yield parameters are effective yields which exclude residues and process losses. However, for the livestock production module it is important to know the amount of crop residues per ha. Crop residues are an important contribution to livestock diets in communal areas, especially during the dry season (Sweet, Burke, 2002: 4.3). Consequently, previously obtained net yields are, at this point, converted into gross yields. Schneiderat (2008: 143) used a regression model developed by Powell (1985, in Preston, 1986) to determine the amount of crop residues in northern Namibia. For this study, her outcomes are slightly modified by using the mean millet yield calculated in previous sections. Table 4.11 determines possible consumable leaves and stalk biomass of millet within the research area. A calculated millet yield of 217 kg per ha delivers a residues yield of 1171 kg per ha.

Table 4.11: Millet net, residues and gross yields and potential palatable leaves and stalk biomass of residues

	Parts of the millet crop	Applied regression model	Yield kg ha $^{-1}$	Share of palatable parts for livestock %	Palatable residues kg ha $^{-1}$
Crop yield			217 [1)]		
Residues yield					
	leaf	Y = 78 + 0.92 x [2)]	278 [3)]	75 [2)]	208 [3)]
	stalk	Y = 178 + 3.3 x [2)]	894 [3)]	20 [2)]	179 [3)]
	total		1,171 [3)]	33 [3)]	387 [3)]
Gross yield			1,388		

1) CSFS (2005). 2) Schneiderat (2008: 143). 3) Own calculations based on Schneiderat (2008: 143).
Source: Own design based on Schneiderat (2008: 143) and the CSFS (2005).

Net yields and residues, e.g. gross yields, add up to 1388 kg per ha. The grain yield consists of 16 % of the plant's total biomass production. The remaining 84 % can be used as residues for livestock. However, only 33 % of residues are palatable by animals. Based on calculations in Table 4.11, this study assumes a yield multiplication factor to obtain gross yields of 6.4. The share of residues on gross yields is 0.84. Table 4.12 summarises all different net, residues and gross yield figures according to the different soil quality classes and production techniques.

Table 4.12: Millet net, residues and gross yields per ha and mm of rainfall for different cultivation techniques, soil qualities and weeding frequencies

Cultivation mode	Soil quality class	Frequency of weeding	Millet gross yields kg ha^{-1} mm^{-1}	Millet crop yields kg ha^{-1} mm^{-1}	Millet residues yields kg ha^{-1} mm^{-1}
Mixed cropping	a	once	3.46	0.54	2.92
		twice	4.16	0.65	3.51
	b	once	2.75	0.43	2.32
		twice	3.33	0.52	2.81
Pure cropping	a	once	4.80	0.75	4.05
		twice	5.76	0.90	4.86
	b	once	3.84	0.60	3.24
		twice	4.61	0.72	3.88

Source: Own design.

As a final aspect, fallows need to be considered. Fallows of different shapes and ages are visible in the research area (Pröpper, 2009: 171). In a survey conducted by Pröpper (2009: 172), a relative majority of interviewees (24 %) named 'letting the field rest' as the dominant strategy to avoid losses of soil fertility. Hence, another impact factor for yield levels is the possibility of including a resting period. The corresponding mathematical specifications are described in Chapter 5.2.

4.3.2 Variable inputs and prices

As outlined in Chapter 2.3.2, the prevailing cropping system in the Kavango Region is more labour-intensive than capital-intensive. Farmers rarely use inputs like manure, compost, chemical fertilisers or pest control (Mutwamwezi, Matsaert, 1998: 5; Mawrd, 2003: 59, 60; 1996: 35; Jones and Cownie, 2001: 32). One significant non-labour input for crop production is seed. A main source of seed is retaining it from previous harvests (Mawrd, 1996: 35; Jones and Cownie, 2001: 32). A major connecting element of crop and livestock production is draught animal power (DAP) (Mutwamwezi, Matsaert, 1998: 5). Results of a baseline survey conducted by Mawrd (2004: 62) show that a large majority of respondents use DAP for ploughing. Those who do not use DAP are often short of draught animals (Mawrd, 2004: 62). Another function of DAP is transport (Mutwamwezi, Matsaert, 1998: 5).

Seed and DAP are not considered in the CSFS; therefore, this study relies exclusively on data from region-specific publications. According to Mawrd (1996: 38), local seed varieties are usually applied at a rate of 4.9 kg per ha (Mawrd, 1996: 38). Vigne and Associates (2005: 91) indicate that under conditions in the research area, four oxen are required to plough one ha in 8.7 hours. Consequently, a minimum of 34.8 ‘oxen hours’ per ha are required for production techniques which use DAP for ploughing. As described in Chapter 2.3.2.2, the use of DAP for weeding is so far not common in the research area. However, MAPOM still considers management options which require DAP for weeding. For these options, it is assumed that DAP requirements are equal to those considered for ploughing (34.8 hours/ha). Some management options necessitate DAP for both tasks; ploughing and weeding. Then, the overall DAP requirement per ha adds up to 69.6 hours. Chapter 4.6.1.3 discusses savings of manual labour per ha for ploughing or weeding.

Since the main part of the millet harvest is used domestically (Jones and Cownie, 2001: 29), data on prices for millet or millet products, either retail or selling prices, are difficult to obtain. But even if data exist, high fluctuations seem to be usual (Table 4.13). This is based on the fact that millet amounts sold or purchased by FHHs are a) often reported in local metrics like ‘cups’ or ‘bags’, b) rather small and c) often (in the case of retailing) already processed into millet flour.

As mentioned before, it is assumed that there is no internal trade between the two included FHH categories in MAPOM. This plausible assumption imposes that price data need to rely on secondary data. Such data are assumed to be more suitable to reflect prices of the outside world. Table 4.13 shows retail and selling prices cited in different region-specific publications. Selling prices are fairly low and in most cases reflect less than 50 % of the retail prices. For MAPOM, a millet selling price of 1.7 N$ per kg and a seed price of 6.5 N$ per kg are assumed as cited by Vigne and Associates (2005: 33, 47). The retail price is an average over the two prices cited by Emongor (2008:121).

Table 4.13: Selling prices of processed millet, retail prices for grain flour and seeds

Source	Retail price N$/ kg	Selling price N$/ kg	Seed price N$/ kg
TPSU (2006: 6)	4.0 1)	1.8	
Vigne and Associates (2005: 33/47)		1.0 2) – 1.7 3)	6.0 4) – 6.5 4)
Emongor (2008: 121)	3.96 5) – 5.80 6)		
Case study on farming systems (2005)		8.0 7)	

1) Kavango Region, no further specifications. 2) Grain price obtained in the informal market (1993/94). 3) Grain price from Namib Mills (2004/05). 4) Namibian Farmers. 5) Retail price at Shoprite in Namibia, Windhoek, 2004 for maize flour. 6) Retail price at Shoprite in Namibia, Windhoek, 2004 for wheat flour. 7) 2 N$ per cup, one cup is made up of 250 g (n = 7).
Source: Own design based on mentioned publications and the CSFS (2005).

4.3.3 Domestic utilisation patterns and nutrition deliveries

In the Kavango Region, a major part of the crop harvest is consumed domestically (Matsaert et al., 1998: 31; Mutwamwezi, Matsaert, 1998: 5; Jones and Cownie, 2001: 29). This phenomenon is also observable directly in the research communities (Table 4.14). At least 81 % of obtained yields are consumed by a FHH.

In MAPOM, FHHs of both categories are compelled to satisfy a specific minimum nutrition constraint. Therefore, it is necessary to identify parameters for nutrition demands and nutrition supplies. Between 1990 and 1992, daily dietary energy supplies in Namibia averaged 2,070 kcal per person (FAO, 2006: 37, Table 2). In 1998, this supply increased to 2,160 kcal (FAO, 1998) and settled at 2,260 kcal per person between 2001 and 2003 (FAO, 2006: 37, Table 2). Hence, each FHH member in MAPOM is obliged to a daily dietary energy rate of at least 2,260 kcal (FAO, 2006: 37, Table 2). These nutrition requirements can be satisfied by the consumption of crop products. Notably, the edible portion of 100 g of pearl millet delivers 363 kcal which results in 3,630 kcal per kg (FAO, 1995, Table 17). Data on yield levels for other food crops (apart from millet), obtained by the CSFS, are inappropriate for a further data analysis (missing observations per crop). Hence, it is not possible to consider yield levels of 'inter-cultivated' crops for the 'mixed cropping' cultivation technique. In order to improve the competitiveness of this cultivation mode, logically higher nutrition deliveries have to to be assumed. This is achieved by simply increasing kcal deliveries by 20 %. Hence, crop products obtained from the ‘mixed cropping’ cultivation mode deliver 4,356 kcal per kg. Notably, nutrition demands of FHHs can additionally be satisfied by livestock products. Corresponding figures are outlined in Chapter 4.4.4.

Table 4.14: Yield shares of different crop species stored, consumed, sold or exchanged

Crops		Share of yield stored %	Share of yield consumed %	Share of yield sold %	Share of yield exchanged %
Millet	n = 31	10.21	82.28	7.13	0.43
Maize	n = 36	18.32	81.65	0.00	0.03
Sorghum	n = 28	12.24	86.61	1.12	0.04
Beans	n = 28	10.35	89.65	0.00	0.01
Groundnuts	n = 17	5.85	94.54	0.00	0.24

Source: Own design based on the CSFS (2005).

4.4 Livestock production

In this chapter, relevant information for determining livestock production functions (input-output relations, not including their labour requirements) is discussed. Further, a brief monetary evaluation of outputs and variable inputs is outlined. Since rural peasant farmers are known to be producers and consumers, a final section of this chapter addresses FHHs’ consumption patterns. The general procedure of how relevant coefficients are obtained for MAPOM is illustrated by Figure 4.3 in the previous chapter.

4.4.1 Identifying most prevalent and other possible management options

Though some FHHs own donkeys, pigs, sheep etc., livestock farming is based primarily on cattle, goats and chickens (Jones and Cownie, 2001: 32; Yaron et al., 1992: 88; Deniau et al., 1997: 113). MAPOM focuses on cattle production with the prevailing breed, Sanga. According to Deniau et al. (1997: 116, 118), cattle management in the northern communal parts is commonly based on a seasonal transhumance. In the dry season, fodder resources become scarce and cattle are often sent to cattle posts outside the village. At the beginning of the rainy season, cattle stay around homesteads. Then they feed on crop residues, the most prominent supplementary feed (Mawrd, 2003: 49; Deniau et al., 1997: 116). As indicated in more detail in Chapter 2.3.3 and summarised in above outlines, livestock production in the research area is fairly extensive. Four different cattle production activities are identified which reflect management activities within MAPOM. Among these activities demand-driven (labour inputs) or outputs-driven (cattle performance) aspects differ. Concrete differentiation elements are a) the soil quality and b) the management technique. Since crop fields are currently established on soil quality ‘a’, livestock pastures or grazing areas can be assumed to be located on soil quality ‘b’. Table 4.15 provides a list of all included livestock production management activities.

Table 4.15: Livestock production management activities

	Soil quality class	**Management practice**
Activity L 1	a	traditional
Activity L 2		improved
Activity L 3	b	traditional
Activity L 4		improved

Source: Own design.

Activity L3 is marked in dark grey. According to outlines of the previous paragraph, this is the most prevalent livestock production activity. Consequently, inputs and outputs of Activity L3 are reflected by data obtained by the CSFS. The present study also aims to include other ‘possible’ management options. Hence, several modifications in terms of cattle performances are necessary. A similar modification process, which is discussed in Chapter 4.6.2, is applied for labour inputs. A traditional livestock production system in which cattle graze on areas of soil quality ‘a’ is so far not existent in the research area. According to van Rooyen and Gartside (1999: 7), animal husbandry practices in the Kavango Region are a major area of improvement for future interventions. Hence, an ‘improved’ cattle production system is considered in MAPOM. This is characterised by higher cattle performances (in terms of weaning rates and body weights) and accordingly higher labour and cash inputs. The different cattle performance indicators are calculated in the following sections in a step-by-step approach.

4.4.1.1 Cattle performance indicators

Important cattle performance indicators considered by MAPOM are a) weaning rates, b) body weights of the different cattle age and sex groups and c) DAP provisions. Systematic milk production does not exist in the research area (Pröpper, 2009: 189). Therefore, milk production is not considered in MAPOM.

According to Deniau et al., (1997: 118) the calving rate for traditional cattle management allows one calf per cow every three years. However, this figure is expected to signify a lower limited for drought years (Deniau et al., 1997: 118). Schneiderat (2008: 161) specifies cattle performance indicators directly in the research communities. She calculated a calving interval of 28.1 months. This leads to one calf per cow every 2.3 years. She further determined the average number of calves per cow to amount to 2.2 calves. Breeding surveys at research stations in Namibia show that weaning percentages of Sanga cattle can range between 88 and 92 % (Mawrd, 1997: 2). Contrarily, results of the CSFS indicate that effectively only 0.44 calves (n=29) are produced per cow per year. This leads to one calf per cow every 2.3 years. Since this figure is calculated by dividing the number of cows by the number of calves of a FHH, it can be interpreted as an effective weaning rate. This effective weaning rate is used in MAPOM to characterise the traditional farming system. For improved livestock management, the lowest weaning rate of Sanga cattle achieved at research stations (0.88) is applied. Keep in mind that this causes higher labour and capital inputs. In both systems, weaning rates are not assumed to vary with soil quality classes. Soil quality in terms of livestock production only plays a role in fodder availability, which is discussed in Chapter 4.4.2.1.

Directly in the research communities, Schneiderat (2008: 161) took some measurement samples of body weights of different cattle groups. She calculated mean body weights for oxen to amount to 410 kg. For bulls and cows, body weights came to 423 kg and 282 kg, respectively. Because of the small sample size and missing measurements for calves, this study uses the figures summarised in Table 4.16 (Schneiderat, 2008: 158). These match weight ranges indicated by Bester et al., (2000: 3; 400 – 700 kg for bulls; 280 – 400 kg for cows). As mentioned for weaning rates, body weights are supposed to show no differences between the two soil quality classes. However, better care can lead to better health status of animals. Hence, for the improved cattle management system, higher average body weights are considered (cows = 300 kg/head; bulls = 420 kg/head; calves = 69 kg/head; oxen = 480 kg/head). Routinely, this leads to higher feed requirements.

Table 4.16: Cattle body weight according to different age and sex groups

		Cattle average	Cows	Bulls	Oxen	Calves
Body weight	kg/head	270	250	350	400	80

Source: Own design based on Schneiderat (2008: 258 Appendix).

A final cattle performance indicator is the provision of draught animal power (DAP). For crop production activities, farmers use DAP to support the ploughing process. As a rather innovative management alternative, MAPOM also tests DAP inputs for weeding. Due to seasonality, ploughing is usually focused on the two months November and December (=

60 days per year). Weeding is accomplished from January to March (= 90 days per year) (Jones and Cownie, 2001: 29; Yaron et al., 1992: 42). Further, it can be assumed that one draught animal cannot be employed for longer than four hours per day. This is due to the hard soils and rather hot weather conditions. To calculate the available amount of DAP per year which can be used for ploughing, the number of draught animals (namely oxen, kept in a specific year) is multiplied by 60 days and 4 hours. Similar calculations are applied in MAPOM for the weeding process. Additionally, farmers have the possibility to rent draught animals either for ploughing or weeding. Inadequate data from the CSFS at this point makes it imperative to derive renting costs from indications in region-specific publications. Vigne and Associates (2005: 52) calculated labour costs per ha for DAP ploughing. Their figures indicate costs of 20 N$ per day. With a usual working time of four hours per day, this leads to a reasonable approximation of 5 N$ per hour.

4.4.1.2 Cattle numbers

In MAPOM, cattle production is presented by cattle herd size dynamics. In this context, 'initial values' of cattle numbers need to be identified. Table 4.17 shows figures of a) the average share of FHHs which are cattle owners and b) the average number of cattle owned by a FHH.

Between 58 and 66 % of FHHs are owners of an average cattle herd size of between 9 and 26 cattle. According to Jones and Cownie (2001: 33), this wide range relates to a number of factors. First, patterns of ownership vary with different zones of the Kavango Region. Following population densities only, 23 % of FHHs in the western inlands do not own cattle, compared to about 50 % of those along the river. Second, livestock ownership is related to the main source of cash income. Thus, those FHHs whose members participate in wage labour have more cattle compared to those that have no cash income. Third, large FHHs are more likely to be cattle owners than those with fewer family members. In addition, bigger FHHs also have larger herds. Finally, ownership varies with regard to the gender of the head of the FHH. Male-headed homes have about 30 % more cattle on average than those headed by females. Surprisingly, there is only a little difference in herd size between male- and female-headed FHHs that are livestock owners, so the 30 % difference is largely due to the fact that fewer female-headed FHHs own livestock (Jones and Cownie, 2001: 33).

Table 4.17: Cattle numbers and shares of farm households owning cattle in the Kavango Region

Source	Cattle numbers heads/FHH	Share of cattle owners %
Jones and Cownie (2001: 33)	15 [1]	60
	9 [2]	
	26 [3]	
	>30 [4]	12 [4]
Yaron et al. (1992: 88)	20 – 25 [5]	<66
	26 [6]	
	13 [7]	
	>35 [8]	
Mawrd (2003: 32)		58
	<30	45
	>50	2
Pröpper (2009: 187)		52 -53
Case study on farming systems (2005)	19	64

1) Includes FHHs not owning any cattle. 2) Among river areas. 3) Among western inland areas. 4) Among the whole region.
5) Average range. 6) Average herd size among cattle owners. 7) Median including FHHs not owning any cattle.
8) Recommendations for sustainable commercial cattle farming.
Source: Own design based on mentioned publications and the CSFS (2005).

Table 4.18 shows the average number of cattle obtained by the CSFS and its division into different age and sex groups. As expected, the number of cows (9.5) is the highest, followed by the number of oxen (4.7). Note that these figures are averages over all-cattle owning FHHs. They exclude those who do not own any cattle. In MAPOM, these cattle numbers serve as 'initial values' for the first year of the simulation period (Activity L3). For the innovative cattle management activities, these initial values equal zero (Activity L1, Activity L2 and Activity L4 in Table 4.15). Their competitiveness is tested in MAPOM.

Table 4.18: Cattle numbers according to age and sex groups

		Cattle	Cows	Bulls	Oxen	Calves
Average number (n = 29)	heads	18.8	9.5	1.5	4.7	3.1

Source: Own design based on the CSFS (2005).

4.4.2 Forage supplies and demands

As mentioned in the crop production module, residues of cultivated crops serve as supplementary fodder in the livestock production process. However, the major part is derived from grazing on communal pastures. In this context, two parameters are relevant for specifications in MAPOM: first, an estimation of the annual ground biomass production which can be further divided into bush, grass and tree biomass, and second, an estimation of fodder demands of livestock. Both parameters will be discussed in the following sections.

4.4.2.1 Estimating biomass production on grazing areas

Following Sweet (1998: 2), rainfall is the primary determinant for estimating usable forage capacity of rangelands. The amount of dry matter phytomass produced on one ha per millimetre of annual rainfall is known as the rainfall use efficiency (RUE: Sweet, 1998: 1). So far, several studies in Africa and Namibia in particular have demonstrated a linear relationship between annual rainfall and primary biomass production (Sweet and Burke, 2002: 4.1). Details are further discussed in Schneiderat (2008: 115). Usually, the RUE ranges between 3 and 6 kg ha^{-1} mm^{-1} for reasonably well-managed arid and semi-arid grazing lands, but it can be as low as 0.5 kg ha^{-1} mm^{-1} in depleted sub-desertic ecosystems (Sweet, 1998: 1).

To estimate the RUE for the research area, figures for primary biomass production and rainfall from region-specific publications are used. Table 4.19 shows some results. RUE levels vary between 4.07 and 6.89 kg ha^{-1} mm^{-1}. Note that these figures are not related to dry matter phytomass – they are estimated from primary biomass production.

According to Sweet (1998: 2), a development of separate *empirical* relationships for different soil and vegetation types seems to be not practicable. Instead, he recommends using specific correction factors for soil and vegetation characteristics (Sweet, 1998: 2). Generally, cattle behave predominantly as grazers (Schneiderat, 2008: 120). Hence, not differentiating available ground biomass might lead to overestimations of available fodder resources in MAPOM. Further, indications or any other recommendations about correction factors for grazing resources in the research area are sorely lacking. Therefore, this study a) uses the smallest value of the RUE indicated in Table 4.19, b) uses only a slight correction factor to incorporate different soil qualities and c) acknowledges the fact that cattle behave more as grazers by roughly differentiating obtained estimates into prevailing vegetation types. The smallest RUE which can be found in the Kavango Region amounts to 4.07 kg ha^{-1} mm^{-1}. To acknowledge the fact that this is an average figure over both soil quality classes, this figure is increased by 10 % for soil quality ‘a’ (4.48) and decreased by 10 % for soil quality ‘b’ (3.67).

Table 4.19: Total seasonal ground biomass production, rainfall and calculated estimates of seasonal above-ground biomass production per rainfall

	Total seasonal above-ground biomass production (mean over growing seasons 1984/85 – 2002/03) kg ha^{-1}	Rainfall mm	Calculated estimates of seasonal above-ground biomass production (RUE) kg ha^{-1} mm^{-1}
Lowest levels in Kavango region	2,400 – 2,800 [5]	550 [1]	4.36 – 5.09
		589 [2]	4.07 – 4.75
		548 [3]	4.38 – 5.11
		523 [4]	4.59 – 5.36
Moderate levels in Kavango region	2,800 – 3,200 [5]	550 [1]	5.09 – 5.82
		589 [2]	4.75 – 5.43
		548 [3]	5.11 – 5.84
		523 [4]	5.36 – 6.12
Highest levels in Kavango region	3,200 – 3,600 [5]	550 [1]	5.82 – 6.55
		589 [2]	5.43 – 6.11
		548 [3]	5.84 – 6.56
		523 [4]	6.12 – 6.89

1) Mean in central Kavengo Region, Jones, Cownie (2001: 10). 2) Long-term mean in Rundu, Schneiderat (2008: 129).
3) Corrected mean in Rundu, Schneiderat (2008: 129). 4) Presumed value in Rundu, Schneiderat (2008: 129).
5) Atlas of Namibia (2006) (bmean8503).
Source: Own design based on mentioned publications.

Cattle are known to be grazers rather than browsers. Hence, total biomass production has to be divided into shares of grass, bush and tree biomass. According to region-specific publications, bushes are the predominant vegetation cover. As indicated in Chapter 2.2.6, grasses and forests can also be found among the native vegetation (Jones and Cownie, 2001: 15). Schneiderat (2008: 60) estimated basal grass coverage directly on communal grazing areas in the research area (Table 4.20). A mean over a wet and a dry season revealed a grass cover of 21 %.

Table 4.20: Mean grass coverage in the research area

		Basal grass		
		Dry season 2002	Wet season 2003	Mean over both seasons
Mean coverage	%	17.4	25.0	21.2

Source: Own design based on Schneiderat (2008: 60).

Supported by visual maps offered by Jones and Cownie (2001: 15), concrete figures on vegetation type shares are estimated to amount to 70 % for bushes, 20 % for grasses and only 10 % for forests. Table 4.21 summarises resulting estimates of consumable biomass production divided by vegetation type. Though related to primary biomass production and not dry matter phytomass, levels of grass biomass seem to be fairly low if compared to Schneiderat (2008: 69). She calculated an RUE for a mean grass dry matter amount of 1.85 kg ha^{-1} mm^{-1}. This difference can be explained by the fact that for the present calculations, the lowest RUE observable in the Kavango Region was used. Fodder demands of livestock are usually measured and calculated in dry matter intake. However, a further conversion of obtained estimates to dry matter biomass does not seem to be plausible. Note that estimates of the grass biomass parameters are already rather low and are below even dry matter figures presented by Schneiderat (2008: 69). The usable share of left-over biomass from a previous period is a final parameter which needs to be specified. Its importance is based on MAPOM's multi-annual character. According to Buß (2006: 122), biomass left over on grazing areas is subjected to insects and fungi. This is respected in MAPOM by determining that only 30 % of left-over biomass can be used in the following period. A similar share is applied for biomass production on natural resource areas (Chapter 4.5.1).

Table 4.21: Calculated estimates of consumable seasonal ground biomass production of grasses, bushes and trees

Vegetation class	Soil quality class	Calculated estimates of consumable seasonal above-ground biomass production kg ha^{-1} mm^{-1}
Grass	a	0.90
	b	0.73
Bush	a	3.14
	b	2.57
Tree	a	0.45
	b	0.37
Total	a	4.49
	b	3.67

Source: Own design.

4.4.2.2 Estimating dry matter intake

Free-grazing livestock units are known to require 2.5 – 3.0 % of their live mass per day in dry matter. Hence, one kg of live animal mass will need 0.025 – 0.030 kg of dry matter per day. According to Schneiderat (2008: 119), dry matter intake might be reduced to 0.020 kg in dry seasons. For MAPOM, a dry matter intake of 0.025 kg is assumed for the traditional livestock management system. Since mentioned figures are related to maintenance, energy demands for additional body functions might be higher. According to Schneiderat (2008: 119), cattle have to walk to water points and grazing areas, which can significantly increase their energy expenditures. Consequently, Schneiderat (2008: 119) increased total energy requirements by an addition of 50 % (see Table A28 in the Appendix). Requirements for further body functions like pregnancy or draught power provision of livestock were not included (Schneiderat, 2008: 119). The present study considers only dry matter needs, while a specification of energy demands is neglected. However, to acknowledge higher energy demands for higher performances, the dry matter demand of cattle under the improved livestock management system is increased by 50 %. This results in a dry matter intake of 0.037 kg per kg of body weight.

Cattle behave to 80 % as grazers (Schneiderat, 2008: 120: Table A27). Hence, 80 % of the calculated dry matter requirements have to be satisfied by produced grass biomass and residues. According to Sweet and Burke (2002: 4.1), the relative scarcity of grasses in most vegetation types in Namibia makes ‘browsing’ an essential component of the diet for all livestock species. Hence, the remaining 20 % can be satisfied by consuming bush biomass.

4.4.3 Variable inputs and prices

Apart from fodder, either obtained from grazing or cropping areas, no further variable inputs are required for traditional livestock production. However, to acknowledge better care for cattle under the improved cattle production system, cash expenditures in terms of veterinarian costs are assumed in MAPOM. Indications of possible veterinarian costs are lacking in publications. Therefore, a lump sum of 50 N$ per cattle and year is assumed.

As indicated in Chapter 2.3.3.5, functions of cattle are manifold in the Kavango Region. According to Pröpper (2009: 202), a large livestock herd is a cultural symbol of status and a successful life. Hence, it is not surprising that different surveys reveal that cattle sales are fairly sporadic (Deniau et al., 1997: 115; Mawrd, 2003: 52). Table 4.22 shows cattle selling prices according to different age and sex groups. In general, prices are higher for older and male cattle. Indicated by the number of estimates, the majority of selling activities concentrate on male cattle over the age of three years.

Table 4.22: Cattle prices according to different age and sex groups

	n	Age group	Price N$/head
Calve (male)	8	< 3 years	800
Calve (female)	9	< 3 years	710
Bull	22	> 3 years	1,030
Cow	15	> 3 years	1,000

Source: Deniau et al. (1997: 119).

Table 4.23 shows sales and purchases of cattle in the research communities. Sales (n=9) are clearly sporadic, as previously mentioned, but they are more common than purchases (n=2). As stated in region-specific publications, calving seems to be a dominate way to increase cattle numbers (Mawrd, 1996: 25). Generally, cattle is sold at an average selling price of 1434 N$ per head, whereas the purchasing price amounts to 783 N$ per head.

Table 4.23: Cattle selling and purchasing prices

	n	Price N$/head	Price N$/kg
Cattle sales	9	1,434	4.78
Cattle purchases	2	783	9.79

Source: Own design based on the CSFS (2005).

The CSFS further revealed that it is difficult to obtain information on age, sex and weight categories of sold or purchased cattle. Hence, a conversion to prices per kg is necessary to calculate the prices per cattle category for MAPOM. Since region-specific publications indicate that predominantly 'mature cattle' are sold, the price per head is divided by the average weight over cows and bulls (300 kg, Table 4.18). Contrarily, for calculating purchasing prices per kg, it is assumed that calves are more likely to be bought. This assumption seems to be plausible if purchasing prices in the CSFS are compared to price specifications in Deniau et al., (1997: 119). Consequently, prices per head are divided by the average calf weight (80 kg, Table 4.18).

4.4.4 Domestic utilisation patterns and nutrition deliveries

As already shown for cattle sales, a voluntary decrease of cattle herd sizes by consumption is rather infrequent (Mawrd, 1996: 38; Deniau et al., 1997: 122). Still, nutrition demands of FHHs can be satisfied by consuming cattle meat (Chapter 4.3.3). According to

Bender (1992: Table 2-11), 100 g of rump steak grilled meat delivers 220 kcal. This results in 2,200 kcal per kg. Apart from chicken and rabbit meat, this is the lowest value of all grilled or boiled meat sources. However, live weights of cattle cannot be equally converted to meat output. A share of only 34 % of the live weight is available for consumption (ratio between carcass weights and live weights) (Bender, 1992: Table 2-10A). To emphasises this rather sporadic consumption of livestock products in the research area, MAPOM includes an additional ‘system constraint’. This constraint prevents MAPOM from satisfying total kcal demands with more than 30 % of livestock products.

4.5 Natural resource production and off-farm employment

In this chapter, relevant information for determining natural resource production functions (input-output relations, not including their labour requirements) is discussed. Further, a brief monetary evaluation of outputs is outlined. Since rural peasant farmers are known to be producers and consumers, one section of this chapter addresses FHHs’ consumption patterns. The general procedure of how relevant coefficients are obtained for MAPOM is illustrated by Figure 4.3 in Chapter 4.3. Another important activity of FHHs in the research area is participation in off-farm employment. Relevant parameters needed to specify off-farm labour participation are also addressed in this chapter.

In general, different natural resource production activities are identified which are reflected by different management activities in MAPOM. In total, six management activities can be distinguished. Concrete differentiation elements are a) the soil quality and b) the management practice. Table 4.24 provides a list of all included natural resource management activities. Since crop fields are currently established on soil quality ‘a’, natural resource areas can be assumed to be located on soil quality ‘b’.

Therefore, the most prevailing natural resource management activities are Activity N4 to Activity N6. Consequently, inputs and outputs of these activities are reflected by data obtained by the CSFS. The present study also aims to include other ‘possible’ management options. Hence, modifications are necessary regarding an improved production potential of natural resource areas located on soil quality ‘a’. These production potentials are calculated in a step-by-step approach in the following sections.

Table 4.24: Natural resource production management activities

	Soil quality class	Practice
Activity N 1	a	Thatching grass collection
Activity N 2		Firewood collection
Activity N 3		Timber logging
Activity N 4	b	Thatching grass collection
Activity N 5		Firewood collection
Activity N 6		Timber logging

Source: Own design.

4.5.1 Estimating biomass production on natural resource areas

This chapter uses the same methods mentioned in Chapter 4.4.2.1, in which biomass production on grazing areas is estimated. Necessary figures for estimating biomass production on natural resource areas are a) above-ground biomass production on soil quality ‘a’ and soil quality ‘b’ (4.48 kg ha^{-1} mm^{-1}, 3.67 kg ha^{-1} mm^{-1}) and b) shares of bushes, grasses and trees in the vegetation cover (70 %, 20 %, 10 %).

Only some grass species are suitable for thatching, and only some parts of the total bush biomass can be used as firewood. Hence, it is necessary to calculate the usable shares of the different biomass types. Based on figures from Kojwang (2000: Annex 1 and 2), a share of timber trees in total tree biomass could be calculated for the Kavango Region. This share amounts to approximately 11 % (Table 4.25). Numbers of timber trees per ha are based on maximal observations and result in 13 timber trees per ha. According to Pröpper (2009: 127), a case study of a community forest project showed that 30 trees could be harvested on an area of 15 ha. This would result in 1.97 timber trees per ha. Since estimates of above-ground biomass production are rather conservative, using a share of 11 % in MAPOM will not exceed a ratio of two timber trees per ha.

Lacking information about all other shares requires this study to include the following assumptions: a) the timber tree share is factored by 2.5 to obtain the share of thatching grass biomass in total grass biomass (approximately 30 %), b) the timber tree share is factored by 3.5 to obtain the share of firewood biomass in total tree biomass (approximately 40 %), and c) the timber tree share is factored by 4.5 to obtain the share of firewood biomass in total bush biomass (approximately 50 %).

Table 4.25: Estimates of tree biomass, timber tree biomass and shares of timber tree biomass in tree biomass in Kavango Region

Timber tree species	**Number of timber trees** [1)] trees/ha	**Average tree biomass** [1)] kg/tree	**Timber tree biomass** [2)] kg/ha	**Total tree biomass** [1)] kg/ha	**Share of timber tree biomass in total tree biomass** [2)] %
Baikiaea	6	180	1,080	20,600	0.05
Pterocarpus	7	180	1,260	20,600	0.06
Total	13		2,340		0.11

1) Kojwang (2000: Annex 1 + 2). 2) Own calculations based on Kojwang (2000: Annex 1 + 2).
Source: Own design based on Kojwang (2000: Annex 1 + 2).

4.5.2 Domestic utilisation patterns

Though property rights for natural resources in central Kavango are controlled by the state, little statutory control is exercised for the exploitation of resources like grass, wildlife, fruits and medical plants (Pröpper, 2009: 287). An exception is the harvest of trees. This is regulated by issuing licenses or permits at certain costs. The issuing process involves agreement from a) the traditional authority offices and b) the local village headmen. However, such a practice has not been observed in the research area so far (Pröpper, 2009: 289). Compliance with this system seems to be lacking because of high transaction costs related to the issuing process. Often, cash income incentives exceed the risk of being caught (Pröpper, 2009: 287). Consequently, an obligation of issuing permits for the use of natural resources is not respected in the baseline run of MAPOM. However, MAPOM does investigate the introduction and enforcement of such a system in one scenario.

In the process of determining domestic utilisation patterns, two obstacles occurred which are related to the data basis. First, whenever quantities of firewood or thatching grass were addressed, respondents of the CSFS usually referred to the ‘bundles’ unit. Second, outcomes of the CSFS on domestic utilisation patterns for thatching grass and timber were partly insufficient for further data analysis or completely missing.

Consequently, the following necessary steps need to be accomplished: a) converting obtained CSFS data on natural resource consumption into metric kilograms, b) estimating the amount of thatching grass which is domestically consumed by using data from RRSP and c) estimating selling prices of thatching grass and timber tree products by using data from the CSFS and RRSP.

4.5.2.1 Thatching grass

In a study by Mmopelwa (2006: 115), different villages were interviewed about their thatching grass and firewood harvesting and consumption habits. Annually, a typical FHH was harvesting between 64, 168 and 514 bundles of thatching grass. This high variation was influenced by the investigated village and the grass species (Mmopelwa, 2006: 114, 116). Related to the grass species, one bundle had a diameter of 500 – 850 mm and a weight of 4.5 – 10.0 kg (Mmopelwa, 2006: 114, 116). Pröpper (2009: 192) discovered that one big bundle of the most prominent thatching grass species in the research area was made up of ten small bundles and had a weight of 0.7 – 1.0 kg (dry and wet). Since Pröpper (2009: 190) did not determine his measuring technique and sample size, this study sticks to a conversion factor of 4.5, meaning that one bundle of thatching grass weighs 4.5 kg (Mmopelwa, 2006: 116). This higher conversion factor depicts a more conservative calculation, and with respect to determine consumption amounts, any lower conversion factor will be covered.

Twine et al., (2003: 468) give an indication of quantities of thatching grass domestically consumed by one FHH. First, they assumed that a roof of a thatched dwelling consists of a mean number of 641 bundles. This matches with experiences reported by Pröpper (2009: 206), who used approximately 700 bundles to build his own thatched roof. Second, this annual consumption was discounted over an assumed lifespan of 25 years. Consequently, one FHH domestically uses 10.4 bundles of thatching grass on average per year (Twine et al., 2003: 468). A conversion into kilograms results in an average amount of 46.8 kg of thatching grass per FHH and year. Pröpper (2009: 206) suggests a lifespan of only five to ten years for a thatched dwelling. This would considerably increase the annual consumption rate of thatching grass. Figures from Mmopelwa (2006: 115, 116, 120) vary between 104 and 2,313 kg of thatching grass, averaging 114 kg per FHH and year. It can be assumed that the figures from Mmopelwa (2006: 115, 116) include thatching grass which was sold and not exclusively used for domestic consumption. He included harvesting rates in his calculations. Bearing above obstacles in mind, this study uses average figures mentioned by Mmopelwa (2006: 115, 116, 120), which amount to 114 kg of thatching grass per FHH and year. The number of houses in a FHH might increase with the number of adult FHH members. Hence, the amount of thatching grass domestically used needs to be related to the number of producers. Consequently, it is obligatory for FHHs in MAPOM to harvest a minimum of 29.5 kg of thatching grass per year and producer.

Results of the CSFS revealed that 1.2 N$ can be earned on average for selling one kg of thatching grass (n = 14). Under the assumption that thatching grass is already a scarce resource, this price seems to be fairly low. According to Pröpper (2009: 202), a big bundle with a weight of between 0.7 and 1.0 kg was sold at 6.0 N$. To be as conservative as possible, the lower price is used in MAPOM.

4.5.2.2 Firewood and timber

The majority of FHHs in the Kavango Region depend on firewood as a source of energy. Firewood is used almost every day for cooking; its usage quantity is therefore much higher than that of thatching grass. Mmopelwa (2006: 118) estimates that 28 kg of firewood are consumed per FHH and week. This amounts to 1,456 kg on an annual basis. Mmopelwa (2006: 118) used a factor of twelve to convert the unit ‘bundles’ into kilograms (one bundle of firewood weights twelve kg). Twine et al., (2003: 470) suggest an annual firewood consumption of 4,510 kg. The FAO (2000) investigated three major surveys on firewood usage in Namibia. They found that consumption of firewood shows some variations. In a first study, conducted in 1992, consumption of firewood in Rundu, the urban centre of the Kavango Region, was estimated to be 1.08 kg per person per day (FAO, 2000: 3, 4, 5). A second study, conducted in 1996, found that consumption of firewood amounted to 1.5 kg per capita per day (FAO, 2000: 5). In a third survey in 1997, the daily consumption per person was estimated to be 0.49 kg (FAO, 2000: 6). Pröpper (2009: 209) states that –one to two bundles of firewood are consumed per FHH and day. With an assumed average FHH size of 9.2 members and a conversion factor of twelve this results in 1.30 to 2.66 kg per person per day. Other literature figures range in some cases considerably below Pröpper’s estimates (0.49 kg per person per day). However, he valuates his rates as being moderate. This stresses the necessity of accurately converting local metrics into scientific metrics.

According to the CSFS, the average firewood consumption per FHH and year amounts to 217 bundles, or 2,605 kg (n = 40) or 0.78 kg per capita per day. If compared to figures from region-specific publications, this amount seems to be plausible. The usage quantities of firewood might increase with the number of adult FHH members. Hence, the amount of firewood domestically used needs to be related to the number of producers. Consequently, it is obligatory for FHHs in MAPOM to collect an amount of 673 kg firewood per producer per year. Selling firewood is fairly uncommon in the research area. Data from the CSFS show that only one FHH was selling firewood (n = 45). Hence, selling firewood is not considered in MAPOM.

Parameter values related to timber tree logging are exposed by the ethnographic awareness movie by Pröpper and Gruber from 2007. The movie depicts a tree being cut into – four to five planks with a pit saw, the most common tool to harvest timber trees traditionally. In most common selling places in Windhoek, one plank is sold for 120 N$. However, it is suggested that illegal tree cutting without permits is lowering prices, so sometimes sellers obtain as little as 40 to 50 N$ (Pröpper, Gruber 2007). In his dissertation, Pröpper (2009: 194, 204) mentions different prices of 15 to 50 N$ and 30 to 70 N$ per plank illegally harvested wood. As described before, the issuing of permits is not considered in the baseline run of MAPOM. Therefore, this study uses an average of mentioned prices for illegal tree products. This amounts to 42.5 N$ per plank. Consequently, the products of one tree are sold at 170 N$. With an assumed average tree biomass of 180 kg (Kojwang, 2000: Annex 1 and 2), this results in a selling price of 0.94 N$ per kg.

4.5.3 Off-farm employment

Off-farm employment is an important aspect in the research area. In order to include off-farm employment in MAPOM, the following steps must be accomplished: a) defining off-farm employment activities, b) specifying related salaries and c) setting upper limits for participation in off-farm labour.

Off-farm labour activities include wage labour and casual work. Wage labour is defined in this study as all labour activities which a) occur beyond the village boundaries of MAPOM and b) have a contract and a monthly salary. For example, wage labour can include work a) in mines, b) for a road construction company or c) for commercial farmers. In the Kavango Region, a rather common occupation after farming is teaching, followed by employment at NGOs or cooperatives. Other labour may take plane in fruit farms, mines, the national defence force or urban locations like Rundu or Windhoek (Pröpper, 2009: 153). Though the local labour economy is struggling to develop, about one third of FHHs have at least one wage earner (Mawrd, 1996: 10; Pröpper, 2009: 153, 196). This can be confirmed by the results from the CSFS. At least one FHH member took part in wage labour in about one quarter of interviewed FHHs (24 % n = 45). Casual work, on the other hand, encompasses all labour activities which a) occur beyond the village boundaries of MAPOM and b) are related to farming activities in neighbouring communities. For example, the following tasks are categorised as casual labour: a) ploughing, b) weeding, c) harvesting, d) clearing, and e) part-time employments like cattle and goat herding. Results from the CSFS reveal that about 54 % (n = 45) of FHHs had one casual worker.

Vigne and Associates (2005: 51) assume that a daily wage rate for DAP ploughing (casual labour) amounts to 20 N$. Based on a labour day of eight hours, this would result in 2.5 N$ per hour. For all other labour tasks in crop production activities, they apply a slightly lower rate of 10 N$ per day (=1.25 N$ per hour). In comparison, the CSFS obtained a wage rate for casual labour of 2.2 N$ per hour (n = 14). This seems to reflect an average of figures presented by Vigne and Associates (2005: 51). According to Pröpper (2009: 153), teachers receive a state salary of about 3,000 N$ per month. Converting this figure into N$ per hour results in 18.75 N$ (20 days per month and eight hours per day). Contrarily, results of the CSFS reveal a wage rate for wage labour of 13.59 N$ per hour (n = 7). This figure is considerable lower than that mentioned by Pröpper (2009: 153). By definition, wage labour also includes tasks which require lower skills than those of a teacher. Therefore, salaries for wage labour obtained by the CSFS seem to be fairly plausible.

Further results of the CSFS show that hours occupied by off-farm labour activities per year vary between casual (145.35, n = 17) and wage labour (1516.36, n = 11). This is because wage labour is permanent, and once a person is involved, the hours worked per year are higher than for casual labour. Because of its character, casual labour is often constrained by the seasonality of the farming system. Obviously, there is a better chance of becoming involved in casual than in wage labour. This is indicated by the number of FHHs involved in those two types of labour activities. Since imperfect labour markets can be assumed, an upper limit for participating in off-farm labour activities is considered in MAPOM. This is constructed by formulating a maximal number of hours which can be spent for off-farm employment. As confirmed by results of the CSFS, the chance to become engaged in off-farm labour is assumed to be generally lower for women than for men. The involvement of females in wage labour activities was considerably lower in the CSFS. Only 0.04 female producers (= 16 % of total wage labour) but 0.20 male producers (= 84 % of total wage labour) participated in wage labour. This might be explained by the general belief among employers that men are better able to cope with intense physical workloads. A similar but less considerable difference in involvement could be observed in casual labour. Here, only 0.16 female producers but 0.38 male producers per FHH were identified as participating in casual labour (n = 45). Both shares are respected in MAPOM by constructing an upper limit for female producers to participate in off-farm employment.

4.6 Family labour requirements

As outlined in Chapter 2.3.1, family labour is the most important input for all farm activities. At the same time, the availability of family labour can be threatened by malnutrition and infections like HIV/AIDS. This chapter discusses all parameter levels of labour requirements which refer to the different FHH activities described in previous chapters.

According to Byerlee (1979: 349), a male adult works approximately 700 to 1,300 hours per year in arid or semi-arid areas. These figures include farm and non-farm work. Males in humid areas, on the other hand, seem to work harder – between 1,400 and 1,500 hours per year. Women are an important part of the labour force; they work approximately 900 hours per year and contribute 39 % of all labour inputs.

The peak demand for labour in the research area usually occurs around the middle of the growing season (December to March). During this time, labour is needed for planting and weeding as well as livestock herding. Unluckily, this high labour demand coincides with the peak period for malaria and when low-income families have already consumed their grain stocks (Matsaert, 1996: 20).

4.6.1 Crop production

Traditionally, family labour is the most significant input in millet production, and the degree to which farmers use physical labour has a great influence on the output. In general, labour inputs per hectare vary according to:

- the frequency of clearing new land for cropping
- the ploughing technique (manual, by DAP)
- the planting technique (row planting/broadcasting)
- the frequency of weeding (once or twice) and
- the weeding technique (manual, by DAP) (Vigne and Associates , 2005: 88).

As indicated in Chapter 2.3.2.4, most crop production activities are more or less tied to specific months. However, their starting points highly depend on the commencement of rainfall events (Yaron et al., 1992: 42). In land clearing, trees and shrubs are cut with axes, heaped and burnt. Larger trees are mainly left in the field, and grasses are burnt (Matsaert et al., 1995: 18). Ploughing can be carried out by DAP or by hand hoeing (Matsaert et al., 1995: 19). Logically, planting follows the ploughing process. There can be up to three weeding sessions in a season depending on rain (Matsaert et al., 1995: 20). Hence, weeding is the most time-consuming component of crop production. It is predominantly carried out with hand tools (hoes) (Matsaert et al., 1995: 20). Using DAP for weeding is an uncommon practice (Mutwamwezi, Matsaert, 1998: 12; Jones and Cownie, 2001: 31). Even harvesting is primary accomplished manually (Matsaert et al., 1995: 21). After being harvested, grain yields are threshed (Jones and Cownie, 2001: 31).

4.6.1.1 Literature review on labour inputs

Figures of labour input from region-specific publications are often formulated in sessions. In the CSFS, however, the unit ‘man hours’ is used. In order to compare figures measured in sessions to results obtained by the CSFS, a conversion from sessions to labour hours is essential. A session represents either a morning or an afternoon and can be treated as 0.5 man days. Further, one man day consists of eight man hours. Table 4.26 shows labour inputs per ha for millet production divided by activity (Mawrd, 1996: 37).

Table 4.26: Family labour requirements per ha of crop production activities by task in the Kavango Region

Task		Sessions/ha	Man days/ha	Man hours/ha
Land clearing		12.8	6.4	51.2
Land preparation				
	manual	11.5	5.8	46.0
	by DAP	8.6	4.3	34.4
Planting		7.7	3.85	30.8
Weeding		23.3	11.7	93.2
Harvesting and threshing		22.4	11.2	89.6
Total 1	including land clearing and manual land preparations	77.7	38.9	310.8
Total 2	including land clearing and DAP ploughing	74.8	37.4	299.2
Total 3	excluding land clearing and including manual ploughing	73.5	36.8	294.4
Total 4	excluding land clearing and including DAP ploughing	62.0	31.0	248.0

Source: Own design based on Mawrd (1996: 37).

On average, 310.8 labour hours are used to cultivate one ha of land. This amount could be reduced to 248.0 labour hours if DAP ploughing is applied and land clearing is not considered. According to Vigne and Associates (2005: 88), total labour inputs per ha (three-hectare fields) range between 200 and 330 labour hours depending on the inclusion or exclusion of hired labour (Table 4.27). They do not acknowledge the activity clearing.

Table 4.27: Labour requirements per ha of crop production activities by task in the Kavango Region including and excluding hired labour

	Inclusive hired labour		Exclusive hired labour	
Task	Man days/ha	Man hours/ha	Man days/ha	Man hours/ha
Land preparation (ploughing + planting)	5.5	44.0	3.7	29.6
Weeding, insect and bird control	22.3	178.4	14.0	112.0
Harvesting	5.6	44.8	2.3	18.4
Threshing	7.8	62.4	5.0	40.0
Total	41.2	329.6	25.0	200.0

Source: Own design based on Vigne and Associates (2005: 88).

4.6.1.2 Empirical evidence on labour inputs

Crop production tasks considered in the CSFS include labour for ploughing, planting, weeding, harvesting, threshing and clearing new fields. Some of these tasks are gender-specific. Most of the FHHs interviewed use a) DAP for ploughing, b) broadcasting planting techniques and c) manual weeding with one weeding session. Hence, figures obtained by the CSFS are related to those practices. Note that clearing is a once-off task, meaning that once a field has been cleared no additional labour is needed. Some publications additionally consider the task of ‘cleaning’. This refers to clearing fields of previous harvest residues. Usually, cleaning is done directly before the ploughing process. However, this study assumes that cleaning tasks are included in ploughing activities.

Weeding with ox-drawn cultivators is not used in the investigated villages. Matsaert et al., (1998: 52) discovered that residents in inland villages are very interested in labour-saving devices and experimenting. Therefore, weeding with DAP is considered in MAPOM as an innovative labour-saving technology. Another crop production technique that is not yet used is row planting. For the present study, it is assumed that row planting requires more labour for the planting process. On the other hand, row planting is related to weeding with DAP, which saves manual weeding labour. When broadcasting planting techniques are used, it is not possible to use DAP for weeding. Both cultivation modes, mixed and pure cropping, can be accomplished with row planting (weeding with DAP) or broadcasting (manual weeding) and ploughing with DAP or manual ploughing.

Table 4.28 indicates that a typical FHH in the research area spends more than 1,000 labour hours per year on crop production. With a mean number of 3.87 producers per FHH, this results in a personal share of 260 labour hours or 32.5 labour days per year. A major labour-consuming task is weeding, followed by threshing and clearing.

Table 4.28: Labour requirements of crop production activities by task

Task	Technique	Man hours/FHH
Ploughing	by DAP	169.3
Planting	broadcasting	99.0
Weeding	manual one session	272.7
Harvesting		72.5
Threshing		213.6
Clearing		179.8
Total		1,006.8

Source: Own design based on the CSFS (2005), (n = 43).

Vigne and Associates (2005: 89) state that 1,224 labour hours per FHH and year are consumed by crop production. Under the same assumption, data sources cited by Pröpper (2009: 179) confirm these tendencies (1,176 man hours per FHH). However, Pröpper's (2009: 179) calculations based on his own collected data reveal higher values: 2,052 labour hours per FHH and year.

For MAPOM, it is necessary to relate the obtained labour hours to the production unit. Therefore, figures obtained by the CSFS are divided by the average size of cropping fields. As indicated in the crop production module, an average field size of 4.2 ha can be assumed. The derived results are presented in Table 4.29. Millet production typically consumes more than 230 labour hours per year and ha (Table 4.29). Since clearing is considered to be a once-off task, only about 200 labour hours are spent on crop production per ha and year. As outlined before, some publications show slightly higher labour inputs per ha, while others show lower ones. Calculations based on the CSFS can confirm the range indicated by Vigne and Associates (2005: 88) (200 to 330 labour hours per ha) but are slightly lower than figures reported by Mawrd (1996: 37) (248.2 and 310.8 labour hours per ha).

Without acknowledging gender specification, 239.71 (196.89) labour hours per FHH and ha would result in a) 61.94 (50.88) labour hours per ha and producer or b) 7.74 (6.36) labour days per ha and year. According to Pröpper (2009: 176), a survey in the Kavango Region on labour inputs for millet production can confirm these levels. Pröpper (2009: 179) himself encountered higher labour input levels per producer. In this context, it needs to be stressed that data collection and calculations for the CSFS focus on millet production. At least for some calculations, Pröpper (2009: 179) considers the production of millet and maize together.

Table 4.29: Labour requirements per ha of crop production activities by task

Task	Technique	Man hours/ha
Ploughing	by DAP	40.3
Planting	broadcasting	23.6
Weeding	manual one session	64.9
Harvesting		17.3
Threshing		50.9
Clearing		42.8
Total 1	including clearing	239.7
Total 2	excluding clearing	196.9

Source: Own design based on the CSFS (2005).

Generally, variations according to labour inputs per ha between data obtained from the CSFS and from other region-specific publications can have several reasons:

1. Data from cited publications and the CSFS are based on memories of respondents. This is related to different cropping seasons. Continual field records of labour inputs might come up with fewer variations.
2. Data from cited publications may a) combine different tasks which are separated in data by the CSFS or b) focus on specific tasks which are not considered by the CSFS.
3. Data from the CSFS are based on specific production modes (see section 4.6.1.2) which are closely linked to different amounts of labour inputs. Thus, the following calculations and conversions of labour inputs for other production modes (pure cropping) might better reflect figures found in publications.

4.6.1.3 Incorporating two weeding sessions and different cultivation modes

Most of the FHHs interviewed in the CSFS apply only one weeding session. Therefore, the labour amount spent on weeding needs to be modified if two weeding sessions are considered. Generally, it can be assumed that the second weeding session is less labour-intensive. Consequently, labour efforts for weeding are multiplied by 1.5 if two weeding sessions are accomplished. Results are presented in Table 4.30.

Table 4.30: Labour requirements per ha of crop production activities by task including one or two weeding sessions

	Technique	Man hours/ha
Weeding	manual one session	64.9
	manual two sessions	97.4

Source: Own design.

As indicated in section 4.6.1.2, different techniques can be used for ploughing, planting and weeding. Manual ploughing, weeding by DAP and row planting are so far not prevalent techniques. However, they can be combined in any comprehensive way in MAPOM. An exception is row planting; this technique is highly related to weeding by DAP. For obtaining labour inputs per ha for these techniques, different modifications need to be made. These modifications are the subject of this section.

Table 4.31 shows estimates on relations between manual labour inputs and DAP inputs. Moreover, the two considered planting techniques reported by Vigne and Associates (2005: 91) and Mawrd (1996: 37) are depicted. The labour input ratio for weeding is 0.15 (DAP) or 6.80 (manual). This indicates that only 0.15 labour hours are required per ha if DAP is used, whereas 6.80 labour hours are required per ha if weeding is done manually. Figures for ploughing are 0.74 (DAP) or 1.34 (manual). A ratio of 0.88 or 1.13 can be assumed for broadcasting or planting in rows, respectively. Using the mentioned ratios for the different production modes results in the figures presented in Table 4.32.

Table 4.31: Labour requirement ratios of manual labour and DAP and different planting techniques in the Kavango Region

Task	Technique	Man hours/ha	Ratio
Ploughing	manual [2)]	46.0 [1)]	1.34
	DAP [2)]	34.4 [2)]	0.74
Weeding	manual [1)]	66.9	6.80
	DAP [1)]	9.9	0.15
Planting	broadcasting [1)]	30.8 [3)]	0.88
	row planting [2)]	34.9 [4)]	1.13

1) 11.5 sessions (5.75 days). 2) 8.6 sessions (4.3 days). 3) 3.85 days with an hour equivalent of eight hours.
4) 4.36 days with an hour equivalent of eight hours.
Source: Own design based on Vigne and Associates (2005: 91) and Mawrd (1996: 37).

Table 4.32: Labour requirements per ha for crop production activities by task

Task	Technique	Man hours/ha
Ploughing		
	manual	54.0
	by DAP	40.3
Planting	by broadcasting	23.6
	by row planting	26.7
Weeding	manual with one session	64.9
	manual with two sessions	97.4
	by DAP with one session	9.7
	by DAP with two sessions	14.6
Harvesting		17.3
Threshing		50.9
Clearing		42.8

Source: Own design.

4.6.1.4 Incorporating gender differentiation

To acknowledge gender in some labour tasks, in a final step, the hours required per task are allocated to female or male producers. For tasks that are not gender-specific, 50 % of labour requirements are equally assigned to each gender.

According to region-specific publications, land clearing is carried out by men and women (Matsaert et al., 1995: 18). Young men play a crucial role in managing DAP for ploughing. Their absence is a serious constraint on crop production (Mutwamwezi, Matsaert, 1998: 10). Planting is carried out by women (Matsaert et al., 1995: 19; Mawrd, 1996: 30). Weeding and harvesting are not gender-specific (Matsaert et al., 1995: 20; Matsaert et al., 1995: 21). Threshing is done by groups of women (Jones and Cownie, 2001: 31). For this study, ploughing and weeding by DAP are defined as male tasks, whereas manual ploughing and weeding are assigned to women. Further, women are responsible for planting either in rows or with broadcasting techniques. All remaining tasks are not gender-specific. Outcomes in terms of labour inputs per ha differentiated by gender and excluding the activity ‘clearing’ are presented in Table 4.33.

Table 4.33: Labour requirements per ha for considered crop production activities by gender and management practices

Activity	Management practice						
	Weeding frequency	Planting technique	Ploughing technique	Weeding technique	Total	Female	Male
					man hours/ha	man hours/ha	man hours/ha
Activity C 1, 9, 17, 25	once	broadcasting	DAP	manual	196.9	122.6	74.4
Activity C 2, 10, 18, 26			manual	manual	210.6	176.6	34.1
Activity C 3, 11, 19, 27		row planting	DAP	DAP	144.8	60.7	84.1
Activity C 4, 12, 20, 28			manual	DAP	158.5	114.7	43.8
Activity C 5, 13, 21, 29	twice	broadcasting	DAP	manual	229.4	155.0	74.4
Activity C 6, 14, 22, 30			manual	manual	243.9	209.0	34.1
Activity C 7, 15, 23, 31		row planting	DAP	DAP	149.7	60.7	89.0
Activity C 8, 16, 24, 32			manual	DAP	163.4	114.7	48.7

Source: Own design.

Table 4.33 shows that crop production requires between 60.72 and 209.01 female labour hours and between 34.1 and 89.0 male labour hours, depending on the different cultivation techniques applied. In total, 32 crop production activities exist (Chapter 4.3.1); however, some cultivation modes (pure or mixed cropping) and soil qualities have no impact on labour inputs. Additional crop production tasks arise if new fields are cleared. One ha consumes 42.8 labour hours, which are equally accomplished by female and male producers (21.4 labour hours per ha each).

4.6.2 Livestock production

In terms of livestock production, quantitative descriptions of labour requirements from region-specific publications are extremely rare. Therefore, calculations are based on data obtained by the CSFS. Generally, there is a strong division of labour: young and adult men are mainly in charge of cattle (Deniau et al., 1997: 115). Women seem to be responsible for milking. However, the consumption of milk or milk products is quite limited in the investigated communities. Hence, labour inputs in terms of livestock production concentrate on herding labour and are calculated in the following section.

Typically, a FHH spends 1,579 labour hours per year on managing livestock (n = 28). Considering only the four months in which herding predominantly occurs (May to August: Mutwamwezi, Matsaert, 1998: 10), this would result in 13.17 labour hours per day and FHH. Considering an entire year, however, would result in 4.33 labour hours of herding per day and FHH. Both figures seem to match figures presented by Pröpper (2009: 207). He mentions in a consumer profile that each man or boy is on duty for several days in a row to herd the cattle for seven to ten hours daily.

For MAPOM, it is necessary to relate the obtained labour hours to the production unit. Therefore, labour requirements per FHH need to be divided by the average number of cattle owned by a typical FHH. This procedure results in a labour input of 83.9 labour hours per head of cattle and year for the traditional livestock management system (Chapter 4.4.1.1: average number of cattle owned by a FHH is 18.8). Breeding management can be assumed to be rather labour-intensive under the considered conditions. Hence, an additional 50 % of total herding labour is added for the improved livestock production system (41.9 man hours per head). This is intended to reflect improved breeding management. In total, 125.8 labour hours per head of cattle and year need to be allocated for the improved livestock management system.

Labour requirements do not differ by soil quality class. This means that Activities L1 and L3 in traditional livestock management require equal labour inputs per cattle, as do Activities L2 and L4 in improved livestock management (Table 4.34). Since livestock production and especially cattle production is known to be gender-specific, calculated figures are assigned exclusively to male producers. However, herding is not accomplished only by adult male producers but is often transferred to younger men. To acknowledge the help of dependents within the FHH, total labour hours spent by producers are reduced by 20 % in MAPOM.

Table 4.34: Labour requirements per cattle for considered livestock production activities by gender

	Management practice	**Female** man hours/head	**Male** man hours/head
Activity L 1, 3	traditional	0	83.9
Activity L 2, 4	improved	0	125.8

Source: Own design.

4.6.3 Natural resource production and off-farm employment

Natural resource production tasks within the research area can be differentiated into the collection of thatching grass and firewood and the harvesting of timber trees.

According to a survey on natural resource production by Mmopelwa (2006: 116), the grass species determines a) the harvesting season, b) harvesting frequency and c) labour input per FHH. Ranges indicate that a) between three and four bundles can be harvested in eight to ten hours twice a week or b) as many as eight bundles can be harvested in ten hours six times per week (Mmopelwa, 2006: 115). Consequently, the total labour input for harvesting grasses varies between 214 hours, 336 hours and even 642 hours per FHH and year (Mmopelwa, 2006: 116). Twine et al., (2003: 470) discover that the availability of firewood in their selected study area had been declining over a time period of five to ten years. Therefore, a head load of firewood (35 kg) that previously took about two hours to collect later had a mean collection time of four hours. This means that a total of 520 hours per year was spent on collecting firewood alone (= 130 head loads) (Twine, et al., 2003: 470).

Except for harvesting timber trees, the collection of firewood and thatching grass is more or less accomplished by both genders. However, data in the CSFS concentrate on firewood and thatching grass collection. A typical FHH spends more than 585.1 labour hours per year on collecting firewood (235.9, n = 41) and thatching grass (349.2, n = 38). The most labour-consuming task is thatching grass collection. For MAPOM, it is necessary to relate the obtained labour hours to the production unit. Therefore, labour requirements per FHH are divided by the average number of bundles collected by a FHH. These figures amount to 217.1 bundles of firewood and 10.4 bundles of thatching grass (Chapters 4.5.2.1 and 4.5.2.2).

Finally, obtained figures were further converted into labour hours per kg. As already introduced in Chapter 4.5.2.1, the following conversion factors are used:

- One bundle of thatching grass has a diameter of 500 mm and an average weight of 4.5 kg (Mmopelwa, 2006: 116)
- One bundle of firewood has a weight of twelve kg (Mmopelwa, 2006: 118)

A typical FHH takes a) 33.6 (7.6) labour hours to collect one bundle (4.5 kg) of thatching grass and b) 1.1 (0.1) labour hours to collect one bundle (12 kg) of firewood. As for crop and livestock production tasks, gender specification needs to be acknowledged. Since thatching grass and firewood collection are not gender-specific, 50 % of calculated labour hours need to be accomplished by female producers and 50 % by male producers Table 4.35.

For timber tree logging, information was gathered from the ethnographic awareness movie by Pröpper and Gruber from 2007. The movie depicts one tree being cut and processed (cut into planks) by three adult men who require one complete day of work. Therefore, 24 labour hours are required to harvest one tree. Tree logging is exclusively the responsibility of men. According to Kojwang (2000: Annex 1 and 2), the biomass per tree amounts to 180 kg on average. This converts 24 labour hours per tree into 0.13 labour hours per kg (Table 4.35). As for livestock and crop production, labour requirements do not vary by soil quality. Apart from timber tree logging, natural resource production tasks can be also accomplished partly by dependents. Hence, necessary labour requirements per kg and producer are reduced by 20 % in MAPOM.

Table 4.35: Labour requirements per kg of considered natural resource production activities by gender

	Practice	Female man hours/kg	Male man hours/kg
Activity N 1, 4	thatching grass collection	3.73	3.73
Activity N 2, 5	firewood collection	0.05	0.05
Activity N 3, 6	timber logging	0.00	0.13

Source: Own design based on Pröpper and Gruber (2007), Kojwang (2000: Annex 1 + 2) and the CSFS (2005).

Independently from labour input in farm production and natural resource production processes, FHH producers can participate in off-farm labour activities. As indicated in Chapter 4.5.3, wage labour is connected to both higher wage rates and longer travel distances. Therefore, one hour of wage labour requires 1.5 hours of family labour. For casual labour which can be done in adjacent communities, only one hour of family labour needs to be invested (Table 4.36).

Table 4.36: Labour requirements per hour for considered off-farm labour activities by gender

	Practice	Female man hours/hour	Male man hours/hour
Activity O 1	Casual labour	1.0	1.0
Activity O 2	Wage labour	1.5	1.5

Source: Own design.

4.6.4 Daily maintenance

Especially in poor rural areas, besides 'productive' farm tasks and off-farm labour, some other activities require high amounts of family labour. These are daily maintenance tasks which can be divided into water fetching, meal preparing, cloth washing, settlement cleaning and repairing tasks. Except settlement cleaning and repairing tasks, these tasks fall predominantly in the domain of women. Child care as another responsibility of women is usually done alongside other tasks and is therefore not considered separately.

Data from the CSFS (n = 41) reveal that a typical FHH spends about 1,618 labour hours per year on maintenance activities. This exceeds labour requirements for single economic activities, e.g. livestock or crop production. Major labour-consuming tasks are preparing meals (1.6 labour hours per day) and by fetching water (1.4 labour hours per day). Pröpper (2009: 208) states in a consumer profile that cooking is a daily activity that consumes 1 to 1.5 hours. Maintenance tasks might increase with the number of FHH members. Therefore, those figures are divided by 9.2, the average number of FHH members (Chapter 4.2.2.1).

Table 4.37 depicts labour requirements for daily maintenance tasks of female and male family members. To acknowledge the highly gender-specific character of daily maintenance tasks, labour hours accomplished by female producers are separated from those in the domain of male producers. Maintenance tasks consume on average 136.7 labour hours per FHH member for female producers and 39.1 labour hours per FHH member for male producers. Further, maintenance tasks can also be partly accomplished by dependents. Hence, the total labour hour requirements for producers are reduced by 20 % in MAPOM.

Table 4.37: Labour requirements per household member for considered daily maintenance tasks by gender

Task	**Female** man hours/FHH member	**Male** man hours/FHH member
Water fetching	54.7	0.0
Meal preparing	63.9	0.0
Cloth washing	18.1	0.0
Settlement cleaning	0.0	22.9
Repairing tasks	0.0	16.3

Source: Own design based on the CSFS (2005).

4.7 Objectives of peasant farm households

One of the major goals of this study is to empirically identify preferences of peasant farmers, e.g. the decision makers in the research area. This is achieved via a traditional conjoint analysis (TCA). Therefore, the first section of this chapter explains a) the theoretical foundation of TCAs, b) possible ‘approach-driven’ benefits, c) limitations and improvements and d) a literature review of TCA applications in developing countries. Another section briefly describes the empirical data collection processes and major results of the applied TCA. With respect to MAPOM, results of the TCA deliver empirically identified arguments and weights of the utility function.

4.7.1 Theoretical foundation of a traditional conjoint analysis

TCAs have been used for more than 30 years in a broad variety of research studies and topics (Klein, 2002: 7; Tano et al., 2003: 7). Primarily, marketing studies on consumer goods applied this approach to identify directions and necessities for product innovations.

4.7.1.1 General approach

A major theoretical foundation of TCAs emerges from the consumer theory developed by Lancaster. He assumed that utility is deduced by different factors (characteristics) of goods (Tano et al., 2003: 5). This implies that goods are not perceived holistically, but each good can be described as a combination of concrete levels of different factors (Klein, 2002: 7; Wiegand, 1992: 2). For instance, a car can be characterised by, among others, three factors: engine power, electronic equipment and colour. All three factors can take on different levels, e.g. for engine power, 80, 100 or 120 PS. In a choice situation, an individual prefers a certain car after he has balanced the utility of this car against other cars. An important element during the decision-making process is how the levels of all different factors are weighted relative to one another. If TCAs are used to investigate preferences for multiple-factor goods, then preferences can be defined as a result of a utility comparison (Klein, 2002: 8). In this context, a TCA is a methodological approach which tries to estimate, on the basis of utility levels obtained with empirical surveys, the contribution of each factor to overall utility (Backhaus et al., 2006: 558). During such an empirical survey, respondents holistically evaluate different choice alternatives (stimuli), which are described by selected factors and factor levels (Backhaus, Frohs, 2008: 9).

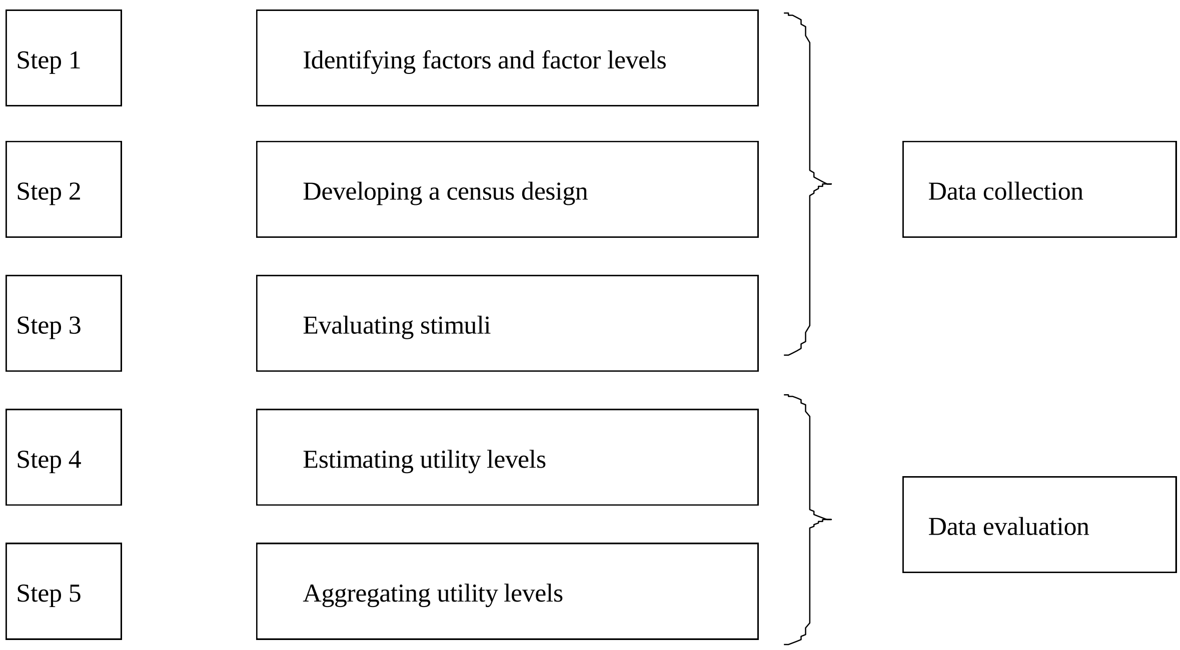
For the decision-making process, two assumptions are highly imperative: a) decision making is based on economic individualism, and b) decision makers have a complete and correct perception of the different levels of all analysed factors (Klink, 2004: 18; Klein, 2002: 11).

In principle, a TCA is a decompositional approach commonly based on a linear-additive utility model which assumes compensatory relationships between part-worth utilities (Backhaus, Frohs, 2008: 15). Consequently, overall utility is a result of adding all considered part-worth utilities obtained from different factors (Backhaus et al., 2006: 558). This implies that negative utility components can be balanced by positive utility components (Teichert, 2001: 61). Such a utility model leads to highly desired robustness and validity (Klein, 2002: 10, 11; Teichert, 2001: 63). On the other hand, additive utility models are thought to be threatened by estimation bias (Backhaus, Frohs, 2008: 15). However, particularly for high-involvement decisions, a compensatory model appears to be suitable

(Backhaus, Frohs, 2008: 15). According to Teichert (2001: 62), additive utility models seem to be appropriate, at least from a normative perspective, for a majority of all economic applications.

In statistical terms, a TCA is a combination of an assessment model and a statistical estimation algorithm (Klein, 2002: 10). While researchers determine all factors (independent variables) and their concrete levels, respondents determine their preferences, e.g. their perceived utility (dependent variables) (Backhaus et al., 2006: 558, 559). Both independent and dependent variables can be either metric or ordinal (Klein, 2002: 11).

According to Backhaus et al. (2006: 561), a TCA can be broken down into five successive steps. Figure 4.4 depicts these steps. In a first step, all factors and levels of factors which are important for the decision-making process of respondents need to be identified. Subsequently, in step 2, researchers develop a census design through which respondents evaluate all presented stimuli (step 3). With the help of obtained data in step 4, researchers estimate part-worth utilities. In a final step, all individual utility levels are aggregated.



Source: Modified from Backhaus et al. (2006: 561).

Figure 4.4: Five steps of a traditional conjoint analysis

To design TCAs, prior to the empirical surveys, statistical methods are used to identify a minimum set of factor level combinations. Then, results of empirical interviews are analysed with a regression analysis. This analysis generates estimated part-worth utilities and standard errors (Backhaus et al., 2006: 590; IFAD, 2007: 2).

4.7.1.2 Identifying factors and factor levels

In a TCA, considered factors and their corresponding levels need to fulfil certain characteristics. Table 4.38 describes recommendable characteristics of considered factors and factor levels. Generally, all factors which are relevant for building a preference of respondents have to be considered (Backhaus et al., 2006: 562). If important factors are neglected or unimportant factors considered, results can become invalid (Klein, 2002: 12, 13). In order to follow the compensatory character of a TCA, all factors need to be independent of one another (Backhaus, Frohs, 2008: 17, Backhaus et al., 2006: 562). Especially in the context of product marketing, all factors need to be influenceable by the product designer (Backhaus et al., 2006: 562). Factors are only recommended to be considered if they are assumed to have a high discriminatory character. This is necessary to obtain a significant variation between different stimuli which have to be evaluated (Klein, 2002: 12, 13). All empirical levels of considered factors need to be theoretically achievable within realistic ranges. Further, they are required to fulfil a compensatory relationship (Klein, 2002: 14; Backhaus et al., 2006: 562, 63). For the empirical survey, it is imperative that considered levels are easy to communicate (Klein, 2002: 14).

Table 4.38: Characteristics of considered factors and factor levels

Characteristics of factors	Characteristics of factor levels
relevant	theoretically achievable
independent	compensational relation
influenceable	realistic range
discriminatory	communicatable

Source: Own design based on Backhaus et al. (2006: 562).

Generally, factors and levels are to be excluded if they might become knockout criteria (Backhaus et al., 2006: 563). It is further recommended to a) constrain the number of factors and levels (Backhaus et al., 2006: 563) and b) keep the number of levels more or less constant (Klein, 2002: 14, 18). In many studies, a maximum of six factors with up to five levels each is used. With an increasing number of factors, the threat increases that respondents feel overburdened (Klein, 2002: 18, 19). Backhaus and Frohs (2008: 16) state that more than five factors should not be evaluated simultaneously to avoid excessive cognitive demands.

4.7.1.3 Developing a census design

For the experimental design of a TCA, different bundles (stimuli) with concrete levels of considered factors are assumed to deliver utility. They are presented to respondents on 'profile cards'.

In most cases, a fractional design is used, in which respondents have to evaluate only an advisable part of all possible stimuli. Such a reduced design is supposed to represent the complete design as well as possible (Backhaus et al., 2006: 566). For instance, a complete design of a 'three factors by three levels problem' would result in 27 stimuli. A fractional design which represents the complete design as well as possible would reduce the number of stimuli to nine. The remaining 18 stimuli can be neglected (Klein, 2002: 20). Such a fractional design can be technically produced with the ORTHOPLAN procedure in SPSS, which uses Adelmann-Plans statistics. For further details, see Backhaus et al. (2006: 584 - 585). Reduced designs include 'holdout cards'. These cards are excluded by SPSS for estimating utility levels and are used exclusively for validity purposes (Backhaus et al., 2006: 586).

In the profile method, one profile card consists of a combination of one level, either desirable or non-desirable, for each factor (Backhaus et al., 2006: 564; Klein, 2002: 18, 19). In accordance with decision making, these profile cards are ranked by respondents via a physical sorting process (Klein, 2002: 18, 19). By using the trade-off analysis, only two factors are considered in one stimulus (Backhaus et al., 2006: 564). Principally, the profile method is preferred if a) the level of reality desired for the decision-making process is high, b) respondents are expected to be cognitively able to fulfil demanded tasks and c) enough time resources are available (Backhaus et al., 2006: 565). Since a high level of reality was desired for the decision-making process, this study used the profile method.

4.7.1.4 Evaluating stimuli

In general, respondents can evaluate the presented profile cards (stimuli) by a) rankings (non-metric), b) ratings (metric) or c) paired comparisons (Backhaus et al., 2006: 570). A popular non-metric preference measure is the ranking approach, which asks respondents to furnish all presented stimuli with order statistics according to their preferences (Klein, 2002: 21). In comparison to metric or paired comparison approaches, rankings imply certain advantages: a) the outcomes are more reliable and valid (at least for a small number of factors), b) choice conditions resemble a realistic decision situation in which only the best alternative wins (two profile cards cannot obtain an equal rank), c) respondents are guided to build a clear preference order and d) respondents need to consider all factors relative to one another. On the other hand, disadvantages of a ranking approach are that a) a high level of administrative power is needed during the interviews and b) respondents can easily feel cognitively overburdened because they need to evaluate all presented stimuli simultaneously (Klein, 2002: 22). In order to reduce the risk of overstressing, it is recommended to split the whole ranking process into two separate parts. During the first part, respondents are asked to start with a rough categorisation of profile cards into different sub-groups like ‘good’ or ‘moderate’. Subsequently, categorised profile cards are re-ordered with more precision (Backhaus et al., 2006: 570).

Bearing the pertinent caveats in mind, this study applied the ranking approach. Explaining and discussing all evaluation approaches is beyond the scope of this study. For further information on the rating or paired comparison approaches see Backhaus et al. (2006: 570).

4.7.1.5 Estimating and aggregating utility levels

With respect to data evaluation, part-worth utilities of each factor level are estimated on the basis of empirically obtained order statistics. Such part-worth utilities can be used to calculate the overall utility and the relative importance of each factor (Backhaus et al., 2006: 571).

Via a conjoint command with several sub-commands, SPSS routinely performs a regression procedure to analyse obtained rankings and generates the final output (IFAD, 2007: 3). For each individual respondent, these outputs consist of a) estimated part-worth utility scores for each factor level, b) relative importance scores for each factor and c) goodness of fit measures (IFAD, 2007: 3). The part-worth scores are not assigned a unit but rather are interpreted as relative values. A positive score represents a positive preference, with higher values indicating stronger preferences. A negative score indicates factor levels that respondents rejected. The relative importance of each factor is measured as a percentage by the relative importance score (IFAD, 2007: 4).

Correlation coefficients are used to determine validation of obtained results. Pearson’s R measures the correlation between the metric values of total utility and the empirical rankings. This correlation coefficient is only applicable if empirically obtained order statistics are metric, e.g. if respondents were asked to attach a preference value to presented stimuli. Kendal’s Tau measures the correlation between the empirical rankings and the estimated rankings of results. Both correlation coefficients can range between 0 (no correlation) and 1 (high correlation) (Backhaus et al., 2006: 592). Additionally, both coefficients are calculated for holdout cards, which then serve as validity indicators (Backhaus et al., 2006: 593).

Often, it is of interest to compare individual utility levels. For such a comparison, it is advisable to first standardise obtained utility estimates (Teichert, 2001: 65). Individual part-worth utilities per level can then be aggregated over all respondents via mean values to derive specific data clusters. Note that SPSS does not routinely deliver standardised part-worth utilities. These need to be calculated separately (Backhaus et al., 2006: 599). In this context, it is verified, for a selected example, that part-worth utilities can vary significantly if standardisation is neglected. However, the relations between standardised and non-standardised part-worth utilities of different considered factors remain equal (Backhaus et al., 2006: 580-581).

Another possibility for obtaining aggregated results is the application of a ‘joint’ conjoint analysis. In this context, each respondent is seen as a replication of the research design (Backhaus et al., 2006: 582). This implies that a design with 10 stimuli and 20 respondents would result in 200 observations. An advantage of this practice is that information about variances remains available and the loss of information is less significant than for the aggregation of individual part-worth utilities (Backhaus et al., 2006: 600). However, a ‘joint’ conjoint analysis is predominantly recommendable if a) the number of data sets is ‘manageable’ (Backhaus et al., 2006: 609) and b) data sets are also subjected to other statistical methods like cluster analyses.

Backhaus et al., (2006: 600) illustrated that part-worth utilities can vary notably according to the chosen aggregation approach while the relative importance of factors remains equal. This study is not interested in generating part-worth utilities of considered factor levels. Instead, obtaining relative importance scores for considered factors is of interest. Therefore, an individual TCA, in which results were aggregated by calculating mean values, was applied.

4.7.1.6 Suitability, limitations and further developments

A major implication of a TCA is that the overall utility for a good can be disaggregated into separate utilities for its factors. One advantage of using this approach is that the importance of one factor is identified relative to other considered factors. With respect to a utility function, this procedure transfers into using a) all considered factors as arguments and b) the obtained importance of factors as weights of such a function (Tano et al., 2003: 5). Being categorised as incentive-neutral, TCAs are fairly suitable for avoiding strategic behaviour of respondents (Backhaus, Frohs, 2008: 15, 16). The decompositional character of TCAs, while not exactly directly *reflecting* rational decision-making behaviour, has the power to *simulate* realistic decision situations (Teichert, 2001: 47, 62).

One major limitation of TCAs is their incompatibility for evaluating excessive stimuli with more than five factors (Backhaus, Frohs, 2008: 16). Thus, adaptive approaches were developed in a vast area of research topics and gained relevance in previous decades. In choice-based conjoints (CBC), respondents are repeatedly confronted with a set of several complete product concepts. From this set, they ought to take a 'choice' representing their preferences. Often, CBCs also include a 'non-choice' alternative (Wildner et al., 2006: 334). Like TCAs, this approach implies a high level of reality in terms of the decision-making process and thus persuades with its high validity (Wildner et al., 2006: 334). Also similarly to TCAs, limits are obvious for including large numbers of factors and levels (Wildner et al., 2006: 335).

In order to manage more factors and levels, another modification is a rating-based conjoint. This approach is known as the adaptive conjoint analysis (ACA) (Wildner et al., 2006: 334). Via three initial steps (identifying unacceptables, ranking levels of factors, and identifying importance of factors), respondents are prepared for the final paired comparison of stimuli with increasing complexity (Wildner et al., 2006: 335). Thus, respondents are asked in detail only about those factors and levels of greatest significance (Fischer and Buchenrieder, 2008: 4). Because of a simulation of less realistic decision-making situations (paired comparison), ACA results are often criticised for their low validity (Wildner, 2006: 335).

Voeth (2000) developed a hierarchical individualised limited conjoint analysis (HILCA), which aims to combine two aspects: a) high validity and b) the ability to encompass more than five factors and levels. In an initial step (hierarchical), the respondents identify their most relevant factors. Afterwards, only factors recognized as 'individually important' are transferred to the conjoint design (Backhaus, Frohs, 2008: 9, 10, 16, 17). Another proposition of a HILCA is that a product needs a specific level of attractiveness. Hence, a set of products with increasing attractiveness is shown to respondents. They are then asked to place a limit card into the set, to reveal that products above this card are generally attractive enough to be bought (Wildner et al., 2006: 336).

All discussed improvements and innovations of TCAs and particularly their empirical accomplishments require special conditions during interviews because of their computer-based characters. Lacking power provision in the research area and insufficient hardware endowments made it more practicable for the present study to use a TCA. In addition to technical obstacles, the respondents' different cultural background made computer-based approaches less attractive.

4.7.1.7 Application to developing countries

Since the early 1970s, TCAs have been used in marketing studies, especially in industrialised economies (Klein, 2002: 7; Tano et al., 2003: 7). Consequently, the most commonly used structure of this approach and its empirical design need to be slightly modified to be appropriate for developing countries. In the context of high illiteracy levels, low educational levels and language differences, researchers must take great care to present a balanced number of stimuli. Since respondents are required to make fairly complex decisions, an adequate number of stimuli need to a) sufficiently investigate respondents' preferences and b) prevent cognitive overburden (Klein, 2002: 19). Often, information overload leads to a simplification of the evaluation process by ignoring less important factors or corresponding levels (Tano et al., 2003: 8).

Generally, data collection in developing countries is more complex, and often a pictorial representation is required (Tano et al., 2003: 8). According to Fischer and Buchenrieder (2008: 5), pictures can a) mediate between the observer and reality, b) bridge cultural differences, c) reduce information overload, d) provide higher homogeneity of perceptions and e) present more realistic and interesting stimuli.

Though several studies have already proved the potential usefulness of TCAs for quantifying preferences of peasant farmers in developing countries (Tano et al., 2003: 8), applications of either a traditional or an adaptive approach are still fairly scarce. So far, existing conjoint applications focus on highly specific topics and do not investigate preferences of peasant farmers in terms of different FHH activities. In respect to a) the country of application or b) the specification of obtained results (gender specification), the surveys conducted by Tano et al., (2003) and Fischer and Buchenrieder (2008) are perceived as relevant for the present study.

Tano et al., (2003) applied a conjoint analysis in southern Burkina Faso to measure preferences for important cattle traits for developing breed-improvement programmes. Highly important traits were disease resistance, fitness for traction and reproductive performance. Beef and milk production performance, however, were considered to be less significant. However, importance and levels of traits seemed to vary among producers depending on the purpose of keeping cattle. Subsistence farmers had the lowest preference for fitness compared to traction and small size and the highest preference for easy temperament. On the other hand, milk and beef producers showed the highest preferences for bulls, which are non-selective grazers, and large-size cows. Mixed crop livestock farmers had the lowest preference for non-selective grazers but the highest preference for reproductive performance, high milk yields and fitness for traction. Reflecting the use of cattle as an energy input in farming, traits related to fitness, traction and disease resistance were consistently higher ranked than traits related to beef and milk off-take. However, often breeding programs are based on improving beef and milk off-take rates (Tano et al., 2003).

An ACA trying to determine gender-specific preferences of rural FHHs for livestock insurance was applied by Fischer and Buchenrieder (2008) in Northern Vietnam. Though there were enormous information and knowledge gaps, generally men and women were interested in livestock insurance. As attributes for an insurance product, they identified the following elements: a) the insured animal, b) the coverage of insurance, c) the terms of payment and d) the contract designed. As can be expected, the ‘insured animal’ was the most important attribute, and for both male and female respondents the ‘buffalo’ was the highest valued animal. Similarly, the attribute ‘coverage’ showed no gender specification; both valued the option ‘death after disease’ as most important. Both genders also argued that an individual contract was preferable to a group contract. Among the remaining attributes, ‘terms of payment’ inspired contrary preferences. While male participants supported a yearly payment option, women preferred a monthly payment. Except for the ‘insured animal’, they further discovered differences in preferences according to different wealth groups (Fischer and Buchenrieder, 2008).

4.7.2 Empirically identifying objectives of peasant farmer households

Unlike the common fields of application, the TCA in this study aims to identify preferences of peasant farmers in terms of different FHH activities. Consequently, neither a specific product nor a specific insurance or breeding program is subjected to evaluation. In fact, peasant farmers are asked to evaluate different possible ‘future life situations’, which differ by the level of important FHH activities carried out. For reasons mentioned in more detail in previous chapters, it is sufficient for this study to apply a ‘traditional’ individual conjoint analysis, by using a profile method in combination with a ranking approach.

4.7.2.1 Identifying factors and factor levels

According to Fischer and Buchenrieder (2008: 4), those factors that are most frequently regarded as relevant can be identified by expert and group interviews as follows. In this study, a CSFS was carried out within the research area prior to the TCA (Chapter 4.1.1).

As one of the findings, the following factors (important FHH activities) were identified as being relevant for the decision-making process of peasant farmers:

- Animal production activities
- Crop production activities
- Other activities using natural resources
- Off-farm labour activities
- Family, cultural and social activities.

Accordingly, levels of all identified factors were determined by interviews with inhabitants and key informants. The results are presented in Table 4.39.

Table 4.39: Identified factors and factor levels

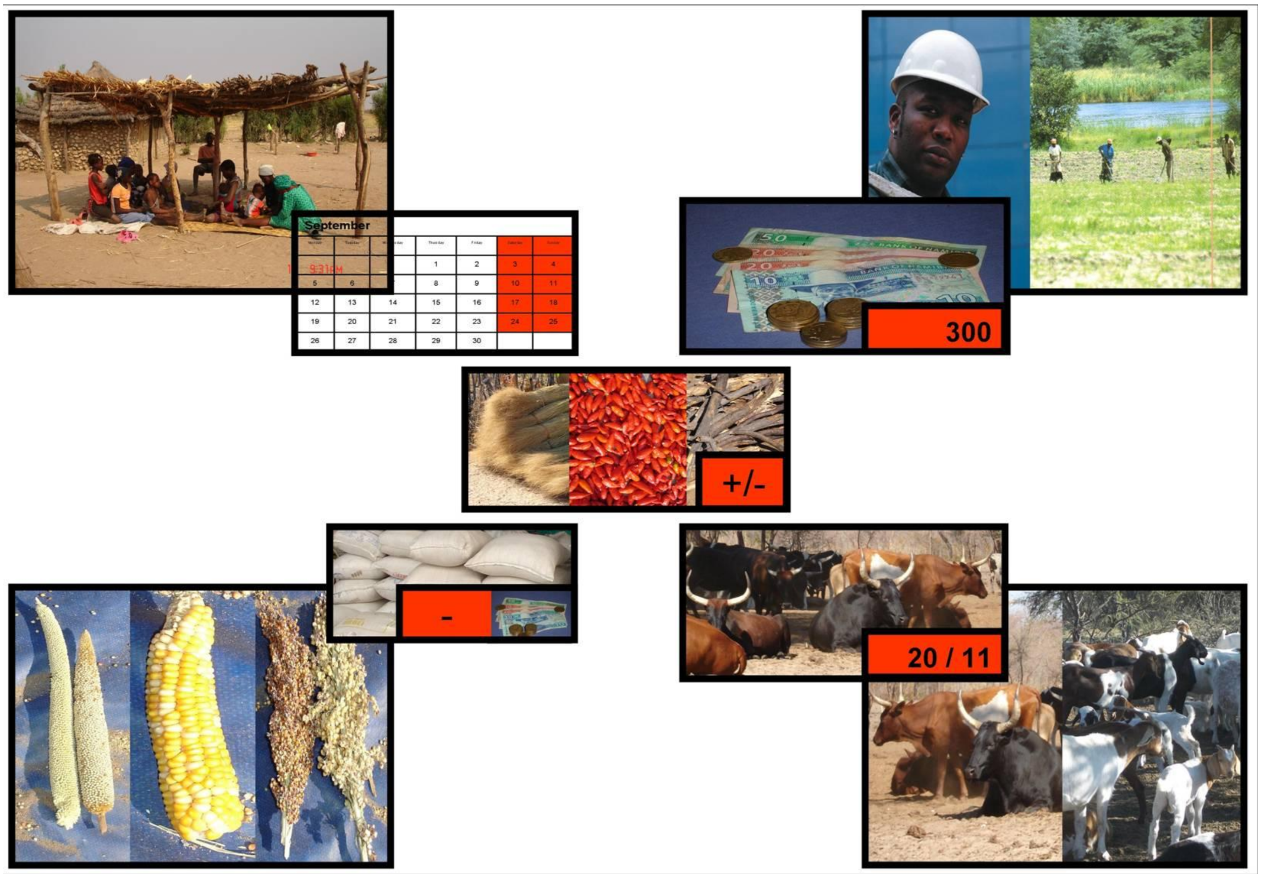
Factor	Level 1	Level 2	Level 3	Level 4
Animal production activities (APA)	0 cattle 0 goats	10 cattle 6 goats	20 cattle 11 goats	30 cattle 17 goats
Crop production activities (CPA)	insufficient	sufficient	surplus	
Other activities using natural resources (OAUNR)	sufficient	surplus		
Off-farm labour activities (OLA)	0 N$	100 N$	300 N$	600 N$
Family, cultural and social obligations (FCSO)	4 days/ month	8 days/ month	12 days/ month	

Source: Own design based on the CSFS (2005).

4.7.2.2 Developing a census design

Using the corresponding software package in SPSS, an orthogonal design was produced with 20 profile cards (including four holdout cards). Bearing possible obstacles during empirical data collection in mind, this study has paid much attention to an adequate research design. Therefore, as additional features, information sheets were designed which explained the factor components, factor symbols and corresponding levels used on the profile cards.

As an example, the information sheet for crop production activities includes factor components with different given levels of achievement for millet, maize, sorghum and other crops such as legumes and vegetables. These components are represented on the profile cards by the picture in the centre, which is the factor symbol (Figure 4.5). The three distinguished factor levels of crop production activities are a) insufficient (a FHH decision maker has to buy crops or crop products to satisfy needs of his family), b) sufficient (a FHH decision maker can satisfy subsistence needs) and c) surplus (a FHH decision maker produces a surplus over subsistence needs and the family can sell some crops or crop products). Animal production activities encompass cattle and goat rearing. The levels range from zero cattle and goats to 30 cattle and 17 goats. The ratio between cattle and goat numbers was obtained by the pre-conducted CSFS. As already indicated in previous chapters, off-farm labour activities include wage labour and casual work. All labour activities are valued in cash income. The different levels used in this study range from 0 to 600 N$ per month. Factor components of 'other activities using natural resources' can bring about the levels 'sufficient' and 'surplus'. They include a) grasses such as reeds or thatching grass, b) wood, including wood for construction and carvings as well as firewood, and c) wild tree and field fruits. Finally, family, cultural and social activities comprise every activity which is somehow related to leisure, like spending time a) in town, b) in adjacent villages or communities, c) within the FHH, or d) on social and cultural obligations. Three levels ranging from four days per month up to twelve days per month can be chosen. Figure 4.5 illustrates one of the 20 profile cards used in the present study's TCA.



Source: Own design.

Figure 4.5: One of 20 profile cards used in the traditional conjoint analysis

This card reflects one possible future life situation. It depicts the following: a) top left corner: eight days of family, cultural and social activities, b) top right corner: 300 N$ per month obtained from off-farm labour activities, c) bottom left corner: insufficient outcome of crop production activities, d) bottom right corner: 20 cattle and 11 goats obtained from animal production activities and e) centre: sufficient outcome of other activities using natural resources. As can be seen in Figure 4.5 all factors and levels on profile cards and information sheets are represented by photos taken from the nearest surroundings of respondents. In the underlying intercultural research context, a pictorial representation helps to overcome obstacles of misunderstandings and leads to a harmonised perception.

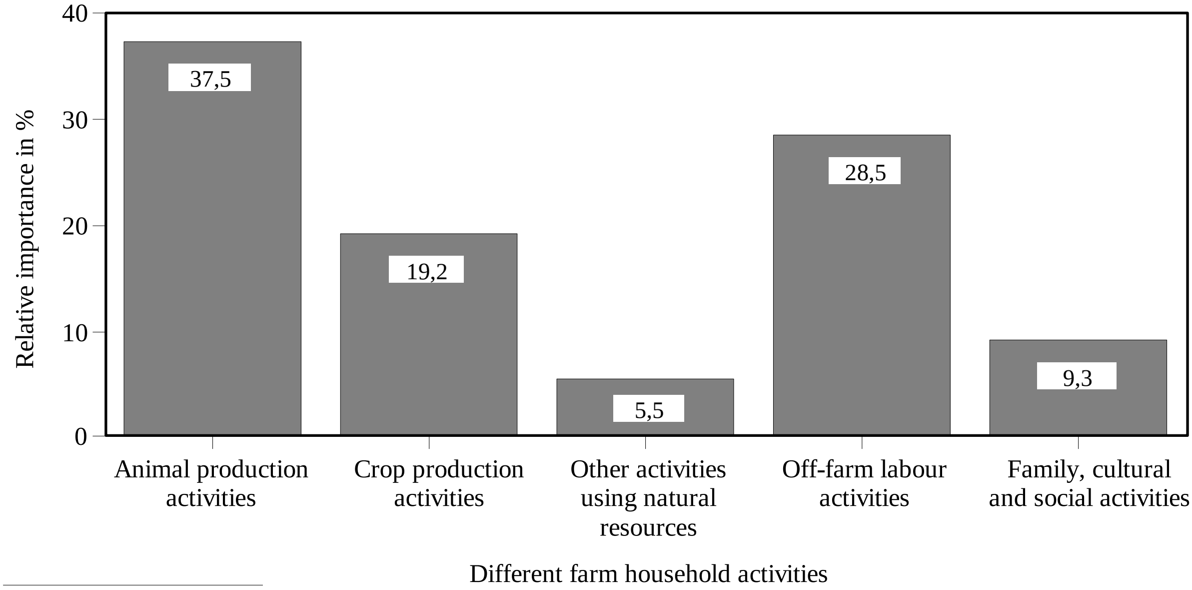
4.7.2.3 Evaluating stimuli

To assure equal sequences and qualities of interviews, a local facilitator was trained to conduct the interviews. He needed some additional assistance from the research team in terms of transportation. With his assistance, a manuscript which explained the information sheets, profile cards and the whole procedure was translated into the local language, Rukwangali. In order to avoid translation gaps caused by words or even 'concepts' which did not exist in the local language, the Rukwangali manuscript was translated back to English by a second translator. This iterative translation process was repeated several times.

In the interviews, respondents were asked to a) consider each profile card as one possible future life situation and b) take all factors into account. To overcome shyness and insufficient self-confidence, respondents were advised that there are no correct or incorrect sequences. This holds as long as the rankings and decisions represent their individual preferences. Since it can be difficult to rank all cards immediately, respondents were guided to take a rough choice, while classifying all 20 cards in one of the following three categories: a) prefer, b) reject or c) neither prefer nor reject. These categories were represented by different photographs which serve as pads for respondents' profile card piles. Respondents were then instructed to comprehensively rank cards from all three categories. This process was supported by a magnetic board which enabled respondents to overview all cards of one category at once. After pre-testing, empirical interviews for the TCA took place in 2005 and were accomplished for a random sample of 66 FHHs in three villages as described in Chapter 4.1.1.

4.7.2.4 Objectives of peasant farm households

Results of the TCA are presented in Figure 4.6. It depicts aggregated relative importance of different FHH activities of peasant farmers in the research area. These results quantitatively prove a high preference for animal husbandry (37.5 %), followed by off-farm labour (28.5 %) and crop production (19.2 %). Cattle have a social function as symbolic capital and are therefore given high importance scores. The fact that some interviewed FHHs owned few or no cattle can be interpreted as an indicator of poverty and ineffective livestock management. While off-farm labour is the second important activity, it is pursued by at most 50 % of FHHs (in terms of casual labour). This might be due to failing or rather imperfect labour markets.

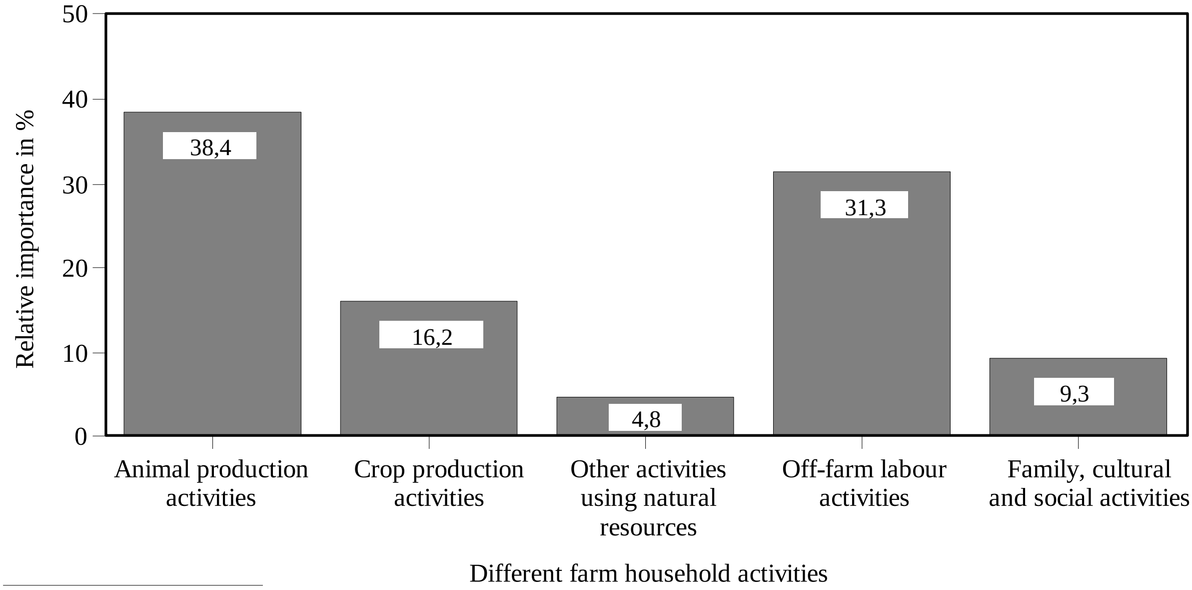


Source: Own design based on TCA (n=66).

Figure 4.6: Relative importance (%) of farm household activities

It is remarkable that the importance of 'other activities using natural resources' is very low (5.5 %). In the research area, illegally cutting trees is fairly common (Yaron et al., 1992; Pröpper, Gruber, 2007). The products of one tree can be sold at an average market price of 75 to 600 N$ (Pröpper, Gruber, 2007). Contrarily, cattle sell at a higher average market price of 710 to 1030 N$ (Deniau et al., 1997: 119). This example indicates that merchantable fractions of local trees are not perceived as a scarce resource, at least for the majority of inhabitants. At this point, a low observed market value matches with a discovered low importance level. However, this is only an indication and the question remains whether prices have an impact on preferences. A Kendal's Tau of T=0.950 specifies that the internal validation of the estimated results is adequate.

As stated by Fischer and Buchenrieder (2008: 2), an analysis of obtained conjoint data with 'average importance' of attributes and 'average utilities' has the power to show only one part of the whole picture. Including specific characteristics of the FHHs and differentiating results among such variables makes results even more valuable. Bearing this in mind, it is notable that a breakdown of respondents in livestock owners and non livestock owners shows only slight differences of about 1 % for animal production and off-farm labour activities. All other factors are attached with a similar importance level by both groups. In contrast, distinguishing between male and female respondents demonstrated that women (22.8 %) seem to assign crop production activities higher utility levels than men (16.2 %) (see Figures 4.7 and 4.8).

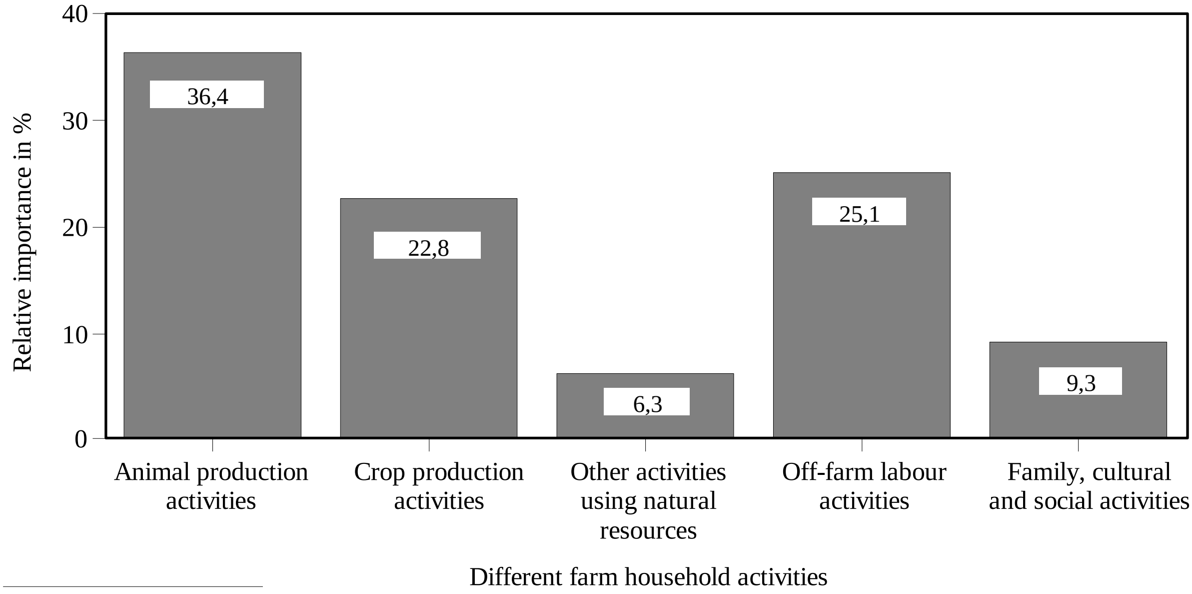


Source: Own design based on TCA (n=36).

Figure 4.7: Relative importance (%) of farm household activities for men

This might be an indicator that women are more anxious to assure adequate nutrition for the family. According to FAO (1992), women are the main providers of meals and nutritional information in the FHH, and they have a fundamental role in assuring nutritional status for everyone. On the other hand, women (25.1 %) assess off-farm labour activities as less desirable than men do (31.3 %). Within the research area, wage labour is generally more respected than casual work. However, men have better chances of participating in wage labour activities than women. As already shown for the aggregated results, the attribute ‘other activities using natural resources’ is the least attractive FHH activity. However, there are slight gender-specific differences (4.8 % men, 6.3 % women). Contrarily, the factor ‘family, cultural and social activities’ does not show any gender-specific differences.

With regard to the utility function used in MAPOM, results of the TCA provide the arguments (different FHH activities) and the weights (relative importance of different FHH activities) for this function. A mathematical determination of the utility function is outlined in Chapter 5.7.

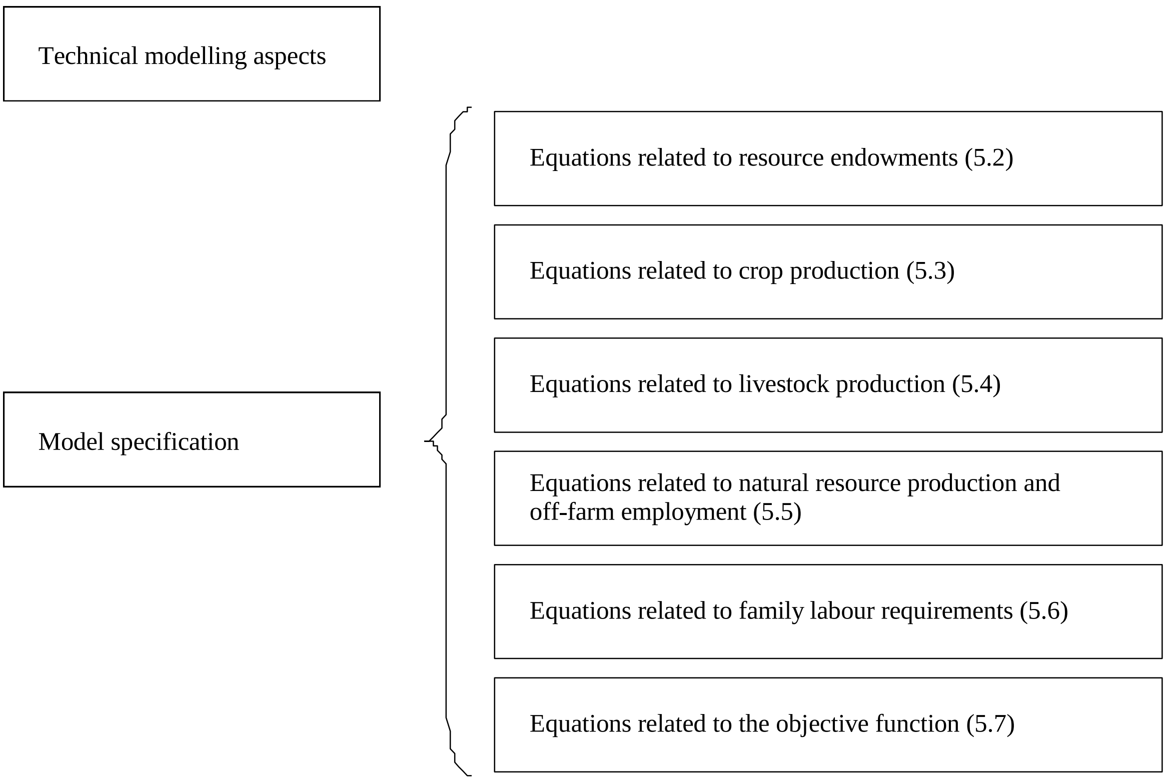


Source: Own design based on TCA (n=30).

Figure 4.8: Relative importance (%) of farm household activities for women

5 Mathematical Model Formulations

In Chapter 3.3, this study presented, in a descriptive way, all major elements and components of MAPOM with their theoretical foundations and underlying assumptions. This chapter concretises those descriptions (Figure 5.1). In a brief introduction, some technical modelling aspects are discussed. Subsequently, the most important equations are outlined which are related to a) resource endowments, b) crop production, c) livestock production, d) natural resource production and off-farm labour, e) family labour requirements and d) the objective function. Outlines of each farm production sector (5.3, 5.4 and 5.5) comprise a quantitative description of production and consumption relationships. Family labour serves as a major input factor for all considered FHH activities. This results in a considerable number of equations. Therefore, all equations which are related to family labour requirements are considered separately in Chapter 5.6.

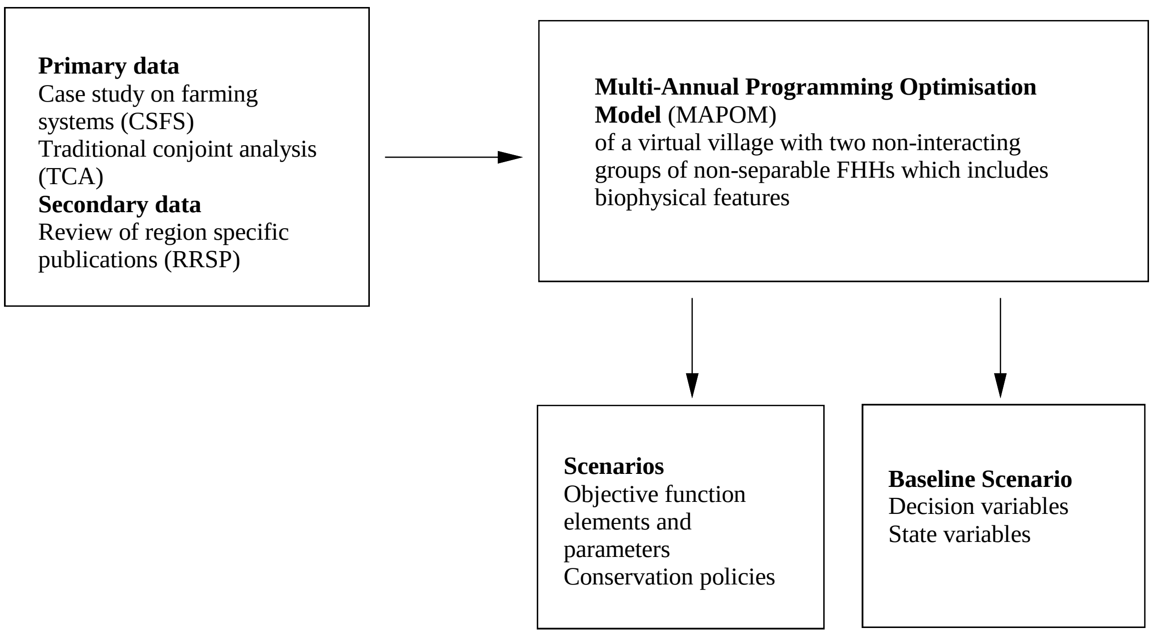


Source: Own design.

Figure 5.1: Organisation of Chapter 5

5.1 Technical modelling aspects and rules

The modelling process of the present study can be technically described by Figure 5.2. Primary and secondary data were used to identify farming activities and their parameters (input-output coefficients). These coefficients served as data input for MAPOM, which maximises utility conditional to several restrictions. The model framework is constructed as a system of equations stating the relationships between decision variables, state variables and parameters. Decision variables are those for which MAPOM determines the optimal level. Parameters are exogenous factors, while state variables are determined by the values of already defined decision variables and parameters. During the baseline run, MAPOM determines the levels of decision and state variables. Finally, different scenarios are simulated. They show changes in FHHs' behaviour induced by a) changes in policy conditions and b) modification in the objective function.



Source: Own design.

Figure 5.2: Modelling process

MAPOM refers to a 'virtual village' which consists of two non-interacting groups of non-separable FHHs. Female-headed farm households (FHFHH) and male-headed farm households (MHFHH) compete for land but manage some land portions commonly. They are not assumed to exchange inputs or products with each other but with communities which are located outside village boundaries. Moreover, MAPOM considers income. Income itself depends on farm outputs produced by each FHH category. These outputs in turn depend on several allocation decisions such as a) the allocation of leisure and labour,

b) the allocation of land and c) the allocation of variable inputs. Additionally, cash income can be derived from off-farm labour activities. A safety first condition is incorporated as well, which encourages FHHs to obtain a minimal nutrition level. Moreover, FHHs are induced to manage production, consumption and distribution activities simultaneously. These activities have to be tailored to prevailing bio-physical conditions.

GAMS is used as a tool for the modelling exercise. This software allows introducing parameters organised in input-output combinations from Excel spreadsheets. Results can also be transferred back to Excel. Discussing equations of the entire model would make this chapter far too long. Hence, focal points in the following chapters are the most relevant equations. In this code, several variables are further differentiated into sub-variables to account for complex interaction of the various components. Contrarily, equations which are presented in the following chapters consist of highly aggregated variables to improve reader-friendliness. Hence, variable names of the following chapters do not necessarily coincide with variable names in the GAMS code. Nevertheless, all equations presented either in this chapter or in the GAMS code follow three simple rules:

1. Parameters or coefficients are written in upper case. If their levels are subjected to changes, they are equipped with a respective index.
2. Variables (state and decision) are written in lower case. If decision variables are discussed, this is carefully mentioned. If their calculations are subjected to changes, they are equipped with a respective index.
3. Indices or sets are written in lower case.

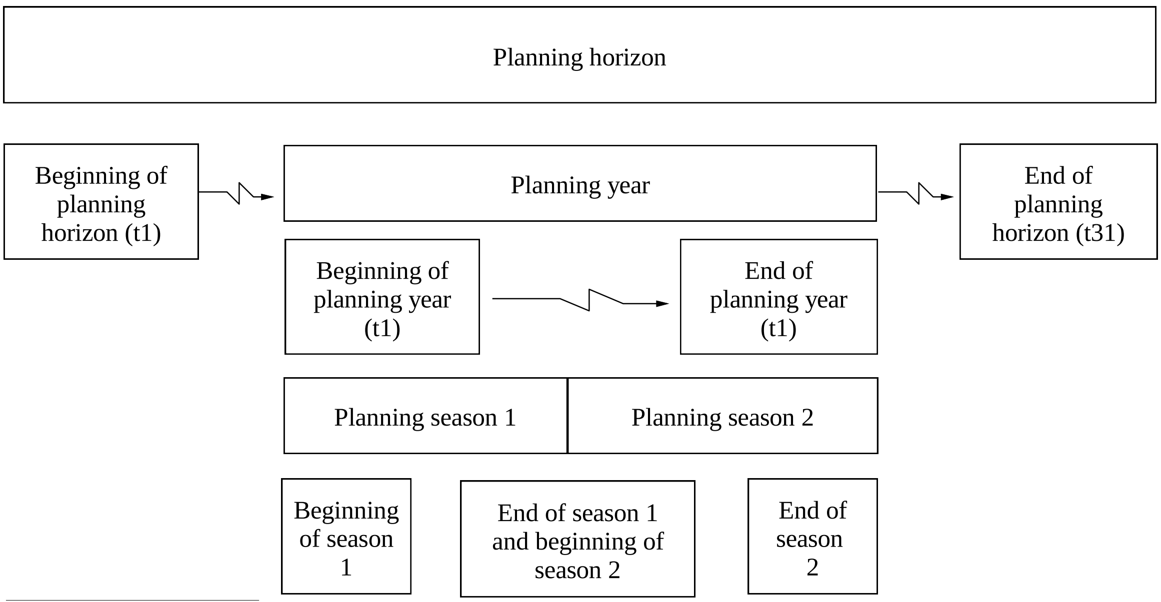
Table 5.1 illustrates all relevant a) indices, b) index descriptions, c) index symbols, d) index elements and e) index element descriptions. Referring to the dynamic character of the model, the most important index is ‘t’, which represents different time periods (years). The entire time period considered in MAPOM is 30 years. Other important indices are a) ‘h’, which refers to the two different FHH categories, b) ‘s’, which refers to different soil quality classes, and c) ‘g’, which refers to the two considered gender categories within each FHH. Since different production sectors and production activities are considered in MAPOM, an index ‘a’ is used as well. This can be further differentiated into the elements a) ‘ac’, describing activities related to the crop production sector, b) ‘al’, describing activities related to the livestock production sector, c) ‘an’, describing activities related to the natural resource production sector, and d) ‘ao’, describing activities related to off-farm labour employment.

As indicated by Figure 5.3, in addition to the entire planning horizon, MAPOM considers each planning year. Further, MAPOM differentiates within one planning year between two different seasons, namely season 1 and season 2. Seasonality predominantly affects labour supplies and requirements. It is therefore exclusively considered in this context.

Table 5.1: Relevant indices

Index description	Index symbol	Index elements	Index element description
Time periods	t	2005, 2006, …, 2034	t_1 = first time period (2005) t_{30} = last time period (2034)
FHH categories	h	f, m	f = FHFHH m = MHFHH
Soil quality classes	s	a, b	a = soil quality class 'a' b = soil quality class 'b'
Gender categories	g	fem, mal	fem = female FHH members mal = male FHH members
Activity categories	a	ac, al, an, ao	ac = crop production activities al = livestock production activities an = natural resource production activities ao = off-farm labour activities

Source: Own design.



Source: Own design.

Figure 5.3: Planning horizon and planning year

5.2 Resource endowments and assets

In general, all different production activities are competing for the resource land. As described in Chapter 4.2.1, land is split into two soil quality classes, namely ‘a’ and ‘b’, with different production potentials and different levels of endowment. Generally, potential land endowments of each soil quality class summed over both FHH categories have to be smaller than or equal to the land endowments on the village scale (Equation 5.1).

$$\sum_h landareapot_{s,h,t} \leq LAN_s \qquad \textbf{(5.1)}$$

$landareapot_{s,h,t}$: potential land area on s of h in t

LAN_s : land endowment of s

For land assigned to crop production, the activity field clearing has to be considered first. Note that field clearing is a decision variable. By applying field clearing, areas assigned to natural resource production are reduced and attached to crop production by using family labour. Hence, the area under cultivation is not fixed and can be expanded if necessary. Once an area of natural resource land has been cleared for cropping, it cannot be transferred to grazing or natural resource areas anymore. This is based on the assumption that crop areas require considerable time periods to recover. Such specifications would encourage both FHH categories in MAPOM to assign always the whole area which has been cleared to crop production. Therefore, the concept of potential crop, grazing and natural resource areas is formulated. This concept gives both FHHs the possibility of assigning a smaller part of land to crop production than has been already cleared in previous years. At the same time, it hinders them from assigning the difference between the area cleared and the area assigned to crop production to the remaining farming sectors. Hence, potential crop areas are based on a function of the level of field clearing in a year (t) plus the potential crop area of previous years (t-1) (Equation 5.2).

$$croareapot_{s,h,t} = levfiecle_{s,h,t} + croareapot_{s,h,t-1} \qquad \textbf{(5.2)}$$

$croareapot_{s,h,t}$: potential crop area on s of h in t

$levfiecle_{s,h,t}$: level of field clearing on s of h in t

In other words, a potential crop area is the whole area which a) has been cleared, b) cannot be assigned to other production sectors and c) does not necessarily need to be under cultivation every year. On the other hand, the actual crop area under use is determined by the decision variable ‘level of production’ (Equation 5.3). In the coefficient matrix, the parameter ‘CA’ has a negative value to declare a ‘need’ and is therefore multiplied by -1.

'CA' simply proclaims that for each crop production activity, one ha of crop land is required and is therefore independent of a) time, b) FHH category and c) crop production activity.

$$croareause_{s,h,t} = \sum_{ac} CA \times crolevpro_{ac,s,h,t} \times (-1) \quad \textbf{(5.3)}$$

$croareause_{s,h,t}$	: crop area under use on s of h in t
$crolevpro_{ac,s,h,t}$	: level of production of ac on s of h in t
CA	: crop area requirement

Potential crop areas can be put under fallow and hence are not used for producing crops. An area which is put under fallow in a previous period (t-1) has positive impacts on possible crop outputs in the current period (t). Crop areas under fallow are determined by the decision variable 'level of fallow' (Equation 5.4). As for the parameter 'CA', the parameter 'CAF' has a negative value in the coefficient matrix. It declares a 'need', and a multiplication by -1 is necessary.

$$croareafal_{s,h,t} = CAF \times fallevcro_{s,h,t} \times (-1) \quad \textbf{(5.4)}$$

$croareafal_{s,h,t}$	: crop area under fallow on s of h in t
$fallevcro_{s,h,t}$	: level of fallow on crop areas on s of h in t
CAF	: crop area requirements for fallow

Finally, crop areas which are assigned to crop production and fallow have to be smaller than or equal to the potential crop area (Equation 5.5).

$$croareapot_{s,h,t} \geq croareause_{s,h,t} + croareafal_{s,h,t} \quad \textbf{(5.5)}$$

In a similar sense, specifications are made for areas attached to natural resource production or livestock production (grazing reserves). However, there are two diverging specifications:

1. Areas assigned to one of these production sectors are not routinely tied to this sector, e.g. areas can be exchanged between both sectors in each year.
2. Areas assigned to one of these production sectors are not routinely tied to the respective FHH category, e.g. areas can be exchanged between FHH categories.

In several previous pre-tested model versions, the first point caused a high level of fluctuations among the entire time horizon. Therefore, MAPOM is now additionally induced to keep at least potential areas of both types either constant or allow for an increase only over the time horizon. Areas used as grazing reserves or used for natural resource production are determined by MAPOM and thus are decision variables. As explained for crop production, both area categories can be put under fallow, which has an impact on the production potential of a following period. Finally, potential areas (assigned to crop production, livestock production and natural resource production for each FHH category and soil quality) have to be smaller than or equal to total land endowments (Equation 5.6).

$$lanareapot_{s,h,t} \geq croareapot_{s,h,t} + graareapot_{s,h,t} + resareapot_{s,h,t} \quad \textbf{(5.6)}$$

$graareapot_{s,h,t}$: potential grazing area on s of h in t

$resareapot_{s,h,t}$: potential natural resource area on s of h in t

All on-farm and off-farm activities of each FHH category are competing for the resource labour. In this context, an important factor is the FHH endowment with producers. As mentioned in Chapter 4.2.2.1, within one FHH two different groups of FHH members can be distinguished. FHH members who are older than 15 and younger than 59 are FHH producers and contribute to the family labour pool. Since some work tasks are (by definition) gender-specific, a differentiation in female and male producers is necessary. One important assumption is that the numbers of producers and dependents within FHHs are growing by population growth rates cited for the Kavango region. Numbers of producers of each gender, year and FHH category are calculated by multiplying the number of FHH producers of the previous year (t-1) by the population growth rate (parameter 'PG') (Equation 5.7).

$$fhhpro_{g,h,t} = fhhpro_{g,h,t-1} \times PG \quad \textbf{(5.7)}$$

$fhhpro_{g,h,t}$: farm household producers of g of h in t

PG : population growth rate

Similar calculations are done for FHH dependents. Total numbers of FHH members each year are based on figures of FHH dependents and FHH producers. For the first year of the planning horizon, equal equations are formulated which use 'initial values' of producers and dependents obtained by the CSFS (Chapter 4.2.2.1).

Labour power is assumed to be delivered exclusively by FHH producers. Available man hours are calculated by multiplying the number of FHH producers by considered working days (parameter '*WD*') and working hours (parameter '*WH*') (Equation 5.8).

$$labava_{g,h,t} = fhhpro_{g,h,t} \times WD \times WH \quad \textbf{(5.8)}$$

$labava_{g,h,t}$: labour hours available of g and h in t

WD : working days per year

WH	: working hours per day

To acknowledge the fact that some tasks are season-specific, total available labour hours are further split and equally allocated to season 1 and season 2 (Equation 5.9).

$$labavasea1_{g,h,t} = labava_{g'fem',h,t} \times 0.5 \tag{5.9}$$

$labavasea1_{g,h,t}$	: labour hour available in season 1 of g of h in t

As an addition to FHH producers, both FHH categories are in the position to hire extra labour from other villages. The level of hiring labour is a decision variable. It is constrained by an upper bound to reflect labour shortages within the research area. While hiring additional labour, expenditures occur by multiplying hired labour hours by the usual wage rate.

Finally, all production activities can generate cash income, which helps to acquire non-farm products and services. Income in terms of cash can be obtained by selling cattle, crops and natural resources products and by participating in off-farm employment. A detailed specification of capital flows (cash income and expenditures) for each production sector is outlined in respective chapters. Another cash income source is interest. To calculate interest, cash income per FHH category and year has to be balanced by respective expenditures. Subsequently, the cash income balance of a previous period is multiplied by the average interest rate. Finally, total cash income of a FHH in each year is a function of income obtained from a) sales of livestock, crop and natural resource products, b) salaries from off-farm employment and c) returns on savings (Equation 5.10).

$$inc_{h,t} = \sum_{al} incliv_{al,h,t} + \sum_{ac} inccro_{ac,h,t} + \sum_{an} incnat_{an,h,t} + \sum_{g}\sum_{ao} incoff_{ao,g,h,t} + inccap_{h,t} \tag{5.10}$$

$inc_{h,t}$	: total cash income of h in t
$incliv_{al,h,t}$	: cash income of livestock production activities al of h in t
$inccro_{ac,h,t}$	: cash income of crop production activities ac of h in t
$incnat_{an,h,t}$	: cash income of natural resource production activities an of h in t
$incoff_{ao,g,h,t}$	: cash income of off-farm labour activities ao of g and h in t
$inccap_{h,t}$	: cash income of capital of h in t

Similar calculations are applied for expenditures. As indicated in Chapter 4.2.3, expenditures for important services like fees for water or education, medical bills and transport are considered as a lump sum. To acknowledge the dynamic character of MAPOM, these expenditures depend on the number of FHH members and thus increase with FHH size.

Total expenditures are a sum of different expenditure posts like a) purchasing livestock, b) renting DAP, c) purchasing crop products and inputs, d) hiring labour and e) paying for important services. Purchases of natural resource products are not considered because of their rare occurrence. Based on an assumed absence of credit markets, cash income in any considered period and of each FHH category has to be at least balanced with expenditures (Equation 5.11).

$$inc_{h,t} \geq exd_{h,t} \qquad \textbf{(5.11)}$$

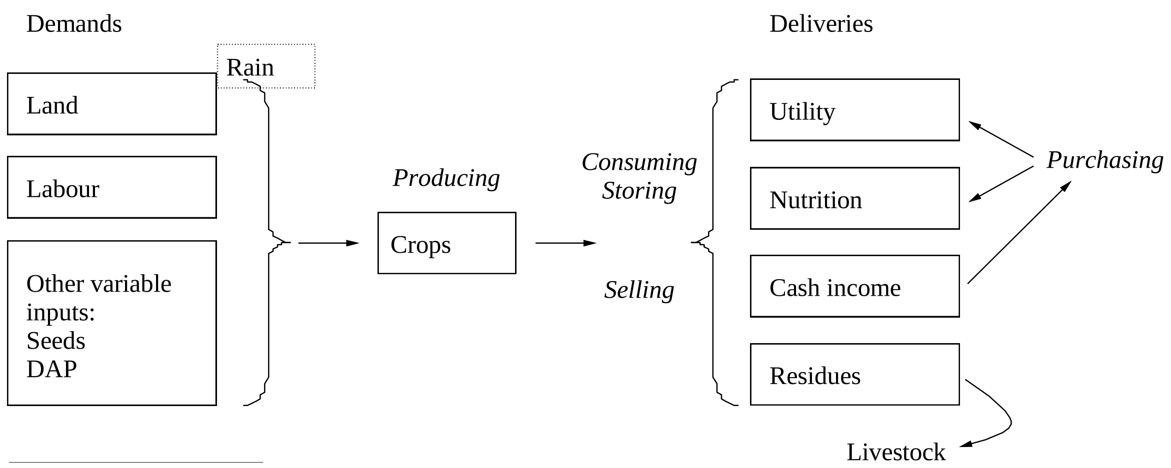
$inc_{h,t}$: cash income of h in t

$exd_{h,t}$: cash expenditures of h in t

A 'system constraint' is introduced in order to reflect the behaviour of FHHs in the research area. This constraint limits the extent of cash income over expenditures.

5.3 Crop production

By consuming crops or crop products as food, the FHH can satisfy nutrition demands, and obtain utility. Contrarily, selling crops delivers cash income. Cash income can be used to buy food which is not produced domestically. As for domestic food, the consumption of purchased food delivers utility and satisfies the nutrition constraint. Decision variables in the crop production module are the amounts of crops produced, consumed, sold, stored and purchased (Figure 5.4). In terms of residues, the crop production process delivers fodder for the livestock production sector.



Source: Own design.

Figure 5.4: Demands, deliveries and decision variables of crop production processes

Compared to all other farm activities, crop production is rather demanding. One of the most significant input factors is family labour, which can be supplemented by hiring labour in peak seasons. While land is the second most important input factor, capital-intensive resources can be neglected. Seeds and DAP are the predominant variable inputs used. However, a large number of FHHs retain seeds from previous harvests and obtain DAP from their livestock production system.

5.3.1 Production patterns

Crop production is predominantly a function of the parameters rainfall and yield coupled with the decision variable 'level of production' (Equation 5.12). As outlined in Chapter 4.3.1, yield levels depend on considered production activities with different production techniques and soil qualities. In order to determine the amount of residues which serve as an input for the livestock production module, gross yields need to be considered. Time dependency is incorporated by the parameter 'RF' (rainfall). This is based on the fact that yield data, usually measured in kg per ha, were converted into kg per ha and mm. Thus, the amount of rainfall in year t determines crop output in year t. The 'level of production' is a decision variable. It needs to be determined by MAPOM according to the production activity, soil quality class, FHH category and time.

$$cropro_{ac,s,h,t} = RF_t \times YD_{ac,s} \times crolevpro_{ac,s,h,t} \times (1.1 - crofalcoef_{s,h,t-1}) \qquad \textbf{(5.12)}$$

$cropro_{ac,s,h,t}$	: quantity of crops produced of ac on s of h in t
RF_t	: rainfall amount in t
$YD_{ac,s}$	: yield level of ac on s
$crolevpro_{ac,s,h,t}$	: level of crop production of ac on s of h in t
$crofalcoef_{s,h,t-1}$	: fallow coefficient of cropping areas on s of h in t-1

To acknowledge the reduction of production potentials caused by a continual usage of the same crop area, a fallow coefficient is considered. Generally, the higher the fallow coefficient of a previous year (t - 1), the lower the potential crop output of the current year (t). Rainfall is the most prominent exogenous factor in MAPOM. It follows a normal distribution and is simulated based on empirical data. In equation 5.13, μ is the expected value and s the standard deviation.

$$RF_t = normal(\mu, s) \qquad \textbf{(5.13)}$$

RF_t	: rainfall in t
μ	: expected value of rainfall
s	: standard deviation

Fallow coefficients for crop production areas, grazing areas and natural resource areas are calculated separately. For crop production, this coefficient is a quotient of potential crop areas, reduced by crop areas under fallow, and potential crop areas (Equation 5.14).

$$crofalcoef_{s,h,t} = (croareapot_{s,h,t} - fallevcro_{s,h,t}) / croareapot_{s,h,t} \qquad \textbf{(5.14)}$$

Unused areas, or fallows, no matter which area category is addressed, are decision variables. If MAPOM determines that the entire potential crop area is used in one year, the fallow coefficient equals 1. Crop yields in the following year are then extremely reduced. Equal equations are applied for grazing areas and natural resource areas.

Labour is the major input factor in crop production and discussed separately in the labour module. Seeds and DAP serve as the second and third input in the crop production process. Their parameter levels are equal for both FHH categories. Generally, quantities of seeds and DAP needed for a production activity are determined by the seed and DAP input per ha as well as by the decision variable 'level of production'. DAP and seeds can either be provided by FHHs' own assets or purchased (rented) at a specific market price. DAP serves as a labour-saving technology for crop production tasks like ploughing and weeding. Quantities of DAP which are available in a FHH are determined by the number of oxen which is multiplied by a specific amount of ploughing days or weeding days per year. These quantities are further multiplied by potential work hours of oxen per day (Chapter 4.4.1.2).

5.3.2 Utilisation patterns and nutrition deliveries

In order to determine specific constraints and input functions, the quantity of millet which can be used by a FHH needs to be calculated. This is done by a) aggregating the amount of millet produced by each crop activity on each soil quality class, b) aggregating the produced amount of millet by each crop activity among the two main cultivation modes ('pure cropping' and 'mixed cropping') and c) adding the quantity stored for nutrition from previous periods excluding storage losses. The strong differentiation between the two main cultivation modes 'pure cropping' and 'mixed cropping' is rooted in the fact that a higher nutrition delivery is assumed for 'mixed cropping' (Chapter 4.3.3). To avoid overloading, the following equations consider only the 'mixed cropping' cultivation mode. However, within MAPOM, specifications are done for both.

Generally, the amount of millet which can be used by each FHH in each year is the sum of millet production levels and stored quantities (Equation 5.15). Storages come from a previous period and need to be reduced by storage losses. The parameter 'CSS' determines the amount of stored quantities which can still be consumed in a following period.

Since storing losses of millet are reported to be rather minor (Jones and Cownie, 2001: 32), it is assumed that 80 % of stored millet can still be used in following periods.

$$croprouse_{ac\_mix,h,t} = \sum_{s} cropro_{ac\_mix,s,h,t} + CSS \times croprostonut_{ac\_mix,h,t-1} \qquad \textbf{(5.15)}$$

$croprouse_{ac\_mix,h,t}$: useable quantities of produced crop products of ac_mix of h in t

$croprostonut_{ac\_mix,h,t-1}$: stored quantities for nutrition of crop products of ac_mix of h in t-1

CSS : consumable shares of stored crop products

FHHs are additionally allowed to supplement their own produced products with purchases. Thus, a similar equation as shown in 5.15 is applied to purchases with the variables *cropuruse*, *cropur*, *cropurstonut*.

In the crop production module, MAPOM needs to consider different constraints. For instance, the quantity produced of each crop production activity needs to be at least equal to the quantity of each crop production activity which is stored, consumed or sold (Equation 5.16). As indicated before, the state variable *croprosto* comprises two further categories: a) *croprostonut*, which considers exclusively stored crop products, intended to be used for nutrition, and b) *croprostoseed*, which considers stored seed amounts for following production periods.

$$croprouse_{ac\_mix,h,t} \geq croprosto_{ac\_mix,h,t} + croprocon_{ac\_mix,h,t} + croprosel_{ac\_mix,h,t} \qquad \textbf{(5.16)}$$

$croprosto_{ac\_mix,h,t}$: stored quantities of produced crop products of ac_mix of h in t

$croprocon_{ac\_mix,h,t}$: consumed quantities of produced crop products of ac_mix of h in t

$croprosel_{ac\_mix,h,t}$: sold quantities of produced crop products of ac_mix of h in t

An equal constraint applies for purchases of crop products with the variables *cropuruse*, *cropursto* (*cropurstonut*, *cropurstoseed*), and *cropurcon*. Note that purchased products cannot be re-sold.

Income is calculated by multiplying the quantity of crop products sold by an average selling price (Equation 5.17).

$$inccro_{h,t} = \sum_{s}\sum_{ac} croprosel_{ac,s,h,t} \times SPC \qquad \textbf{(5.17)}$$

SPC : selling prices of crop products

On the other hand, quantities of crop products purchased by a FHH are multiplied by a purchasing price. Additionally expenses occur if seeds are bought (Equation 5.18).

$$exdcro_{h,t} = cropurnut_{h,t} \times PPC + cropurseed_{h,t} \times PPS \qquad \textbf{(5.18)}$$

$exdcro_{h,t}$: expenditure induced by purchases of crop products of h in t

$cropurnut_{h,t}$: quantities of purchases used for nutrition of h in t

$cropurseed_{h,t}$: quantities of purchases used as seeds of h in t

PPC : purchasing prices of crop products

PPS : purchasing prices of seeds

To account for safety first paradigms, a nutrition constraint is formulated which describes the minimal kilocalorie (kcal) intake of each FHH member. Minimal kcal intakes are calculated by multiplying the number of FHH members by their recommended minimal kcal intakes (Equation 5.19). The parameter 'KI' was previously factored by the number of days per year. Levels of the parameter 'KI' were calculated in Chapter 4.3.3.

$$\min kcal_{h,t} = \sum_{g} ffhhmem_{g,h,t} \times KI \qquad \textbf{(5.19)}$$

$minkcal_{h,t}$: minimal kilocalorie intake of h in t

$fhhmem_{g,h,t}$: farm household members of g of h in t

KI : kilocalorie intakes

This minimal calorie intake can be served by calorie deliveries of crop and livestock products and hence by their consumption. Kilocalorie deliveries of crop production activities are a function of millet quantities consumed by a FHH multiplied by average kcal deliveries of millet products (Equation 5.20). For 'mixed cropping' cultivation modes, this amount is increased by a specific share to acknowledge the fact that in addition to millet, the remaining inter-cultivated crops can be consumed. Note that this is not possible for the 'pure cropping' mode.

$$crokcaldel_{ac\_mix,h,t} = crocon_{ac\_mix,h,t} \times KDC \times SKI \qquad \textbf{(5.20)}$$

$crokcaldel_{ac\_mix,h,t}$: kilocalorie delivery of crop products of ac_mix of h in t

$crocon_{ac\_mix.h,t}$: quantity consumed of crop products of ac_mix of h in t

KDC : kilocalorie deliveries of crop products

SKI : share of kilocalorie delivery increase

Total kcal delivery is the sum of livestock-induced kcal deliveries and crop-induced kcal deliveries of both cultivation modes (Equation 5.21).

$$kcaldel_{h,t} = \sum_{al} livkcaldel_{al,h,t} + \sum_{ac\_mix} crokcaldel_{ac\_mix,h,t} + \sum_{ac\_pure} crokcaldel_{ac\_pure,h,t} \quad \textbf{(5.21)}$$

$kcaldel_{h,t}$: kilocalorie delivery of h in t

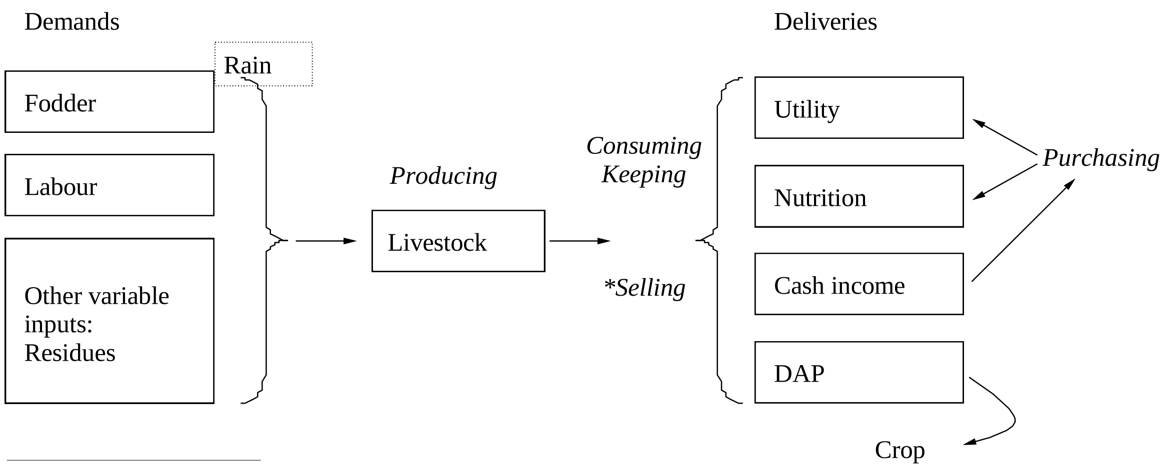
$livkcaldel_{al,h,t}$: kilocalorie delivery of livestock products of al of h in t

$crokcaldel_{ac\_mix,h,t}$: kilocalorie delivery of crop products of ac_mix of h in t

$crokcaldel_{ac\_pure,h,t}$: kilocalorie delivery of crop products of ac_pure of h in t

5.4 Livestock production

As mentioned before, livestock keeping is a major objective in peasant farmers' decision making. Nevertheless, the livestock production system in the research area is prestige-oriented rather than market-oriented. In order to strengthen this fact, deliveries to the utility function are assumed to be twofold: first, if cattle are consumed, and second, if cattle are kept (neither consumed nor sold). As with crop products, cattle can be bought by spending cash and enter the utility function either as a consumed market product or as a kept market product. If livestock products are consumed, they help to satisfy food security. Decision variables in the livestock production module are the amounts of cattle produced, consumed, sold, kept and bought (Figure 5.5).



Source: Own design.

Figure 5.5: Demands, deliveries and decision variables of livestock production processes

The livestock production process also delivers DAP, which can be used in various crop production processes. One of the most significant input factors is family labour, which can be supported by hiring labour in peak seasons. Fodder is another important input factor which is indirectly linked to the availability of land. Land assigned as grazing area is a decision variable in this process. On grazing areas, biomass is produced which serves as forage in the livestock production module. Residues obtained from the crop production processes support forage demands of cattle. Within MAPOM, cattle are further differentiated into different age and sex groups; the asterisk * in Figure 5.5 marks that not all considered sex and age groups can be sold.

5.4.1 Production patterns

MAPOM considers two cattle production activities, one with traditional management and one with improved management. In general, all calculations are completed for both cattle production activities. However, to avoid overloading, the following outlines and equations exclusively consider traditional livestock management. To represent differences in biomass demands and nutrition deliveries, different age and sex classes of cattle are distinguished. Hence, livestock production functions are separated into four different groups on the two soil quality classes. Produced cows are calculated as 50 % of the number of calves kept (stored, not consumed or sold) three years ago (Equation 5.22). The remaining 50 % are assigned to the bull population.

$$livpro_{al\_tra'cow',s,h,t} = 0.5 \times livsto_{al\_tra'cal',s,h,t-3} \tag{5.22}$$

$livpro_{al\_tra'cow',s,h,t}$: quantity of livestock produced of al_tra'cows' on s of h in t

$livsto_{al\_tra'cal',s,h,t-3}$: quantity of livestock kept (stored) of al_tra'cal' on s of h in t-3

MAPOM is restricted to calf producing and keeping – consumption and sales are not possible. This is because calves which were kept in t-3 could have been consumed or sold in t-2 and thus cannot enter the cow or bull population in t. For the bull population, Equation 5.22 is additionally reduced by the number of oxen, which deliver DAP for crop production processes.

Produced calves (in the current year t) are the product of a) the weaning rate and b) the number of cows kept at the beginning of the previous year (Equation 5.23). The weaning rate (parameter 'WR') is independent of soil quality, FHH category and time but is different for the traditional and improved livestock production systems (Chapter 4.4.1.2).

$$livpro_{al\_tra'cal',s,h,t} = WR_{al\_tra} \times popsta_{al\_tra'cow',s,h,t-1} \tag{5.23}$$

$livpro_{al\_tra'cal',s,h,t}$: quantity of livestock produced of al_tra'cal' on s of h in t

$popsta_{al\_tra'cow',s,h,t-1}$: starting population of al_tra'cow' on s of h at the beginning of t-1

WR_{al_tra} : weaning rate of al_tra

In order to describe herd dynamics in a time-discrete model, two variables have to be specified for each cattle category. The two variables define the pool of animals in the beginning of a year, here 'popsta', and at the end of a year, here 'popend'. Hence, a particular population at the beginning of a year equals the population at the end of the previous year (Equation 5.24).

$$popsta_{al\_tra,s,h,t} = popend_{al\_tra,s,h,t-1} \tag{5.24}$$

$popsta_{al\_tra,s,h,t}$: population of livestock of al_tra on s of h at the beginning of year t

$popend_{al\_tra,s,h,t-1}$: population of livestock of al_tra on s of h at the end of year t-1

Likewise, the population at the end of a year equals the population at the beginning of a year plus inflows due to domestic production and purchases reduced by outflows due to sales and consumption (Equation 5.25).

$$popend_{al\_tra,s,h,t} = popsta_{al\_tra,s,h,t} + livpro_{al\_tra,s,h,t} + livpur_{al\_tra,s,h,t} - livsel_{al\_tra,s,h,t} - livcon_{al\_tra,s,h,t} \tag{5.25}$$

$popend_{al\_tra,s,h,t}$: population of livestock of al_tra on s of h at the end of year t

$popsta_{al\_tra,s,h,t}$: population of livestock of al_tra on s of h at the beginning of year t

$livpro_{al\_tra,s,h,t}$: quantity of livestock produced of al_tra on s of h in t

$livpur_{al\_tra,s,h,t}$: quantity of livestock purchased of al_tra on s of h in t

$livsel_{al\_tra,,s,h,t}$: quantity of livestock sold of al_tra on s of h in t

$livcon_{al\_tra,s,h,t}$: quantity of livestock consumed of al_tra on s of h in t

Note that the variable *livcon* consists of two items a) *livprocon*, livestock consumed from domestic production, and b) *livpurcon*, livestock consumed from purchases. Moreover, the livestock balance of *popend* reflects the state variable *livkep*, which also consists of a) *livprokep* and b) *livpurkep*. For calves, the population at the end of a year is additionally reduced by the number of calves kept three years ago. They enter the cow or bull population by the variable *livsto* (see Equation 5.22).

5.4.2 Forage supplies and demands

One major fodder source for livestock is native biomass which is grown on grazing areas. Generally, this biomass production is a function of a) rainfall, b) rainfall use efficiencies, c) sizes of grazing areas under use and d) fallow coefficients (Equation 5.26). The rainfall use efficiency is a parameter which depicts a mean amount of above-ground biomass production per mm of rainfall. This parameter depends on the soil quality class but is directly independent of time. Time dependency is incorporated by the parameter 'RF' (rainfall). This is based on the fact that rainfall use efficiencies are usually measured in kg per ha and mm. Thus, the amount of rainfall in year t determines the amount of above-ground biomass which is produced in year t. A fallow coefficient acknowledges the fact that pastures lose production potentials if they are used continuously without resting periods.

$$biopro_{s,h,t} = RF_t \times RUE_s \times graareause_{s,h,t} \times (1 - grafalcoef_{s,h,t-1}) \qquad \textbf{(5.26)}$$

$biopro_{s,h,t}$	: biomass produced on s of h in t
RUE_s	: rainfall use efficiency on s
$grafalcoef_{s,h,t-1}$	: fallow coefficient of grazing area on s of h in t-1
$graareause_{s,h,t}$	: grazing area under use on s of h in t

However, not all biomass produced by Equation 5.26 is palatable for cattle. It needs to be further differentiated into bush, grass, and tree biomass according to observable shares of respective vegetation covers (Chapter 4.4.2.1). A second forage source for livestock is delivered by crop production processes in terms of residues. In this context, amounts of residues produced by each crop production activity and shares of these residues which are palatable for livestock are important factors.

Finally, total dry matter which can be consumed by cattle is a function of a) produced bush, grass, and crop biomass and b) biomass surpluses still available from previous periods (Equation 5.27). In addition, produced bush, grass, and crop biomass needs to be multiplied by a specific share. This share determines the recommended amount of these elements in the diet of cattle. Only 30 % of left-over biomass from a previous year can be consumed by livestock in the current year.

$$\begin{aligned} drymat_{s,h,t} = {} & (bioprogras_{s,h,t} + \sum_{ac} bioprocro_{ac,s,h,t}) \times SGD + bioprobush_{s,h,t} \times SBD \\ & + bioprosur_{s,h,t-1} \times SCBS \end{aligned} \qquad \textbf{(5.27)}$$

$drymat_{s,h,t}$	: dry matter produced on s of h in t
$bioprobush_{s,h,t}$	: bush biomass produced on s of h in t

$biopro gras_{s,h,t}$	: grass biomass produced on s of h in t
$bioprocro_{ac,s,h,t}$	: crop biomass produced (residues) of ac on s of h in t
$bioprosur_{s,h,t}$	: biomass surplus on s of h in t
SGD	: shares of grass biomass in the livestock diet
SBD	: shares of bush biomass in the livestock diet
SCBS	: shares of consumable biomass surpluses

Biomass production surpluses occur if the quantities produced (in a year) exceed the quantities consumed. This difference feeds into the biomass production function of the following year.

Total forage requirements of the different cattle categories are based on a) population size, b) bodyweight and c) dry matter intake rates per kg body weight and year (Equation 5.28). In this context, the start population of a year is used to determine biomass requirements. Body weight (parameter ‘BW’) is dependent on cattle age and sex groups, and the parameter ‘SDMIBW’ is different for the two considered livestock production systems (traditional and improved).

$$biore_{al\_tra,s,h,t} = popsta_{al\_tra,s,h,t} \times BW_{al} \times SDMIBW_{al\_tra} \qquad \textbf{(5.28)}$$

$biore_{al\_tra,s,h,t}$	: biomass required by livestock of al_tra on s of h in t
BW_{al}	: bodyweight of al
$SDMIBW_{al\_tra}$	: share of dry matter intake per bodyweight of al_tra

Obviously total dry matter has to equal or exceed biomass requirements of livestock in any considered period.

5.4.3 Utilisation patterns and nutrition deliveries

As for crop production, the most important logical constraint is a trivial one. It states that the number of cattle which is produced needs to be at least equal to the number of cattle which is consumed, kept or sold (Equation 5.29).

$$livpro_{al\_tra,s,h,t} \geq livprosel_{al\_tra,s,h,t} + livprokep_{al\_tra,s,h,t} + livprocon_{al\_tra,s,h,t} \qquad \textbf{(5.29)}$$

$livprokep_{al\_tra,s,h,t}$	: quantity of produced livestock kept of al_tra on s of h in t

Similar assumptions hold true for purchases of livestock with the variables *livpurkep* and *livpurcon*. Note that purchased livestock cannot be re-sold. Consumption and keeping of produced or purchase cattle can be aggregated in the variables *livkep* and *livcon*. Generally, numbers of cattle sold are multiplied by selling prices and deliver cash income, whereas numbers of cattle purchased are multiplied by purchasing prices and cause expenses. Notably, oxen can be produced, purchased, sold and rented but are not consumed.

For some calculations, the unit 'head' needs to be converted into the unit 'kg'. This is done by multiplying the numbers of cattle by the average weight of the specific cattle category. Hence, income generated by cattle production is calculated by multiplying the number of cattle sold by a) the average body weight of the corresponding cattle category and b) the selling price (Equation 5.30).

$$incliv_{al,h,t} = \sum_{al} livprosel_{al,s,h,t} \times BW_{al} \times SPL \qquad \textbf{(5.30)}$$

SPL	: selling price of livestock

Expenditures caused within the livestock production module are the product of a) number of livestock purchased, b) average bodyweights and c) purchasing prices. Moreover, expenditures are caused by renting oxen to obtain additional DAP.

A consumption of livestock products delivers kilocalories. This delivery is calculated on the basis of a) the consumption quantity, b) the body weight, c) the proportion of the carcass weight, and d) the average kcal delivery of a specific cattle product (Equation 5.31).

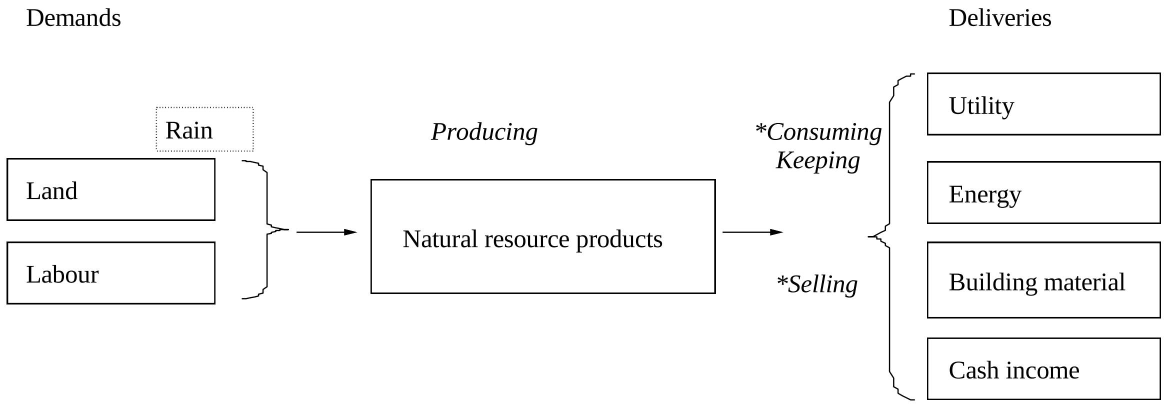
$$livkcaldel_{al,h,t} = \sum_{s} livcon_{al,s,h,t} \times BW_{al} \times SCWBW \times KDL \qquad \textbf{(5.31)}$$

$livkcaldel_{al,h,t}$	: kilocalorie delivery of livestock products of al of h in t
$SCWBW$	: share of carcass weights on bodyweights
KDL	: kilocalorie delivery of livestock products

To acknowledge the fact that livestock products are rarely consumed by FHHs, an additional 'system constraint' limits kcal delivery of livestock products. It says that only 30 % of total kcal requirements can be satisfied by livestock products.

5.5 Natural resource production and off-farm employment

Generation of natural resource products demands rather few inputs. Only land and labour, for harvests, are required. Commonly, utility, energy, building material or cash income is delivered, depending on the character of the natural resource product. Firewood satisfies energy demands and contributes to utility as a z-good. Thatching grass, on the other hand, contributes to a) utility, by providing building material, and b) cash income generation, by being sold to traders. Tree logging generates only cash income. This cash income can be used to a) buy other important products which deliver utility or b) pay for services which are necessary to shape lives of FHHs. Decision variables in the natural resource module are amounts of natural resources produced, stored, and partly sold (Figure 5.6).



Source: Own design.

Figure 5.6: Demands, deliveries and decision variables of natural resource production processes

Based on their different commercial characters, not all natural resource products can be consumed or sold. This is marked by the asterisk * in Figure 5.6. Notably, purchasing natural resource products is not possible.

5.5.1 Production patterns

Similarly to biomass production on grazing areas, natural resource production is a function of a) rainfall, b) rainfall use efficiencies (RUE) and c) sizes of natural resource areas which are under use. In this context, natural resource areas under use are decision variables and can differ with the soil quality class, FHH type and time. A fallow coefficient is considered to acknowledge a reduction of production potentials caused by a continuous usage of an equal portion of land. The more the fallow coefficient of a previous year equals 1, the lower is the production of natural resources of a current year.

$$natpro_{s,h,t} = RF_t \times RUE_s \times resareause_{s,h,t} \times (1 - resfalcoef_{s,h,t-1}) \qquad \textbf{(5.32)}$$

$natpro_{s,h,t}$: natural resources produced on s of h in t

$resareause_{s,h,t}$: natural resource area under use on s of h in t

$resfalcoef_{s,h,t-1}$: fallow coefficient of natural resource areas on s of h in t-1

As indicated for biomass production on grazing areas, natural resource biomass cannot be used per se. It needs to be further differentiated into bush, grass, and tree biomass according to their observable shares of respective vegetation covers.

Generally, three main products of natural resource production are used by a FHH. These are firewood, thatching grass and timber. Firewood can be delivered by bush and tree biomass (Equation 5.33). Thatching grass (timber) can only be obtained from grass biomass (tree biomass) (Equations 5.34, 5.35). Since not all grasses are suitable for thatching and not all trees are timber trees, biomass according to vegetation types needed to be multiplied by different utilisation shares.

$$fwoodpro_{s,h,t} = bushpro_{s,h,t} \times SFB + treepro_{s,h,t} \times SFT \tag{5.33}$$

$$tgraspro_{s,h,t} = graspro_{s,h,t} \times STG \tag{5.34}$$

$$timbpro_{s,h,t} = treepro_{s,h,t} \times STT \tag{5.35}$$

$bushpro_{s,h,t}$	: bush biomass produced on s of h in t
$graspro_{s,h,t}$	: grass biomass produced on s of h in t
$treepro_{s,h,t}$	: tree biomass produced on s of h in t
$fwoodpro_{s,h,t}$	: firewood produced on s of h in t
$tgraspro_{s,h,t}$	: thatching grass produced on s of h in t
$timbpro_{s,h,t}$	: timber trees produced on s of h in t
SFB	: share of firewood in bush biomass
SFT	: share of firewood in tree biomass
STG	: share of thatching grass in grass biomass
STT	: share of timber trees in tree biomass

Total quantities of firewood, thatching grass and timber are a calculated sum of produced amounts for the current year on both soil quality classes plus surpluses from the previous year. Surpluses are subjected to losses and only a share of 30 % can be used in following periods.

5.5.2 Utilisation patterns

Apart from land and labour, natural resource production does not demand any further inputs. Thus, harvesting labour is the only variable input, and it is further discussed in the labour module.

A minimal level of firewood and thatching grass needs to be obtained by each FHH in MAPOM. This is because FHHs depend on firewood as an important energy source and thatching grass as an important building material. In order to have a flexible restriction which takes population growth into account, a minimal consumption quantity per FHH producer is included. In Equations 5.36 and 5.37, these lower bounds are represented by the two parameters ‘MINCFW’ and ‘MINCTG’. Both parameters are independent of the FHH category and time period. MAPOM assumes that timber is only marketed, so a lower timber boundary does not exist.

$$fwoodcon_{h,t} = MINCFW \times fampro_{h,t} \tag{5.36}$$

$$tgrascon_{h,t} = MINCTG \times fampro_{h,t} \tag{5.37}$$

$fwoodcon_{h,t}$	: quantity of firewood consumed of h in t
$tgrascon_{h,t}$	: quantity of thatching grass consumed of h in t
$MINCFW$	: minimal consumption level of firewood
$MINCTG$	: minimal consumption level of thatching grass

Usually, FHHs do not sell firewood, but they do sell thatching grass and timber. Levels of both selling activities are decision variables in MAPOM. Though thatching grass and timber are sold, it is assumed that FHHs do not buy any natural resource products. As for the previous modules, the most important logical constraint says that the quantity of natural resources produced has to exceed quantities (partly) consumed and (partly) sold (Equations 5.38 – 5.40).

$$\sum_{s} fwoodpro_{s,h,t} \geq fwoodcon_{h,t} \tag{5.38}$$

$$\sum_{s} tgraspro_{s,h,t} \geq tgrascon_{h,t} + tgrassel_{h,t} \tag{5.39}$$

$$\sum_{s} timbpro_{h,t} \geq timbsel_{h,t} \tag{5.40}$$

$tgrassel_{h,t}$	: quantity of thatching grass sold of h in t
$timbsel_{h,t}$	: quantity of timber sold of h in t

In general quantities sold are further multiplied by selling prices and deliver income (Equation 5.41).

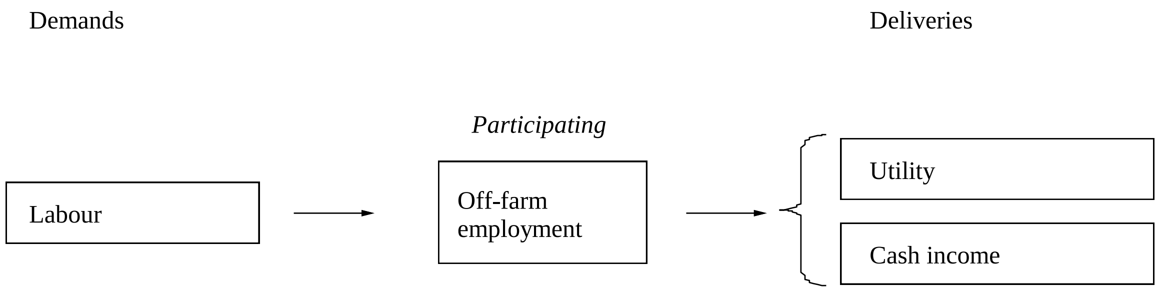
$$incnat_{h,t} = tgrassel_{h,t} \times SPTG + timbsel_{h,t} \times SPTT \tag{5.41}$$

$SPTG$	: selling price of thatching grass
$SPTT$	: selling price of timber

Note that purchases of natural resources products are not considered. They are rather uncommon in the research area. Hence, expenditures on natural resource products are not existent. To acknowledge the fact that sales of illegally cut timber are quite common in the research area, MAPOM is obliged to another system constraint. It states that a minimal amount of timber products needs to be sold each year.

5.5.3 Off-farm employment

In addition to on-farm production activities, FHHs can engage in off-farm labour, namely wage labour or casual work. While participating in either the one or the other, only labour is need. Utility and cash income are delivered (Figure 5.7).



Source: Own design.

Figure 5.7: Demands, deliveries and decision variables of off-farm employment

Labour hours assigned to casual and wage labour are decision variables and thus determined by MAPOM. In this context, Equation 5.42 considers labour requirements for wage and casual labour. Labour inputs (parameter 'LIW') of wage labour are higher than labour inputs for casual work (parameter 'LIC'). This is a plausible assumption, since wage labour requires that FHH members travel longer distances.

$$offre_{h,g,t} = parwag_{h,g,t} \times LIW + parcas_{h,g,t} \times LIC \qquad \textbf{(5.42)}$$

$offre_{h,g,t}$	: labour hours required for off-farm labour of h in t
$parwag_{h,g,t}$	: labour hours participating in wage labour of h in t
$parcas_{h,g,t}$	: labour hours participating in casual labour of h in t
LIW	: labour hour input requirements for wage labour
LIC	: labour hour input requirements for casual labour

Though existing labour markets are assumed, this assumption is now slightly restricted. In Equations 5.43 and 5.44, an upper bound on the labour hours spent in wage and casual labour, respectively, is introduced by the parameters 'MAXPW' and 'MAXPC'.

$$\sum_g parwag_{h,g,t} \leq MAXPW \qquad \textbf{(5.43)}$$

$$\sum_g parcas_{h,g,t} \leq MAXPC \qquad \textbf{(5.44)}$$

MAXPW	: maximum hours of wage labour participation
MAXPC	: maximum hours of casual labour participation

Though wage rates of both off-farm labour activities are assumed to be equal for men and women in MAPOM, the chance of becoming engaged in off-farm labour is gender-specific. Female producers are assumed to face stronger obstacles to participating in wage and casual labour. Hence, an extra constraint is considered exclusively for female producers (Equations 5.45 and 5.46).

$$parwag_{h,g'fem',t} \leq 0.16 \times MAXPW \qquad \textbf{(5.45)}$$

$$parcas_{h,g'fem',t} \leq 0.29 \times MAXCW \qquad \textbf{(5.46)}$$

Income-obtained from an off-farm labour activity is calculated by multiplying the hours allocated to off-farm employment by the corresponding wage rates.

5.6 Labour requirements

In MAPOM, labour is supplied either by FHH members or by external workers, and labour is demanded by the different FHH activities. In general, labour supply and demand have to be balanced. Though some activities can be accomplished by men or women, the major part is gender-specific. Therefore, labour pools need to be differentiated for female and male producers. Similarly to the FHH composition section, this is accomplished by using the index 'g'. To reduce complexity and improve reader friendliness, all equations of labour supply and demand are only described for female producers which are members of either MHFHH or FHFHH. Within MAPOM, these equations are also formulated for male producers. In general, all labour demands and supplies are measured in 'man hours'.

Labour is required for crop production, livestock production, natural resource production and daily maintenance activities. For crop production, the total labour requirement is the product of the labour requirement per production unit and the level of production (Equation 5.47).

$$labrefemcro_{s,h,t} = \sum_{ac} crolevpro_{ac,s,h,t} \times LRFC \qquad \textbf{(5.47)}$$

$labrefemcro_{s,h,t}$	: labour hour requirements of females for crop production on s of h in t
LRFC	: labour hour requirements of females for crop production

The parameter *'LRFC'* is further differentiated into different crop production tasks, such as ploughing, planting, weeding, harvesting, threshing and field clearing. As an example, total labour requirements for field clearing are presented in Equation 5.48. In this equation, the level of field clearing is multiplied by the labour requirement per clearing unit, which is represented by the parameter *'LRFFC'*. Notably, labour requirements related to crop production have to be served completely by the producers of a FHH.

$$labrefemfiecle_{s,h,t} = levfiecle_{s,h,t} \times LRFFC \quad \textbf{(5.48)}$$

$labrefemfiecle_{s,h,t}$	: labour hour requirements of females for field clearing on s of h in t
LRFFC	: labour hour requirements of females for field clearing

For livestock production, total labour requirements are determined by the livestock population in a year multiplied by labour requirements per livestock unit (Equation 5.49). Here, it is assumed that a specific share of the total labour demands can be served by dependents of a FHH (parameter *'SPWLL'*). As indicated before, labour requirements related to livestock production are predominantly herding tasks. By definition, these tasks fall in the domain of male FHH members. Hence, Equation 5.49 delivers zero labour requirements for female producers.

$$labrefemliv_{s,h,t} = \sum_{al} popsta_{al,s,h,t} \times LRFL \times SPWLL \quad \textbf{(5.49)}$$

$labrefemliv_{s,h,t}$	: labour hour requirements of females for livestock production on s of h in t
LRFL	: labour hour requirements of females for livestock production
SPWLL	: share of producers' workloads for livestock production

For natural resource production, the total labour requirements are determined by a) the quantity of firewood and thatching grass which is used domestically, b) the quantity of thatching grass and timber which is sold, c) the labour requirements per harvesting unit and d) the share of total labour requirements which needs to be accomplished by producers (Equation 5.50). As with livestock production, logging of timber trees is a male-specific task. Hence, female labour inputs are not required.

$$\begin{aligned} labrefemnat_{h,t} = {} & (fwoodcon_{h,t} \times LRFF) + (tgrascon_{h,t} + tgrassel_{h,t}) \times LRFT \\ & + (timbsel_{h,t} \times LRFT) \times SPWLN \end{aligned} \quad \textbf{(5.50)}$$

$labrefemnat_{h,t}$	: labour hour requirements of females for natural resource production of h in t

LRFF	: labour hour requirements of females for firewood production
LRFT	: labour hour requirements of females for thatching grass production
SPWLN	: share of producers' workload for natural resource production

In addition, different daily maintenance tasks need to be accomplished. Here, labour requirements are determined per FHH member to acknowledge increasing demands with increasing FHH sizes (Equation 5.51).

$$labrefemdm_{h,t} = fhhmem_{g'fem',h,t} \times LRFDM \times SPWLDM \tag{5.51}$$

$labrefemdm_{h,t}$	: labour hour requirements of females for daily maintenance of h in t
LRFDM	: labour hour requirements of females for daily maintenance per FHH member
SPWLDM	: share of producers' workloads for daily maintenance

To reflect seasonality, all labour requirements have to be allocated among the two considered seasons (Equations 5.52 and 5.53). Season 1 is supposed to be the rainy season. Therefore, the major part of labour demands for crop production has to be satisfied in this season. However, field clearing is usually accomplished shortly before the rainy season and before a new cropping cycle starts. Hence, this task is completely assigned to season 2. Labour demands for livestock production are not season-specific and are therefore split equally between the two seasons. The same applies for natural resource production and daily maintenance tasks. Casual work is predominantly related to crop production. Thus, its labour requirements are mostly (75 %) allocated to season 1. Labour demands of wage labour, on the other hand, are completely assigned to season 2.

$$\begin{aligned} labrefemsea1_{h,t} &= 1 \times \sum_{s} labrefemcro_{s,h,t} + 0 \times \sum_{s} labrefemfiecle_{s,h,t} \\ &+ 0.5 \times \sum labrefemliv_{s,h,t} + 0.5 \times labrefemnat_{h,t} + 0.5 \times labrefemdm_{h,t} \\ &+ 0.75 \times (parcas_{h,g'fem',t} \times LRFC) + 0 \times parwag_{h,g'fem',t} \times LRFW \end{aligned} \tag{5.52}$$

$$labrefemsea2_{h,t} = 0 \times \sum_{s} labrefemcro_{s,h,t} + 1 \times \sum_{s} labrefemfiecle_{s,h,t}$$
$$+ 0.5 \times \sum labrefemliv_{s,h,t} + 0.5 \times labrefemnat_{h,t} + 0.5 \times labrefemdm_{h,t} \quad \textbf{(5.53)}$$
$$+ 0.25 \times (parcas_{h,g'fem',t} \times LRFC) + 1 \times parwag_{h,g'fem',t} \times LRFW$$

$labrefemsea1_{h,t}$: labour hour requirements of females in season 1 of h in t

$labrefemsea2_{h,t}$: labour hour requirements of females in season 2 of h in t

In MAPOM, total labour supplies are influenced by two decision variables. On the one hand, they are reduced by the level of participation in family, social and cultural obligations. On the other hand, they are increased by the level of external labour hired. In the end, labour supplies in one season have to exceed labour requirements in the same season (Equation 5.54). Note that an upper bound on the level of hiring labour is introduced.

$$labavasea1_{g'fem',h,t} - parfcsosea1_{g'fem',h,t} + labhiresea1_{g'fem',h,t} \geq labrefemsea1_{h,t} \quad \textbf{(5.54)}$$

$parfcsosea1_{g'fem',h,t}$: labour hours participating in family, social and cultural obligations in season 1 of g'fem' of h in t

$labhiresea1_{g'fem',h,t}$: labour hours hired in season 1 of g'fem' of h in t

5.7 Objective function

The objective function in MAPOM is derived from a usual Cobb-Douglas function (Equation 5.55). This function represents theory by suggesting a declining marginal propensity to consume and allows estimating utility with the arguments x and y.

$$U(X,Y) = x^{\alpha} \times y^{1-\alpha} \quad \textbf{(5.55)}$$

Under specific circumstances, the non-linearity of a Cobb-Douglas function can cause some disadvantages. Using such a function can impede high costs while additional benefits gained by accuracy are superimposed. Specifically, this can be observed for models with a high level of detail or several non-linear functions and constraints. On the other hand, linear programming is often limited, as non-linear, convex consumption functions can only be represented by linear approximations (Hazell and Norton, 1986). However, from a modelling point of view the assumption of linearity is sometimes more practicable. MAPOM already includes several non-linear functions for the different production sectors. Therefore, this study assumes simply a linear relationship for the elements of the objective function. Consequently, the first derivative of Equation 5.55 is used.

$$U'(X,Y) = \alpha \times x + (1-\alpha) \times y \quad \textbf{(5.56)}$$

In the present study, the arguments of the utility function (x, y) as well as the weights attached to these arguments (α, 1- α) were empirically identified by a traditional conjoint analysis (Chapter 4.7.2.4). The considered arguments of this function are a) consumption of own produced agricultural products (CONPRO), b) consumption of market-purchased goods (CONPUR), c) consumption of z-goods (CONZ), d) participation in family, social and cultural obligations (PARFSO) and e) participation in off-farm employment (PAROFF). By applying optimisation, utility is maximised (Equation 5.57) and the sum of the considered weights 'α1' to 'α5' equals 1.

$$\begin{aligned} & MAXU(CONPRO, CONPUR, CONZ, PAROFF, PARFSO) \\ & = \alpha 1 \times conpro + \alpha 2 \times conpur + \alpha 3 \times conz + \alpha 4 \times paroff + \alpha 5 \times parfso \end{aligned} \quad \textbf{(5.57)}$$

However, some further modifications are necessary for the modelling exercise (Equation 5.58). All considered elements have to be indexed by the time period (t) and the FHH category (h). Since U is the sum over the entire planning horizon and both FHH categories, it is index-less. As a general economic rule, future revenues need to be discounted. Particularly in developing countries where current revenues can decide on survival, discounting is imperative. Hence, the sum over all elements of the utility function has to be multiplied by the quotient $1/\text{'DR'}^{t}$. The parameter 'DR' is the discount rate.

Generally, an updating of resource stocks from period to period is imperative in a model with multi-annual time periods. At the same time, depletions of resources in the final period are often observable in such models. According to Holden (2004: 20) these phenomena cannot be accepted unless they are realistic. For instance, a typical FHH in the research area strives to consume or keep cattle but does not directly strive to earn cash income. This aspect would cause MAPOM to spend the entire cash income in the last period of the planning horizon to buy cattle. In this context, extremely overstocked grazing areas would have no negative effects on future revenues because the modelling period ends. However, to counteract this depletion phenomenon, an element can be included in the objective function which delivers returns to the resource stocks of the last period by assuming that it is sustained forever (Holden, 2004: 20). Hence, the second component of the utility function in MAPOM is the 'FHH activity continuing term'. This term acknowledges the fact that a FHH will continue farming even after the planning horizon. It considers cash income of the last year directly in the objective function, which is multiplied by an 'eternal' interest rate. This eliminates depletion in MAPOM.

$$U = \sum_{t}\left(\sum_{h}(conpro_{t,h} + conpur_{t,h} + conz_{t,h} + paroff_{t,h} + parfsco_{t,h}) \times (1/DR^{t})\right)$$
$$+ \sum_{h}\left(\sum_{t\_last}(incbal_{t\_last,h} \times (1/1 + DR^{t-last}))\right) \quad \textbf{(5.58)}$$

$conpro_{t,h}$	: consumption of own produced products of h in t
$conpur_{t,h}$	: consumption of market-purchased products of h in t
$conz_{t,h}$	: consumption of z-goods of h in t
$paroff_{t,h}$	: participation in off-farm employment of h in t
$parfsco_{t,h}$	: participation in family, social and cultural obligations of h in t
$incbal_{t\_last,h}$	: cash income balance of the last year of the planning horizon of h
DR	: discount rate

The consumption of own produced agricultural goods is a function of quantities consumed valued at considered selling prices and factored by the corresponding sector-specific weights (Equation 5.59). Prices are equal for both FHH categories.

$$conpro_{t,h} = \sum_{ac}(conprocon_{ac,t,h} \times SPC) \times WC_{h} + \sum_{al}(livprocon_{al,t,h} \times BW_{al} \times SCWBW \times SPL)$$
$$\times WL_{h} + (tgrascon_{t,h} \times SPTG) \times WN_{h} \quad \textbf{(5.59)}$$

$croprocon_{ac,h,t}$	: quantity of produced crop products consumed of ac of h in t
$livprocon_{al,s,h,t}$	: quantity of produced livestock products consumed of al on s of h in t
$tgrascon_{h,t}$	: quantity of produced thatching grass consumed of h in t
WC_{h}	: relative weight of importance of crop production activities of h in t
WL_{h}	: relative weight of importance of livestock production activities of h in t
WN_{h}	: relative weight of importance of natural resource production activities of h in t
SPC	: selling prices of crop products
$SPTG$	: selling prices of thatching grass
SPL	: selling prices of livestock or livestock products

BW_{al} : bodyweight of livestock al

$SCWBW$: share of carcass weights on bodyweights

Notably, the weights of importance are not activity-specific but simply production sector-specific and differ between FHFHHs and MHFHHs. As explained in Chapter 4.7.2.1, five different elements which are significant in peasant farmers' decision making were identified. Three of them refer to farm production, namely livestock production, crop production and natural resource production. This simple production sector specification means, for instance, that amounts of consumed millet obtained by 'mixed cropping' and 'pure cropping' cultivation modes are multiplied by the same weight. Similarly, numbers of consumed cattle of different age and sex groups are multiplied by the same weight. However, experimental designs of the empirical identification process (TCA) increase exponentially by adding another element to the preference evaluation process (Chapter 4.7.1.2). Hence, activity-specific weights could not be considered in this study.

A similar mathematical structure is applied to the consumption of market-purchased goods (Equation 5.60). Note that consumption of natural resource products which have been purchased at the market is not relevant for the research area.

$$conpur_{t,h} = \sum_{ac}(cropurcon_{ac,t,h} \times SPC) \times WC_h + \sum_{al}(livpurcon_{al,t,h} \times BW_{al} \times SCWBW \times SPL) \times WL_h \quad \textbf{(5.60)}$$

$livpurcon_{al,h,t}$: quantity of purchased livestock products consumed of al of h in t

$cropurcon_{ac,t,h}$: quantity of purchased crop products consumed of h in t

As empirically proved and similar to other peasant communities, residents of the research area have high aspirations for livestock *keeping*. Since the consumption and sale of livestock or livestock products is quite low, livestock keeping is the FHH's priority. According to Low (1986: 40), characteristics of cattle, like prestige and security, can be defined as z-goods. Such z-goods are considered in Equation 5.61. Another z-good is the consumption of firewood, due to its non-tradable character. Quantities of z-goods which are consumed are valued by corresponding prices and multiplied by weights of the specific production sector.

$$conz_{t,h} = \sum_{al}\sum_{s}(livkep_{al,s,h,t} \times BW_{al} \times SCWBW \times SPL) \times WL_h + (fwoodcon_{h,t} \times SPF) \times WN_h \quad \textbf{(5.61)}$$

$livkep_{al,s,h,t}$: quantity of livestock kept of al on s of h in t

$fwoodcon_{h,t}$	: quantity of firewood consumed of h in t
SPF	: selling price of firewood

In the case of crop and natural resource products, 'storing' (an activity which equals 'keeping' in livestock production) is not considered in the objective function but can indirectly satisfy important constraints. Stored crop products, reduced by storage losses, can be used for future consumption and thus satisfy the nutrition constraint. The amount of natural resource products which is not consumed in one period can be transferred and partly used in a following period. Notably, the 'keeping' of livestock provides additional production potential and utility but, on the other hand, causes additional costs in terms of forage and labour requirements.

Off-farm employment activities include wage labour and casual work. Wage rates are assumed to be equal for both genders, though comparative advantages between genders are obvious (referring to the chance of becoming engaged in off-farm employment). However, MAPOM acknowledges a difference in wage rates for casual and wage labour. The contribution to utility of time spent in off-farm labour activities consists of a) the level of time spent on casual and wage labour activities, b) the wage rates of casual and wage labour and c) the relative weight of importance identified for off-farm employment (Equation 5.62).

$$paroff_{t,h} = (\sum_{g}(parcas_{g,t,h} \times WRC) + \sum_{g}(parwag_{g,t,h} \times WRW)) \times WO_h \qquad \textbf{(5.62)}$$

$paroff_{t,h}$	: labour hours participating in off-farm labour of h in t
$parwag_{h,g,t}$	: labour hours participating in wage labour of g of h in t
$parcas_{h,g't}$	: labour hours participating in casual labour of g of h in t
WO_h	: relative weight of importance of off-farm labour of h
WRC	: wage rate for casual labour
WRW	: wage rate for wage labour

Participation in family, social and cultural obligations can be more simply expressed as a participation in leisure. In most societies, the term 'leisure' or the aspiration of an individual to spend leisure time is often negatively valued and referred to as being lazy. By empirically identifying the elements of the utility function, this negative perception was avoided by using the more complex term of 'family, social and cultural obligations'. To acknowledge the concept of opportunity costs, time spent on family, social and cultural obligations is valued by the average wage rate of casual and wage labour (Equation 5.63).

$$parfsco_{t,h} = \sum_{g} (parfsco_{g,h,t} \times AW) \times WF_h \tag{5.63}$$

$parfsco_{g,h,t}$: labour hours participating in family, social and cultural obligations of g of h in t

AW : average wage rate

WF_h : relative weight of importance of family, social and cultural obligations of h

Opportunity costs can be explained as the foregone amount of cash income which could have been earned by participating in off-farm labour. Hence, the advantage of a FHH in MAPOM in spending time on off-farm employment instead of leisure is that cash income is generated.

6 Scenarios and Discussion

In the following chapters, major results of model runs from MAPOM are outlined. Table 6.1 depicts four different scenarios.

Table 6.1: Scenarios

		Modifications
Scenario 1	Baseline scenario	All parameter levels and equations of Chapters 4 and 5 are included
Scenario 2	A scenario based on changes of objective function elements	Modifications are related to elements of the utility function
Scenario 3	A scenario based on changes in policy conditions for natural resource usage	Modifications are related to policy conditions of natural resource usage
Scenario 4	A scenario based on changes in weighting factors of the objective function	Modifications are related to weights attached to elements of the utility function

Source: Own design

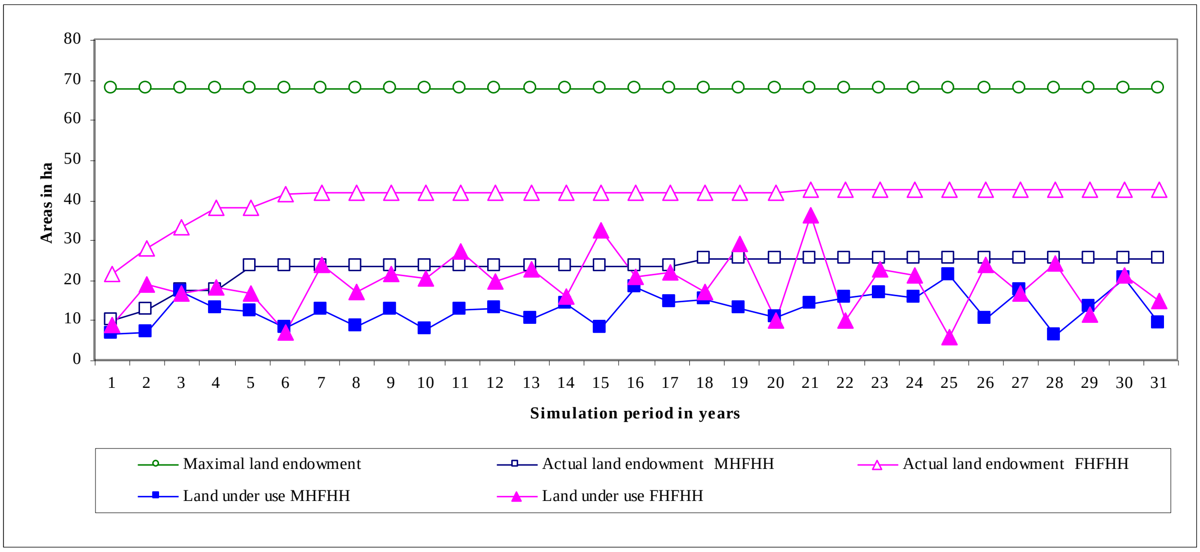
A first scenario delivers results of the baseline (BL), with all parameter levels discussed in Chapter 4 connected with equations described in Chapter 5. Based on these findings, a second scenario (SC2) is related to a modification of one element in the objective function. In a third scenario (SC3), a change in policy conditions with respect to natural resource conservation is presented. Finally, scenario 4 (SC4) addresses the issue of how optimal framing strategies might change if objectives of peasant FHHs are not adequately respected.

6.1 Baseline scenario

In the following chapter, major results of the baseline scenario are described. As can be derived from previous model descriptions, results of MAPOM are manifold. Therefore, this section concentrates on the most significant tendencies and important results.

6.1.1 Resource endowments

Before analysing optimal farming strategies under important system constraints in more detail, Figure 6.1 illustrates land dynamics of the baseline run. It depicts maximum land endowments, actual land endowments and areas under use summed over both soil quality classes for both FHH categories.



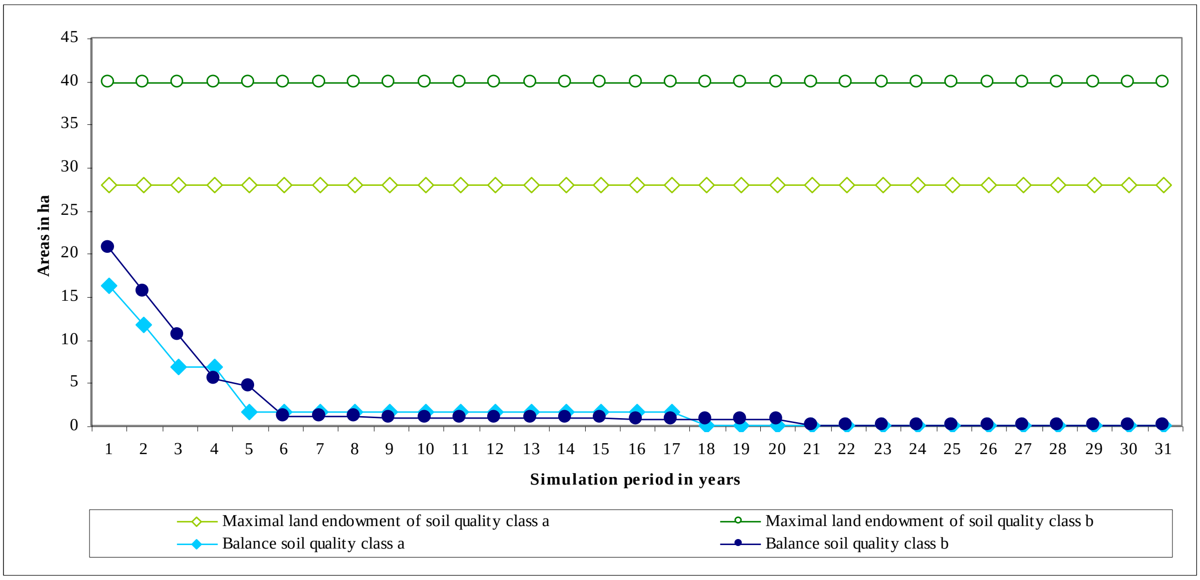
Source: Own design based on MAPOM results.

Figure 6.1: Maximum land endowments, actual land endowments and areas under use

The maximum land endowment, based on a rather conservative estimate of 67 ha for both FHH categories, starts to become scarce after year 5 of the planning horizon. An absolute limit is reached after year 21. Generally, actual land endowments, or land declared as potential areas for crop, livestock and natural resource production, are higher for FHFHHs (40 ha) (23 ha for MHFHHs). Another important aspect is that both FHH categories do not use these potential areas completely. Note that fallows play a major role in the farming system (Chapter 4.3.1.5). Land under use only exceeds 30 ha once (FHFHHs in year 21) and amounts to on average 13 ha for MHFHHs and 19 ha for FHFHHs, e.g. about 50 % of the actual land endowments. This is because for all production sectors, production functions are negatively impacted if FHHs do not apply resting periods in a previous production period (Chapters 5.3.1, 5.4.1, 5.5.1). MHFHHs seem to have a more stable and balanced production pattern. Their areas under use show minor fluctuations over the planning horizon.

Investigated shortcomings of land endowments might be more apparent for the better soil quality class ‘a’. Figure 6.2 shows maximum land endowments and balances between maximum land endowments over actual land endowments, e.g. potential cropping, grazing and natural resource areas, by soil quality class aggregated over both FHH categories. Though declining to 2 ha already after year 5 of the planning horizon, the absolute limit of soil quality class ‘a’ is reached in year 18. For soil quality class ‘b’, a total bound is reached three years later (year 21). Apparent initial declines in both curves are based on the fact that more land than is imposed by initial values needs to be potentially usable for each FHH.

Internally, obliged by mathematical model formulations, potential areas of grazing and natural resource reserves are only allowed to be constant or to increase (Chapter 5.2). Field clearing takes land from natural resource areas; this is especially evident in the first years of the planning horizon when FHHs start to establish more crop fields.



Source: Own design based on MAPOM results.

Figure 6.2: Maximum land endowments, balances of maximum and actual land endowments by soil quality class

Actual land endowment of MHFHHs is similarly allocated to the two considered soil quality classes. It amounts to 13 ha under soil quality class 'a' and 10 ha under soil quality class 'b'. Note that fallow is not included. Slightly more than 50 % of actual land endowments are attached to more nutrient-rich soil types. FHFHHs occupy more land (70 % of actual land endowments) under soil quality class 'b' (27 ha) compared to soil quality class 'a' (13 ha). It is surprising to learn that both FHH categories seem to share equal proportions of land under soil quality class 'a'.

Generally, labour capacities are similar for both FHH categories and comprise on average 83 % family and 17 % hired labour. Notably, MAPOM implies an upper bound on the labour hiring capacity each year (Chapter 4.2.2.2). Both FHH categories take full advantage of hiring external labour and consume it up to its imposed maximum. This is already a first indicator that labour might be a limiting factor and that shortages prevail.

Based on included system constraints and different objectives of both FHH categories, it can be summarised that:

- Both FHH categories face limitations in actual land endowments in terms of both soil quality classes towards the end of the planning horizon. Generally, FHFHHs occupy more land than MHFHHs.
- Both FHH categories do not completely use actual land endowments of the different production sectors in each year, but alternate periods of usage with periods of resting.
- Both FHH categories possess equal amounts of labour, which consists predominantly of family labour, but also take full advantage of hiring external labour.

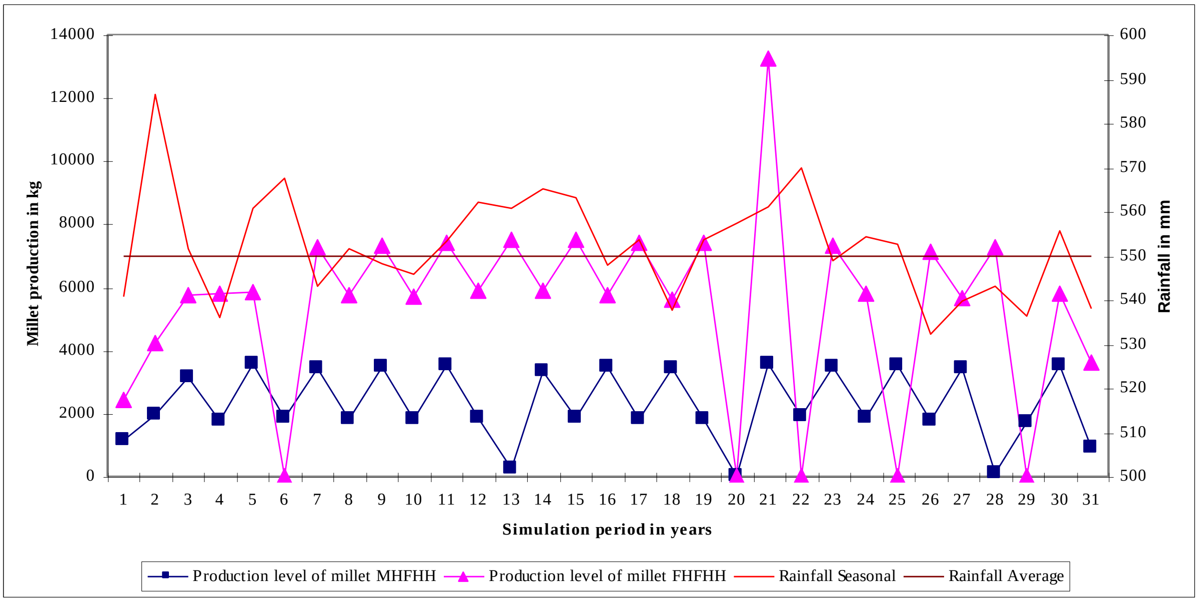
6.1.2 Crop production

Both FHH categories in MAPOM can choose their most preferred cultivation modes from a set of 32 different millet production activities. For these, demands and/or outputs differ according to a) soil quality classes or b) cultivation practices (Chapter 4.3.1).

Over the entire planning horizon of MAPOM, FHFHHs establish and cultivate larger fields with a size of up to 11.6 ha on soil quality class ‘a’ and a size of up to 18.5 ha on soil quality class ‘b’. This indicates that up to 83 % of their total land endowments of soil quality class ‘a’ and up to 68 % of their total land endowments of soil quality class ‘b’ are entirely under use for crop production. Contrarily, MHFHHs cultivate cropping areas of up to 3.7 ha on soil quality class ‘a’ and up to 8.8 ha on soil quality class ‘b’. Their actual land endowments under use by the crop production sector consist of a) up to 29 % of soil quality class ‘a’ and b) up to 85 % of soil quality class ‘b’. Hence, land for crop production consists predominantly of soil quality ‘a’ for FHFHHs and of soil quality class ‘b’ for MHFHHs. However, these are figures with reference to averages over the entire planning horizon. Both FHH groups alternate years of crop production processes with years of resting periods.

A general tendency (obvious for both FHH groups) is that they focus on millet production under the non-mixed cultivation mode. This mode delivers a) higher yield levels per ha but b) lower kilocalorie amounts in terms of nutrition. Hence, assumed higher yield levels of non-mixed cropping activities seem to outweigh additional kilocalorie supplies of mixed cropping activities in importance. Another major affinity of both FHH groups is that within the ‘non-mixed’ cultivation mode, they chose activities with two weeding sessions. Though consuming more labour, two weeding sessions deliver higher yield levels. These yield levels seem to compensate for additional labour requirements. At a first glance, one could suggest that labour might not be a binding constraint. This suggestion is refuted after looking at the four predominantly chosen crop production activities in detail. While all chosen activities use row planting and consequently DAP weeding, two of them even use DAP ploughing. Hence, both FHH categories prefer crop production activities which deliver high yield levels and use a considerable degree of labour-saving technologies.

The sizes of fields under cultivation indicate that production levels of millet are higher for FHFHHs. Figure 6.3 shows production levels of millet on cropping areas summed over both soil quality classes for both FHH categories. Moreover, respective rainfall patterns are depicted.



Source: Own design based on MAPOM results.

Figure 6.3: Millet production level and rainfall

Apart from being considerably higher, production levels of FHFHHs seem to follow the direction of rainfall events in at least 14 years of the planning horizon (years: 2, 5, 10, 11, 16-19, 21, 25, 28-31). This means that if rainfall amounts increase compared to the previous period, production levels increase too and vice versa. A similar pattern but with reference to partly different years can be observed for MHFHHs (years: 1, 2, 4, 5, 10, 11, 13-15, 21, 26, 27, 30, 31). Though yield levels depend on rainfall amounts, production outputs for millet seem to be more influenced by sizes of cropping fields. This becomes even more obvious with calculations outlined in Table 6.2. Yield levels per ha and mm rainfall are referenced to the millet non-mixed cropping cultivation mode with two weeding sessions on soil quality class ‘a’. Rainfall amounts represent averages. Influences of the fallow coefficient which are a third impacting factor on production levels are neglected. As can be seen over all situations, the impacting degree of rainfall on production levels declines with increasing field sizes but constant yield levels and rainfall amounts.

This explains these slightly observable rainfall-following characters of FHHs' production patterns. Hence, yield dependency on rainfall can be less important than sizes of fields allocated to production. In other words, the external factor rain has a smaller impact on production outcomes than actual decisions of FHHs. However, MAPOM does not consider the timing of rainfall events, which might have a more striking impact on production levels.

Table 6.2: Impacting degree of rainfall amounts on production levels

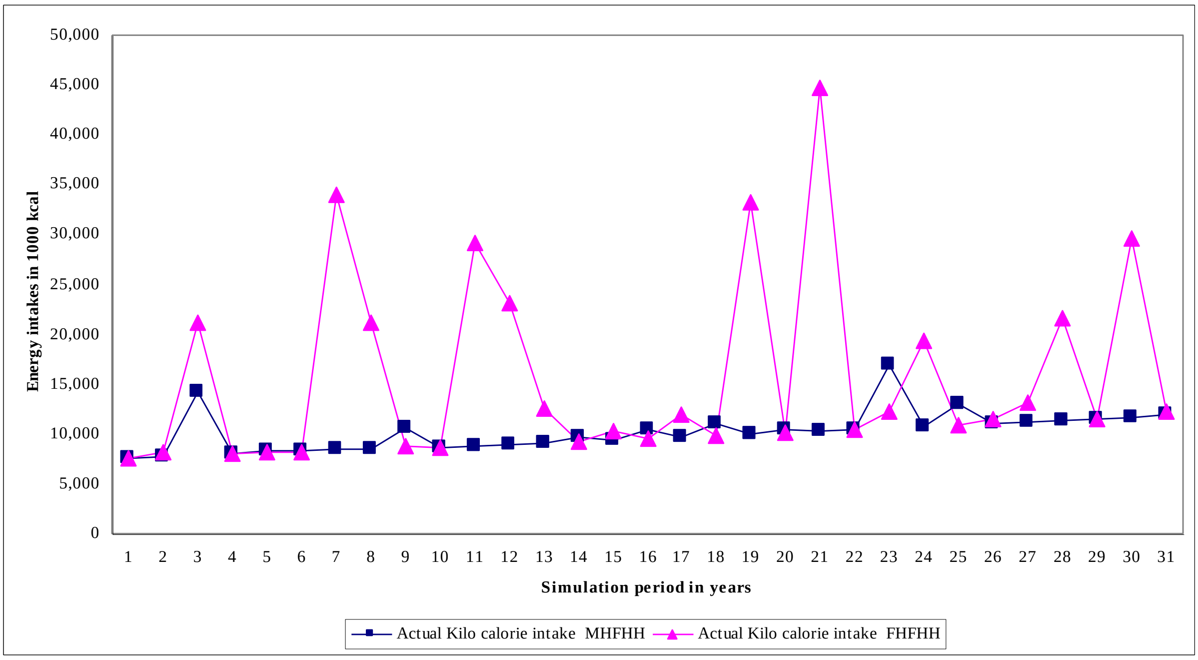
	Rainfall mm	Yield level kg ha^{-1} mm^{-1}	Field size ha	Production level kg	Impaction degree of rainfall
Situation 1	550	0.9	1	495	1.0
Situation 2	550	0.9	2	990	0.5
Situation 3	550	0.9	3	1485	0.4
Situation 4	550	0.9	4	1980	0.3
Situation 5	550	0.9	5	2475	0.2

Source: Own design.

Obvious collapses in production levels for some years in Figure 6.3 can be explained by the fact that both FHH categories can additionally purchase crop products or store crop products from production outcomes of previous periods. This paragraph describes this process for FHFHHs. Production levels of FHFHHs equal zero for the years 6, 20, 22, 25 and 29 of the planning horizon. Apart from year 20, FHFHHs predominantly use stored crop products from corresponding previous years. This matches with apparent peak production levels in years 5, 21, 24, and 28. Peak production levels also match with peak levels of areas under use for FHFHHs. Notably, for FHFHHs the highest amount of areas under use is recognised in year 21. While inspecting purchase movements it becomes apparent that though supplementing domestic production levels continuously, FHFHH purchase volumes are considerable only in year 20. Similar dynamics can be detected for MHFHHs, although they apply more balanced production patterns. Production output is zero for only one year (20) of the planning horizon.

Over the entire planning horizon, both FHH categories do not sell any crop products. Though MAPOM implies a system constraint which regulates annual income balances to a specific bound, income balances are zero in several years. Hence, FHHs could possibly sell some crop products. Obviously, other FHH activities are more promising for cash income generation or levels of minimum consumption requirements are not yet exceeded. Generally, lower production levels, following from smaller field sizes, of MHFHHs can be explained by their lower tendency to consume crop products. This is expressed by a lower weighting factor for crop products in their utility functions (Chapter 4.7.2.4). However, when comparing production levels of FHFHHs and MHFHHs, it becomes questionable if MHFHHs meet the major constraint in MAPOM of a minimum kilocalorie intake level for each FHH member.

In Figure 6.4, minimum kilocalorie intakes summed over all FHH members are illustrated for MHFHHs and FHFHHs over the entire planning horizon. Kilocalories (kcal) are supplied by domestic agricultural production from both the crop and livestock sectors and supplemented by corresponding purchases. However, before being able to satisfy this constraint, produced and purchased products need to be 'actively' consumed (decision variable) by FHHs. As outlined in Chapter 5.4.3, MAPOM includes an additional 'system constraint' on the kcal delivery potential of cattle products. Based on this important constraint, at least 70 % of total kcal requirements have to be satisfied by crop products.



Source: Own design based on MAPOM results.

Figure 6.4: Minimum kilocalorie intakes

Though MHFHHs produce considerably lower amounts of crop products, they meet minimum kilocalorie requirements of all their FHH members over the entire planning horizon. Contrarily, FHFHHs and their members exceed minimum kilocalorie intakes. Since no upper bounds are included, kilocalorie intakes of FHFHHs are sometimes (years 7 and 21) even more than four times higher than minimum kilocalorie requirements. This extreme picture for specific years can be misleading. On average, FHFHHs supply 67 % more kilocalories than the minimum bound demands. As outlined in Chapter 4.3.3, minimum daily dietary energy rates amount to 2,240 kilocalories. Factoring this figure by

1.67, results in an average energy consumption of 3,741 kilocalories per day and person. This considerable improvement in nutrition is not apparent in MHFHHs. Minimum daily dietary energy rates are on average exceeded by only 8 %, resulting in a kilocalorie intake rate of 2,419 per person.

Note that figures presented in Figure 6.4 are minimum kilocalorie intakes. In the present model formulations, this figure is represented by the variable *minkal*. This variable is defined as being greater than or equal to minimum kilocalorie requirements. Contrarily, kilocalorie deliveries are defined as being greater than or equal to *minkal*. Hence, actual kilocalorie deliveries might be even higher.

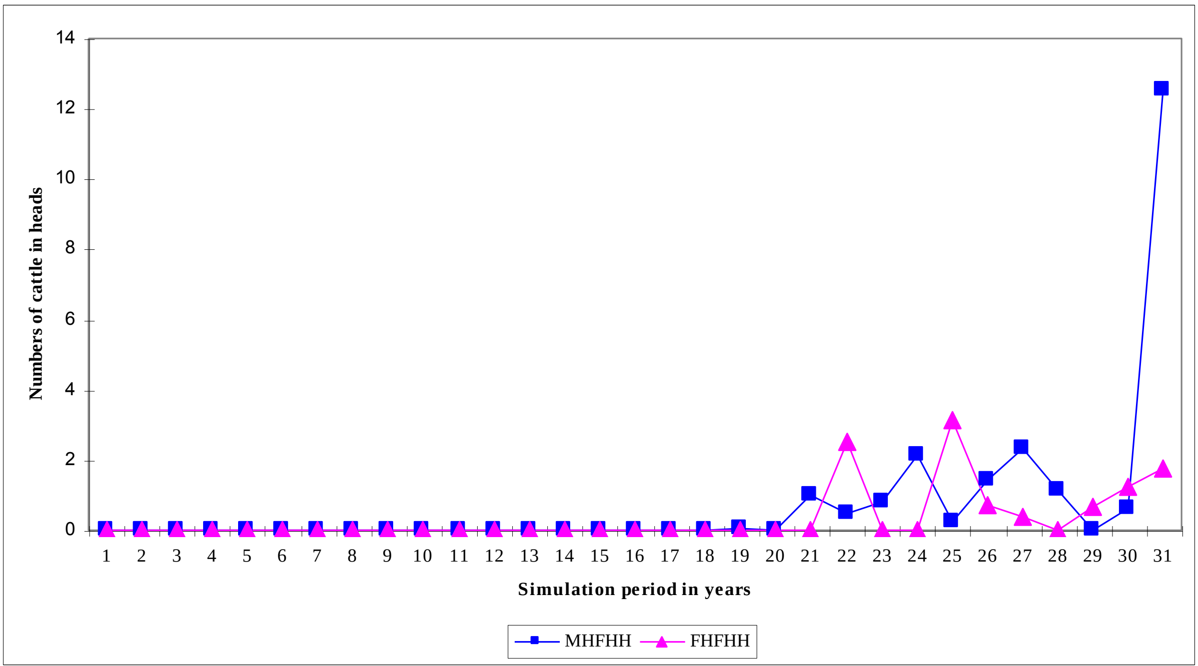
Based on included system constraints and different objectives of both FHH categories, it can be summarised that:

- Both FHH categories are attracted by a) labour-saving technologies for weeding and ploughing tasks and b) millet production activities which promise high yield levels.
- Both FHH categories a) supplement domestic millet production continuously with purchases, b) store outputs in years of peak production levels to balance insufficient production levels in following periods and c) do not sell any crop products.
- FHFHHs produce and consume more millet products and can therefore provide their members improved food energy intake rates.
- MHFHHs produce and consume less millet products but offer their members at least minimum kilocalorie requirements.

6.1.3 Livestock production

Generally, cattle production (either by the traditional or improved system) does not seem to be relevant in optimal farming strategies of MAPOM. A first indication of this phenomenon can be provided by sizes of declared potential grazing areas. Both FHH categories assign only one ha of each soil quality class to grazing reserves. This results in an average grazing area of 4 ha summed over both FHH categories and soil types. MAPOM explicitly considers the ‘keeping’ of cattle as a source of utility generation. Hence, low uptakes of livestock production activities become even more evident by analysing the number of cattle kept by both FHH categories. This is illustrated in Figure 6.5.

Both FHH categories keep only some cattle under the traditional livestock farming system during the end of the planning horizon. MHFHHs start with continuous cattle keeping in year 21, whereas FHFHHs start one year later. It can be clearly seen that both FHH categories seem to alternate cattle production. This is because grazing areas are not tied to a specific FHH category. As long as one FHH is not using any grazing reserves, the potential grazing area proclaimed by both FHH categories can be entirely used for cattle production (Chapter 5.2). Unlike FHFHHs, which reduce the number of cattle kept almost every third year to zero; MHFHHs seem to build up at least a small cattle herd. Over the entire planning horizon, 0.73 and 0.33 heads of cattle are kept on average by MHFHHs and FHFHHs, respectively.



Source: Own design based on MAPOM results.

Figure 6.5: Numbers of cattle kept

In terms of the cattle category, mostly calves and oxen are kept. Notable numbers of cattle kept demonstrate some kind of balance between a) cattle produced or purchased and b) cattle consumed or sold (Chapter 5.4.1). Hence, figures of actual production or purchase levels can be higher, but corresponding products are then immediately (within the same year) consumed by FHHs. Both FHH categories focus on purchasing calves for building up a cattle herd but from time to time also buy oxen, bulls or cows for immediate consumption. Following modelled cattle dynamics, calves are reared for at least three years. Afterwards, they enter cow and bull populations or can be immediately consumed. Since calves which are kept are not primarily produced by FHHs themselves but are accumulated by purchases, this explains why the improved cattle farming system is not considered by both FHHs. Apart from higher labour requirements, the improved system is predominantly characterised by higher weaning rates of cows (Chapter 4.4.1.2). Such higher weaning rates are of no benefit if calves are predominantly accumulated from purchases and not produced on the farm. As can be concluded from low numbers of cattle kept compared to crop production activities, both FHH categories are not involved in any selling activities.

By above outlines it becomes clearly evident that, though cattle production is considered in the utility function with the highest importance weight at least for MHFHHs (Chapter 4.7.2.4), it plays a minor role in overall optimal farming strategies for MAPOM.

This imposes the question of why FHHs in MAPOM do not build up larger cattle herds. Generally, three factors which combined seem to limit cattle production can be identified:

1. A reduced or non-existent potential to satisfy important consumption constraints.
2. A conflict with other production sectors for the factor land.
3. A conflict with other production sectors or occupations for the factor labour.

Crop production is the prime source to serve the minimum nutrition demand. This is imposed by an additional ‘system constraint’ on the potential to satisfy kilocalorie requirements by livestock products (Chapter 4.4.4). Higher weighting factors in the utility function for cattle consumption and keeping seem to be less important than fulfilling the most binding constraint in MAPOM.

As indicated already in Chapter 6.1.1, land is a limiting factor for both FHH categories. Hence, factors 1 and 2 play a combined role in limiting cattle production. To satisfy nutrition requirements, more of the limited resource land is allocated to crop production. Likewise, more land is allocated to natural resource production for which similar minimum requirements – for energy and building materials (Chapter 4.5.2) – are obliged to be met. Utilisation of hired external labour within the limits imposed by the system and results in terms of crop production indicate that labour might be a limiting factor. Both FHH categories focus on crop production activities with a high level of labour-saving technologies.

Generally, labour capacities slightly increase over the planning horizon, following population growth. After balancing labour inflows and outflows, it becomes evident that all labour resources are employed. Over the entire planning horizon, FHFHHs (MHFHHs) spend on average a) 1,950 labour hours per year (823 labour hours) on crop production and b) 73 labour hours (88 labour hours) on livestock production. Labour hours consumed by natural resource production and daily maintenance tasks are equal for both FHH categories. They amount to 2,535 labour hours for natural resource production and 1,632 labour hours for daily maintenance tasks. Specifically, labour hours spent on crop production and natural resource production are binding in MAPOM. This is imposed by certain minimum consumption demands. However, a considerable share of labour hours is also used to participate in family, social and cultural obligations. An average over all time periods considered for MHFHHs shows that labour requirements for productive activities make up only 55 % of total labour capacities. The remaining facilities are consumed by family, social and cultural obligations. A similar but less striking trend is also observable for FHFHHs. They use on average 37 % of their total labour capacities to participate in family, social and cultural obligations.

Neglecting for one moment already identified constraints on cattle production, this raises the question of why both FHH categories are highly interested in participating in family, social and cultural obligations. Leisure provides only utility and consumes only family labour (Chapter 5.6 and 5.7). Contrarily, cattle production can potentially provide a) utility, even in two instances by consuming and keeping cattle, and b) cash income. Additionally, it can satisfy to a specific degree the nutrition constraint (Chapter 5.4). On the other hand, it demands land and labour (Chapter 5.2 and 5.6).

As outlined in Chapter 5.7, in the utility function leisure is valued at an average wage rate of casual and formal employment and is afterwards factored by the importance weight found by a traditional conjoint analysis (TCA). In a similar sense, each cattle is valued by its bodyweight, the respective carcass weight and the average selling price of cattle. As for leisure, the importance weight found in TCA is attached afterwards. As results indicate, it seems to be more ‘profitable’ for both FHH categories to allocate one additional hour to participation in family, social and cultural obligations than to allocate one additional hour to cattle production. In this context, Table 6.3 shows example calculations of labour productivity for leisure and cattle production for one specific point in time. Before weighting, one hour of leisure is worth 7.9 units of utility. Contrarily, one hour invested in cattle production is worth between 7.7 and 1.6 units of utility. This is calculated as follows: one head of cattle weighs between 80 kg (calves) and 400 kg (oxen) and is in need of 85 labour hours per year. Hence, one labour hour produces on average between 4.7 and 0.9 kg cattle live mass or 1.6 and 0.3 kg cattle carcass mass. Each kg of cattle is valued in the utility function at 4.8 N$, the average selling price.

This reveals that for adult cattle, one hour of labour is transformed into only 7.7 units of utility. Leisure, on the other hand, delivers 7.9 units of utility and demands no additional assets. Thus, it more easily enters the optimal solution. Though this situation is switched after weighting, at least for adult cattle, the differences are significant. In a second situation, Table 6.3 indicates that without respecting the conversion of cattle live mass into carcass mass, cattle production can be assumed to become more attractive. Neglecting such a conversion can be specifically assumed for cattle which are kept and not consumed. Deeper considerations of these aspects play a major role in the first scenario discussed in Chapter 6.2.

Table 6.3: Labour productivity for family, social and cultural activities and cattle production

	Spending one hour for family, cultural and social activities	Spending one hour for cattle production	
		Situation 1 respecting carcass weights	**Situation 2 without respecting carcass weights**
	Unity of utility	Units of utility	Units of utility
Before weighting	7.9	1.6 (7.7)	4.5 (22.5)
After weigthing	0.7	0.6 (2.8)	6.6 (8.3)

Source: Own design.

Based on included system constraints and different objectives of both FHH categories, it can be summarised that:

- Both FHH categories are a) insignificantly engaged in cattle production activities of the traditional livestock system by allocating one ha of each soil quality class to grazing reserves, b) building up small cattle herds by purchasing calves and c) not involved in any livestock selling activities.
- MHFHHs keep slightly more cattle than FHFHHs.
- A most limiting factor faced by both FHH categories is a lacking or reduced potential of cattle production to satisfy important consumption needs, followed by land and labour constraints.

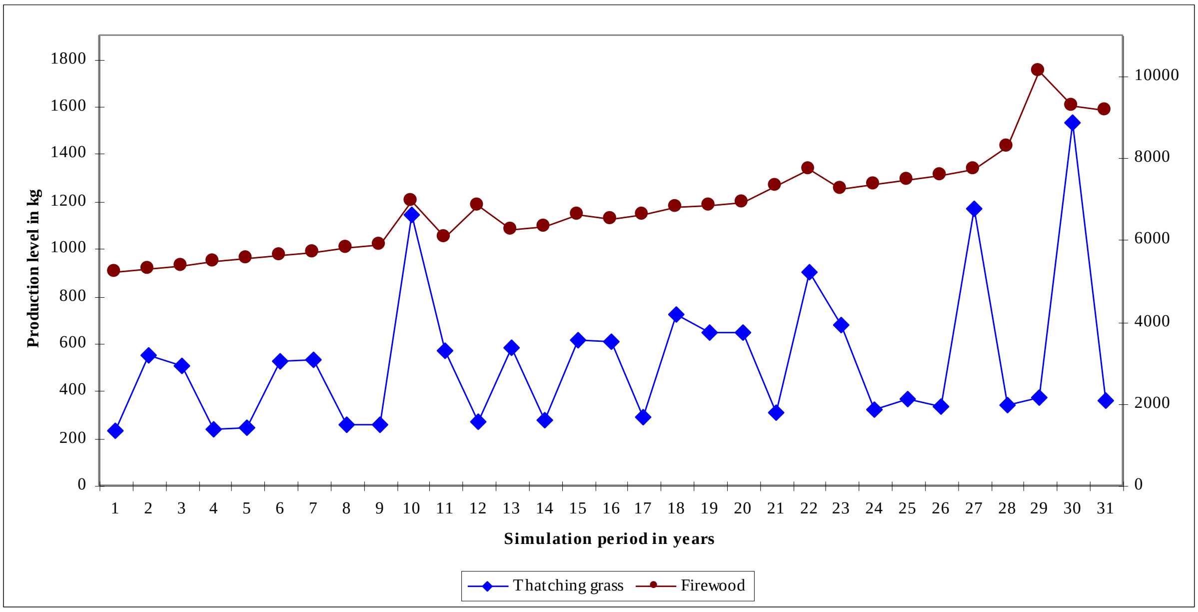
6.1.4 Natural resource production and off-farm employment

Natural resource production includes firewood, thatching grass and timber extractions, which are based on total native biomass production on natural resource areas (Chapter 4.5). In MAPOM, all three harvested products vary in their commercial character. Firewood is non-commercial, e.g. exclusively used to satisfy domestic energy requirements. Thatching grass, on the other hand, is semi-commercial, e.g. can be used to satisfy domestic building material requirements and can be traded. Finally, timber is completely commercial, e.g. can only be traded.

Actual land endowments declared as natural resource areas are rather large, are more or less constant and only fluctuate to a minor degree over the entire planning horizon. Summed over both FHH categories and soil types, they amount to 21.0 ha. Further, they belong with an amount of 10.6 ha to soil quality class ‘a’ and with an amount of 10.4 ha to soil quality class ‘b’. A size of 10.6 ha is the average for MHFHHs, and FHFHHs have an average of 10.4 ha. Note that both FHH groups can use areas potentially assigned to the other FHH group.

Total native biomass production on natural resource areas increases slightly over the entire planning horizon and respects for several fluctuations. Summed over both FHH categories, natural resource biomass amounts to 17,129 kg on average per year (13,338 – 26,929 kg). Based on its rather large area occupation and its stability, natural resource biomass production does not significantly follow rainfall events. As for crop production, larger sizes are more important than yield dependency on rainfall amounts. Another factor impacting the non-existent rainfall-following character is that MAPOM respects for ‘leftover’ biomass from previous periods. Hence, effects of lacking rainfall events in one period can be weakened by FHH decisions about natural resource extractions in previous periods. Consequently, rainfall becomes even less of a factor.

As described in Chapter 4.5.1, total natural resource biomass production is differentiated by vegetation type and then further grouped into firewood, thatching grass and timber tree biomass. Figure 6.6 presents firewood and thatching grass production summed over both FHH categories and soil quality classes. While the right y-axis addresses firewood, the left y-axis addresses thatching grass.

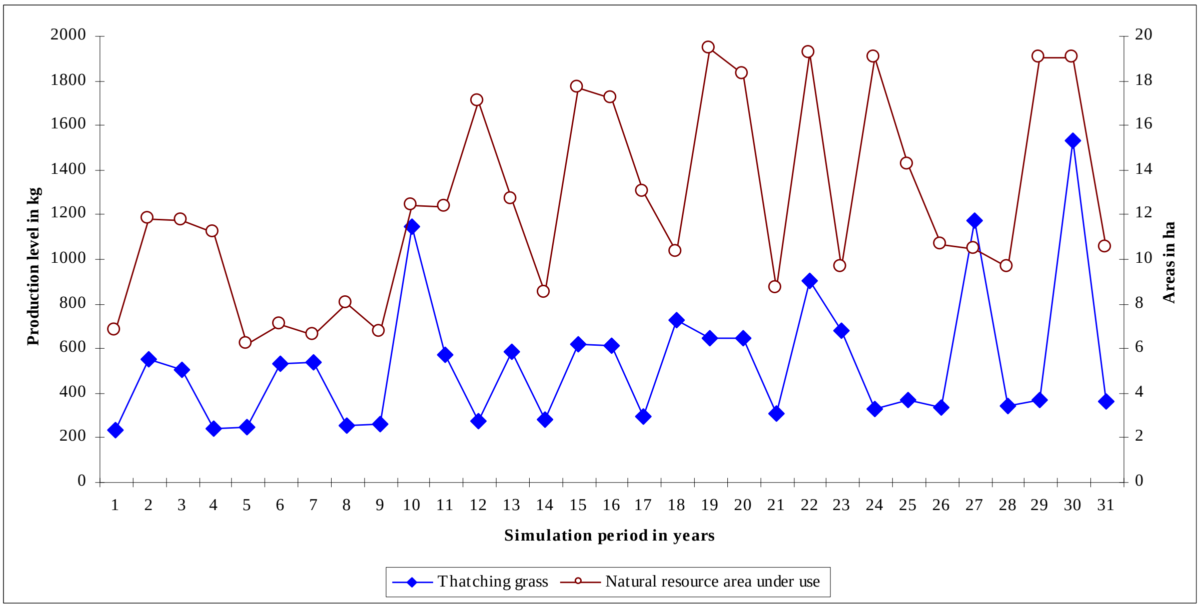


Source: Own design based on MAPOM results.

Figure 6.6: Firewood and thatching grass production

Two general tendencies become apparent. First, both curves follow a slightly increasing straight line. Second, this straight line is interrupted by several peaks. The first tendency becomes more apparent for firewood production and can be explained as both FHH groups need to consume a minimum amount of firewood to satisfy energy demands.

Similar consumption requirements are imposed for thatching grass as an important building material (Chapter 4.5.2). Slight increases are based on the fact that both amounts depend on population growth within FHHs. Causes for the several peaks of the curve for thatching grass production can be explained by two important model formulations. First, production levels depend slightly on rainfall, but more significantly on sizes of areas allocated to natural resource production which are in use. In this context, Figure 6.7 illustrates thatching grass production on the left y-axis and natural resource areas in use on the right y-axis. Peaks in production levels significantly follow peaks of areas in use for natural resource production.



Source: Own design based on MAPOM results.

Figure 6.7: Thatching grass production and natural resource areas in use

A second impacting factor is that ‘simply’ production of natural resources does not consume any labour resources. Since only harvesting labour is needed, labour requirements depend on the amounts harvested e.g. consumed domestically or, in terms of thatching grass, possibly even sold. Hence, the production side of natural resources is predominantly determined by area allocation decisions of FHHs.

The fact that observed peaks are more apparent for thatching grass than firewood is simply based on higher consumption requirements for firewood (Chapter 4.5.2). Production of both goods is coupled and depends on areas declared as natural resource reserves. Therefore, FHHs allocate as much land to natural resource production as they need to satisfy energy requirements. Simultaneously, thatching grass is produced on these areas. Lower demands for thatching grass result in a higher surplus production and finally in higher peaks. On the other hand, alternating significant fall-backs to the minimum required production levels can be explained by technical equation formulations of MAPOM. In general, MAPOM needs as much freedom as possible to find an optimal solution. Several equations and constraints are therefore formulated as 'x is equal to or less (greater) than y' instead of 'x is equal to y'. Hence, illustrated production levels might be even higher for years where the curve sticks to the straight imaginable line.

On average over the entire planning horizon, annual production levels of MHFHHs (FHFHHs) equal 3,398 kg (3,428 kg) firewood, 260 kg (267 kg) thatching grass and 76 kg (88 kg) timber tree biomass. As indicated in the beginning, firewood and thatching grass can both satisfy domestic requirements for energy and building material. Over the entire planning horizon, domestic consumption requirements are exactly met for both FHH categories without any over or under-compensations.

In periods where thatching grass production exceeds domestic needs, as indicated for several years in Figure 6.6 and 6.7, surpluses could be possibly sold. However, both FHH categories do not sell any thatching grass over the entire planning horizon. This reaction is based on two aspects. First, before it can be sold, thatching grass needs to be harvested and then consumes additional labour. Hence, cash incomes which could be obtained by selling surplus thatching grass do not seem to compensate higher labour efforts. Second, MAPOM involves a specific system constraint which defines an upper bound on the cash income balance (Chapter 5.2).

In the context of natural resource production another, minor binding constraint requires FHHs in MAPOM to sell at least some timber products formulated as a lump sum over both FHH groups and the entire planning horizon (Chapter 5.5.2). Though no specific period or no specific FHH category is addressed by this constraint, two major tendencies become apparent. First, both FHH categories sell timber. Second, both FHH categories start with timber selling activities towards the end of the planning horizon. Sold timber products are not considered in the utility function and generate only cash income. However, imposed by the income balance constraint, selling timber seems to be a less attractive income generation activity to both FHH categories.

As indicated in the previous paragraph and chapters, sale activities are rather minor, especially if compared to purchases. Nevertheless, both FHH categories seem to meet budget constraints and are not even obliged to sell surplus thatching grass. This leads to considerable explicit results obtained from MAPOM with respect to off-farm employment activities. As an important aspect, both FHH groups focus on formal employment (wage labour). MHFHHs are also engaged to a minor extent in casual labour activities in only three years (1, 20, 31). With some insignificant differences, MHFHHs and FHFHHs slightly increase labour hours spent on formal employment up to the year 21, where both reach the upper bound of 1,516 hours per year. This level is kept till the final period. Over the entire planning horizon, MHFHHs invest 1,432 labour hours on average per year in off-farm employment. FHFHHs invest slightly lower amounts of 1,417 labour hours. Cash income generated by off-farm labour activities significantly shapes the cash income balance.

Based on included system constraints and different objectives of both FHH categories, it can be summarised that:

- Both FHH categories are to a more or less equal degree involved in natural resource production for predominantly satisfying domestic energy and building material requirements.
- Both FHH categories are to a more or less equal degree engaged in off-farm labour activities, the major source of cash income, and focus on wage labour.

6.1.5 Impacts on the natural resource base

Production levels of all considered on-farm production activities in MAPOM are influenced to a certain degree by bio-physical components (rainfall) and applied conservation strategies (resting periods). Likewise, all production activities use native or natural resource biomass to some degree. Deforestation is the major environmental threat in the research area (Chapter 2.4.1). To quantify the extent of deforestation, MAPOM calculates a native biomass loss index after model runs. Corresponding calculation processes are based on equations 6.1 – 6.5.

Initially, the potential native natural resource biomass production is estimated under the assumption that the entire land endowment is assigned as a natural reserve, without any human land use activities.

$$natpropot_{s,h,t} = RN_t \times RUE_s \times lanareapot_{s,h,t} \qquad \textbf{(6.1)}$$

$natpropot_{s,h,t}$	: potentially produced native natural resource biomass on s of h in t
$lanareapot_{s,h,t}$	: potential land area of s of h in t
RN_t	: rainfall in time t
RUE_s	: rainfall use efficiency on s

Then, the potential native biomass production on potential cropping areas is determined. Since these areas are completely cleared, this signifies the destruction of native biomass attached to crop production.

$$natloscro_{s,h,t} = RN_t \times RUE_s \times croareapot_{s,h,t} \quad \textbf{(6.2)}$$

$natloscro_{s,h,t}$	: native natural resource biomass loss based on crop production on s of h in t
$croareapot_{s,h,t}$	: potential crop area on s of h in t

Native biomass losses based on livestock production amount to grazing biomass consumed by cattle.

$$natlosliv_{s,h,t} = \sum_{al} biore_{al,s,h,t} \quad \textbf{(6.3)}$$

$natlosliv_{s,h,t}$	: native natural resource biomass loss based on livestock production on s of h in t
$biore_{al,s,h,t}$	: biomass required by livestock of al on s of h in t

In a similar way, native biomass extraction due to utilisation activities of FHHs towards natural resources is determined.

$$natlosnat_{h,t} = fwoodcon_{h,t} + tgrascon_{h,t} + tgrassel_{h,t} + timbsel_{h,t} \quad \textbf{(6.4)}$$

$natlosnat_{h,t}$	: natural resource biomass loss based on natural resource production of h in t
$fwoodcon_{h,t}$	: quantity of firewood consumed of h in t
$tgrascon_{h,t}$	: quantity of thatching grass consumed of h in t
$tgrassel_{h,t}$	: quantity of thatching grass sold of h in t
$timbsel_{h,t}$	: quantity of timber sold of h in t

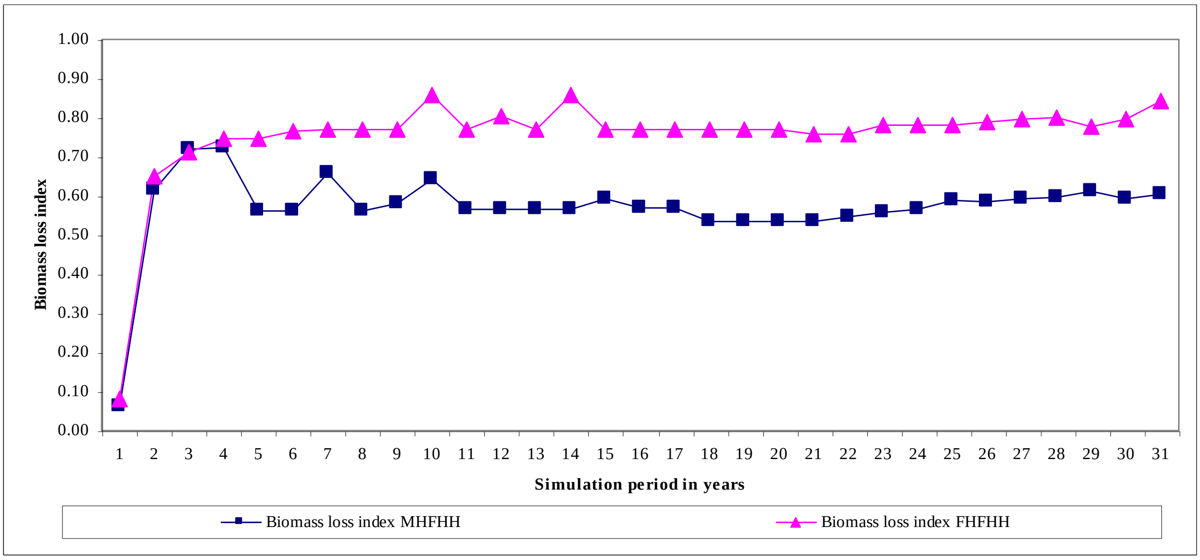
Finally, all identified native biomass loss figures are divided by the amount of potential biomass production on the entire area.

$$natloind_{h,t} = \left(\sum_{s} natloscro_{s,h,t} + \sum_{s} natlosliv_{s,h,t} + natlosnat_{h,t} \right) \Big/ \sum_{s} natpropot_{s,h,t} \quad \textbf{(6.5)}$$

$natloind_{h,t}$	: native natural resource biomass loss index of h in t

This indicator is clearly a simplification of ‘actual’ impacts on the environment based on human land use. Generally, it implies three weaknesses. First, for crop production it considers the potential areas and not actual areas under use. This might lead for some years to an overestimation of the destruction potential. Contrarily, considering areas in use would underestimate ‘actual’ impacts on the natural environment since potential crop areas are completely cleared. Second, for cattle production and natural resource production it considers the 'actual' withdrawing of native biomass from grazing and natural resource areas. This is a plausible assumption at this point, since it can be assumed that no further human impacts occur on these areas. Negative trampling effects on grazing areas induced by cattle activities can be assumed to be balanced by positive effects like manure accumulation. Third, total native biomass production is considerably determined by the total potential land endowment of each FHH category. If, for instance, FHFHHs occupy larger area sizes than MHFHHs but are in need of a) equal feed requirements for cattle and b) equal consumption requirements of natural resources, the biomass loss index becomes routinely smaller. Hence, equal amounts of native biomass exploitation are valued differently by the same index.

Bearing above described shortcomings in mind, Figure 6.8 illustrates native biomass loss indices for each FHH category over the entire planning horizon.

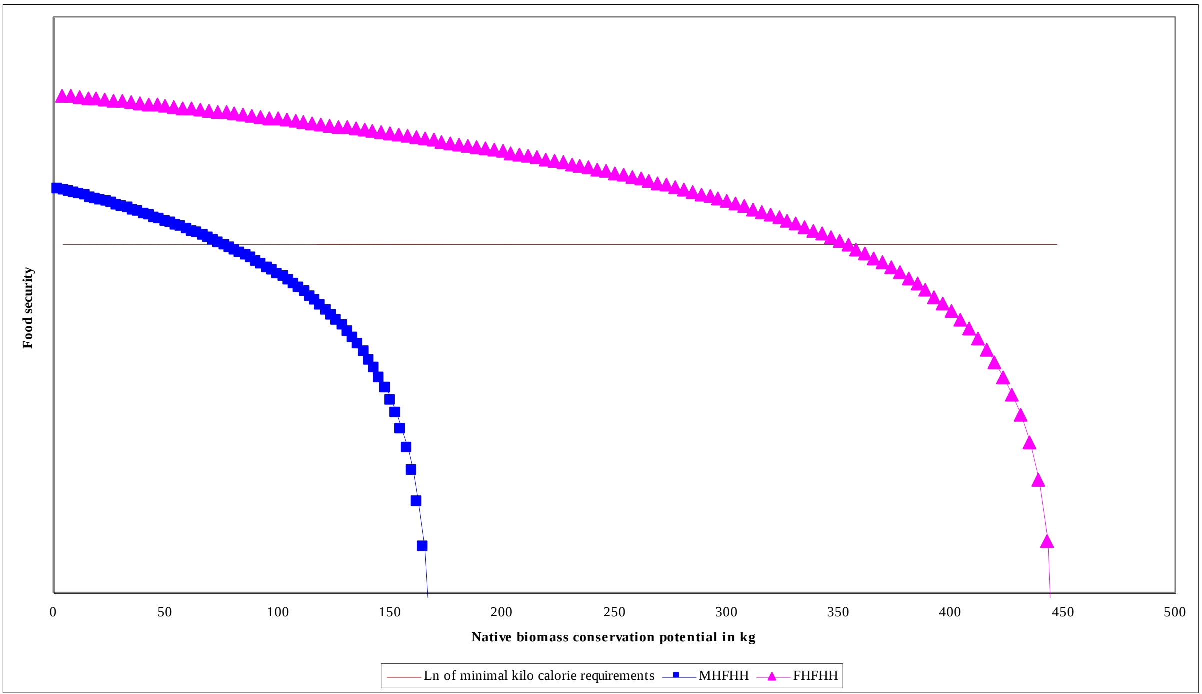


Source: Own design based on MAPOM results.

Figure 6.8: Native biomass loss index

Obviously, an increase of native biomass loss is imperative in the first few years of the planning horizon. This matches with high-volume clearing activities in these years. Afterwards, native biomass loss increases insignificantly and becomes constant with a few fluctuations. A major aspect is that FHFHHs seem to focus on farming activities which are significantly more destructive for native biomass. Note that FHFHHs assign larger areas to crop production. Though it is a simplification, the biomass loss index signifies a clear relationship between native biomass loss and crop production. This relationship becomes even more evident if portions of crop, livestock and natural resource production on total native biomass loss are investigated. Over the entire planning horizon, the contribution of crop production to the biomass loss index is 85 % for MHFHHs and as much as 93 % for FHFHHs.

Crop production is the major farming activity which generates food, in terms of kilo-calories. At the same time, it destroys significant amounts of native biomass. Hence, a clear trade-off between food security and native biomass conservation can be assumed. Such a relationship can be illustrated by trade-off curves as exemplified in Figure 6.9. Summed over the entire planning horizon, results of MAPOM for MHFHHs show that a production of 1,000 kilocalories destroys an average of 2.39 kg native biomass. For FHFHHs, this figure amounts to 3.85 kg. At a maximum, MHFHHs produce 16,891,000 kilocalories based on crop production in one year of the planning horizon. For FHFHHs, this level is 44,696,000 kcal. Assuming that these amounts are produced without any conservation measures delivers the intersection with the y-axis. This means that native natural resource conservation equals zero where a maximum of kilocalories can be supplied by crop production and vice versa. Reducing this amount continuously by 2.39 (3.85) kg delivers the intersection with the x-axis.



Source: Own design based on MAPOM results.

Figure 6.9: Trade-off between food security and native biomass conservation in baseline scenario

The straight line illustrates the lower limit of kilocalories that need to be produced each year on average over the entire planning horizon. Requiring natural resource conservation to go beyond this line would threaten food security to a major degree. This minimum bound is reached by MHFHHs at a rather low conservation rate of 74 kg native biomass.

As can be expected, the assumed relationship for FHFHHs is similar but on the other hand more relaxed. Since FHFHHs produce a considerable surplus of kilocalories, the area between the curve and the straight line is larger. Consequently, they could conserve more native biomass without threatening food security (354 kg).

Based on included system constraints and different objectives of both FHH categories in MAPOM, it can be summarised that:

- FHFHH are more engaged in native biomass destruction activities, since they use larger areas for crop production.
- Both FHH categories face a trade-off between native biomass conservation and food security.
- For MHFHHs, the potential of conserving native biomass is more limited, since their crop production output only slightly exceeds minimum kilocalorie requirements.

6.1.6 Summary of the baseline scenario

Results of the baseline scenario of MAPOM indicate some general tendencies in terms of optimal land use strategies under important system constraints. Over all production activities, both FHH categories face limitations in actual land endowments. Limitations are more striking on soil quality class ‘a’. Actual land endowments for the different production sectors are not completely used but put to 50 % under fallow. Both FHH categories possess equal amounts of labour and take full advantage of hiring external labour. This indicates that labour is a limiting factor. Generally, FHFHHs occupy more land than MHFHHs.

In terms of crop production, FHFHHs cultivate larger field sizes than MHFHHs. Both FHH categories are attracted by a) labour-saving technologies in terms of weeding and ploughing and b) millet production activities which promise high yield levels. Both FHH categories continuously supplement domestic millet production with purchases. Moreover, they store outputs in years of peak production levels to balance insufficient production levels in following periods. They do not sell any crops. FHFHHs produce and consume more millet and can therefore provide their members with relatively high food energy intake rates. MHFHHs meet at least minimum kilocalorie requirements.

In terms of livestock production, it can be summarised that both FHH categories are insignificantly engaged in cattle production based on the traditional livestock system. They do not take part in improved cattle-rearing activities. Even though this study explicitly considers the keeping of cattle as a source of utility delivery, cattle numbers are small and slightly higher for MHFHHs than for FHFHHs. As a consequence, both FHH categories do not sell any cattle. A most limiting factor faced by both FHH categories is the lacking or reduced potential of cattle production to satisfy important consumption needs. Moreover, land and labour endowments also constrain cattle production.

In terms of natural resource production and off-farm labour, some tendencies are obvious. Both FHH categories are to a more or less equal degree involved in natural resource production for predominantly satisfying domestic energy and building material requirements. Likewise, they are to an equal degree engaged in off-farm labour activities, the major source of income, and focus on wage labour activities.

With respect to impacts on the environment, it can be summarised that FHFHHs are more involved in native biomass destruction activities, since they use larger areas for crop production. Both FHH categories face a trade-off between native biomass conservation and food security. For MHFHHs, the potential for conserving native biomass is lower, since they already produce at the limit in terms of food security.

6.2 A scenario based on changes of objective function elements

As indicated in Chapter 6.1.3, based on one specific equation in MAPOM, one labour hour invested in cattle production contributes, among other factors, to a lower utility value before weighting than one hour invested in family, social and cultural activities. Without respecting the mathematical conversion of cattle live mass into the carcass mass, cattle production can be assumed to become more attractive. Neglecting such a conversion can be specifically assumed for cattle which is kept and not consumed.

In this scenario, Equation 5.61 from Chapter 5 is transferred into Equation 6.5. Unlike cattle which are consumed, cattle which are kept provide a z-good and are evaluated at their complete live mass.

$$conz_{t,h} = \sum_{al,s}(livkep_{al,s,h,t} \times BW_{al} \times SPL) \times WL_h + (fwoodcon_{h,t} \times SPF) \times WN_h \qquad \textbf{(6.6)}$$

$livkep_{al,s,h,t}$: quantity of livestock kept of al on s of h in t

SPL : selling prices of livestock / livestock products

BW_{al} : bodyweight of al

WL_h : relative weight of importance of livestock production activities of h in t

6.2.1 *Resource endowments*

Before showing the impact of these changes on optimal farming strategies under important system-imposed constraints, Table 6.4 illustrates land dynamics of the present scenario (SC2). It depicts actual land endowments, and land under use for both soil quality classes between the BL and SC2 for both FHH categories.

It can be clearly seen that FHFHHs still occupy more land than MHFHHs, but they also occupy more land than compared to the baseline. Actual land endowments over the entire planning horizon for FHFHHs equal 45 ha on average, whereas MHFHHs occupy only 18 ha on average. Land in use over the entire planning horizon amounts to 12 ha on average for MHFHHs and 18 ha for FHFHHs. Hence, for both FHH groups, land set under fallow is slightly increased and cultivation is less intense. With respect to the different soil quality classes, it becomes apparent that land of soil quality class ‘a’ already becomes a limiting factor after year 6. Contrarily, land resources under soil quality class ‘b’ become scarce in year 9 and limiting after year 20.

Table 6.4: Actual land endowments and areas in use by soil quality class and FHH category in scenario 2

	Actual land endowment			**Land in use**		
	Total	**Soil quality class 'a'**	**Soil quality class 'b'**	**Total**	**Soil quality class 'a'**	**Soil quality class 'b'**
	ha	ha	ha	ha	ha	ha
Baseline scenario						
MHFHH	23	13	10	13	4	9
FHFHH	40	13	27	19	10	9
Scenario 2						
MHFHH	18	6	12	12	6	6
FHFHH	45	21	24	18	8	10

Source: Own design based on MAPOM results.

Compared to the BL, FHFHHs now clearly occupy more land on soil quality class ‘a’, whereas MHFHHs occupy more land on soil quality class ‘b’. Actual land endowments of FHFHHs are more or less equally distributed between both soil quality classes. MHFHHs occupy more land (67 %) under soil quality class ‘b’.

Generally, labour capacities are similar for both FHH categories and match exactly with labour capacities from the BL.

In contrast to results of the BL, it can be summarised that:

- Limits in land endowments occur earlier and are especially more striking for soil quality class 'a'.
- FHFHHs occupy even more land and MHFHHs occupy even less land.
- No changes are apparent in labour capacities.

6.2.2 Crop production

Over the entire planning horizon, FHFHHs in SC2 cultivate larger fields than MHFHHs, with a size of up to 9.5 ha on soil quality class 'a' and a size of up to 16.0 ha on soil quality class 'b'. This indicates that up to 46 % of their total land endowments of soil quality class 'a' and up to 66 % of their total land endowments of soil quality class 'b' are entirely used for crop production. Contrarily, MHFHHs cultivate cropping areas of up to 4.1 ha on soil quality class 'a' and up to 7.2 ha on soil quality class 'b'. Actual land endowments in use by the crop production sector amount for them to a) up to 68 % of soil quality class 'a' and b) up to 58 % of soil quality class 'b'. Both FHH groups alternate years of crop production processes with years of resting periods.

As can be seen in Table 6.5, compared to the BL, FHFHHs cultivate smaller fields on both soil quality classes. They assign significantly less land under soil quality class 'a' to crop production with up to 46 % of actual land endowments and cultivate more or less equal portions under soil quality class 'b' with up to 66 % of actual land endowments.

Table 6.5: Actual land endowments and potential crop areas by soil quality class and FHH category in scenario 2

	Actual land endowment			Potential crop areas		
	Total	Soil quality class 'a'	Soil quality class 'b'	Total	Soil quality class 'a'	Soil quality class 'b'
	ha	ha	ha	ha	ha	ha
Baseline scenario						
MHFHH	23	13	10	13	4	9
FHFHH	40	13	27	31	12	19
Scenario 2						
MHFHH	18	6	12	11	4	7
FHFHH	45	21	24	26	10	16

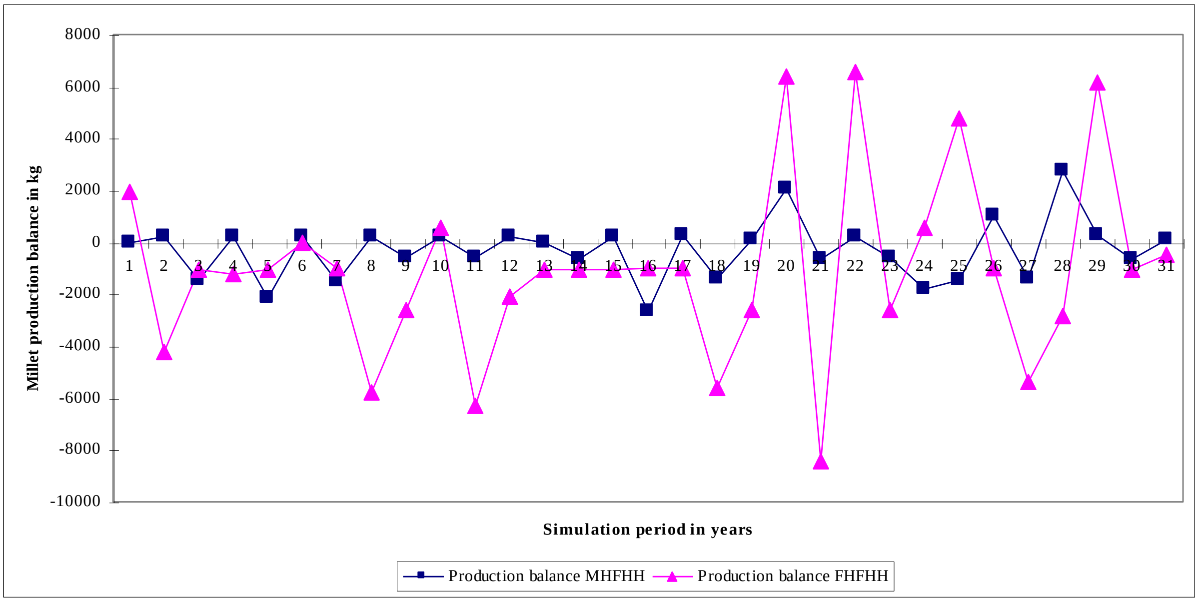
Source: Own design based on MAPOM results.

MHFHHs cultivate fields of equal size on soil quality class 'a' and smaller fields on soil quality 'b'. They assign more land of soil quality class 'a' to crop production, with up to

68 % of actual land endowments, and put less land of soil quality class ‘b’ under crop cultivation, with up to 58 % of actual land endowments.

In comparison to the BL, no changes occur in terms of preferred cropping activities. Both FHH groups a) focus on millet production under the pure cultivation mode, b) choose activities with two weeding sessions, c) predominantly choose activities which require row planting and consequently DAP weeding and d) even prefer two activities which also involve DAP ploughing.

Sizes of fields under cultivation indicate already that production levels of millet are generally smaller compared to the BL. Figure 6.10 shows production balances between millet production levels of the BL and SC2 summed over both soil quality classes for both FHH categories. It can be clearly seen that, especially in the beginning of the planning horizon, both FHH categories produce less millet than in the BL. During the end of the planning horizon, from year 20, both FHH categories increase production levels. However, average production balances over the entire planning horizon are negative and amount to -1,083 kg per year for FHFHHs and -301 kg per year for MHFHHs.



Source: Own design base on MAPOM results.

Figure 6.10: Millet production balances

As for the BL, both FHH categories supplement domestic production continuously with purchases and store millet amounts from peak production years. Likewise, both FHH categories do not sell any crop products over the entire planning horizon.

Though producing even less kilocalories in terms of crop production compared to the BL, MHFHHs meet minimum kilocalorie requirements of all their FHH members over the entire planning horizon. Kilocalorie balances of FHFHHs indicate that the welcoming increase over minimum food energy intakes obvious in the BL has diminished. In SC2, FHFHHs supply an average of only 28 % more kilocalories than the minimum bound demands (67 % in BL). This results in an energy consumption of 2,867 kilocalories per day and person (3,741 in BL). For MHFHHs, nutrition levels are even less comfortable. Surpluses over minimum nutrition intake rates amount to only 2 % (8 % in BL) and result in a daily food intake of 2,285 kilocalories per person (2,419 in BL).

In contrast to results of the BL, it can be summarised that:

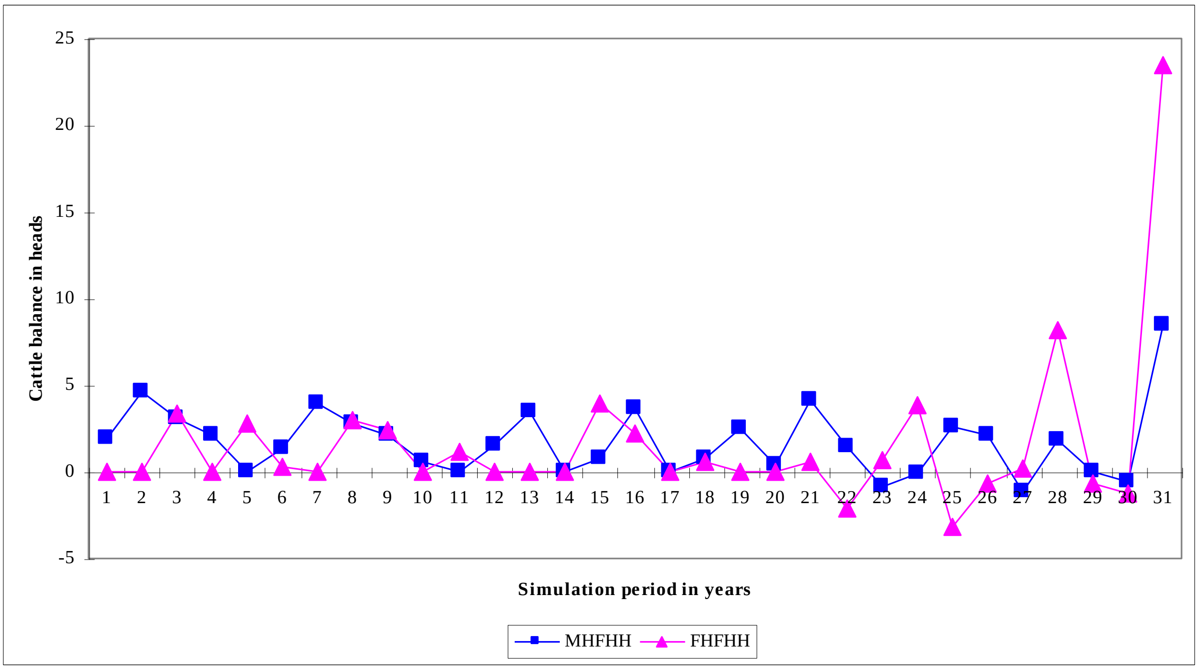
- FHFHHs cultivate smaller fields, assign significantly less land under soil quality class ‘a’ to crop production and cultivate more or less equal portions under soil quality class ‘b’.
- MHFHHs cultivate larger fields on soil quality class ‘a’ and smaller fields on soil quality ‘b’ and assign more land of soil quality class ‘a’ to crop production but put less land of soil quality class ‘b’ under crop cultivation.
- No changes occur in terms of the preferred cropping activities. Both FHH groups a) focus on millet production under the pure cultivation mode, b) choose activities with two weeding sessions and c) predominantly choose activities which require labour-saving technology.
- Both FHH categories produce less millet, since average yearly production balances over the entire planning horizon are negative.
- Both FHHs meet minimum kilocalorie requirements, but welcoming increases over minimum food energy intake rates are reduced.

6.2.3 Livestock production

In the BL, cattle production (produced by either the traditional or improved livestock production system) does not seem to be a promising farming strategy for both FHHs. This phenomenon is less significant in SC2. A first indication can be illustrated by sizes of areas declared as grazing reserves. MHFHHs declare 1.0 ha (soil quality class ‘a’) and 5.0 ha (soil quality class ‘b’) as grazing reserves. For FHFHHs areas being used for cattle grazing amount to between 1.0 (soil quality class ‘a’) and 1.2 ha (soil quality class ‘b’). Note that such areas can be used by both FHH categories. In comparison to the BL, grazing areas covered by both soil quality classes and for both FHH categories doubled from 4.0 ha to 8.1 ha.

Figure 6.11 illustrates balances of cattle kept between the BL and SC2, summed over both soil quality classes for MHFHHs and FHFHHs. As can be seen, two tendencies become apparent. First, both FHH categories start with cattle keeping already in the beginning of the planning period (MHFHHs in year 2 and FHFHHs in year 3). Second, cattle balances are primarily positive apart from some years during the end of the planning horizon. Over the entire planning horizon, MHFHHs build up a cattle herd of on average 2.46 heads of cattle (0.73 in BL). For FHFHHs, the average cattle herd size amounts to 1.91 heads (0.33 in BL).

In terms of the cattle category, mostly bulls and cows are kept. This is another significant change compared to the BL, where cattle herds consisted predominantly of calves and oxen. Comparable to the BL, both FHH categories focus on purchasing calves for building up a cattle herd, but from time to time also buy oxen, bulls or cows for immediate consumption. In the BL, calves which entered the bull and cow population are immediately consumed. In this scenario, calves are reared for three years and enter cow and bull populations but then continue to be kept. Similar to the BL, calves which are kept are not primarily produced by FHHs themselves but are accumulated by purchases. This explains again why the improved cattle farming system still is not considered in the optimal solution. Both FHH categories are not involved in any selling activities.



Source: Own design based on MAPOM results.

Figure 6.11: Balance of cattle kept

Based on the above data, it becomes clearly evident that the attractiveness of cattle production has considerably improved, though it still is not the prime production direction. All three limiting factors apparent in the BL remain crucial for both FHH categories. These are a) a reduced or non-existent potential of cattle production to satisfy important consumption constraints, b) a conflict with other production sectors for the factor land and c) a conflict with other production sectors and occupations for the factor labour.

Over the entire planning horizon, FHFHHs (MHFHHs) spend 1,571 labour hours (708 labour hours) on crop production on average per year. Livestock production consumes 246 labour hours (382 labour hours) in SC2. Labour hours spent on natural resource production and daily maintenance tasks are equal for both FHH categories. They amount to 2,535 labour hours for natural resource production and 1,632 labour hours for daily maintenance tasks. In comparison to the BL, both FHH categories spend less labour on crop production (FHFHHs 1,950 labour hours in BL; MHFHHs 823 labour hours in BL). Contrarily, they invest more labour capacities in cattle production (FHFHHs 73 labour hours in BL; MHFHHs 88 labour hours in BL). Similar to the BL are labour hours consumed by natural resource production and daily maintenance tasks.

In contrast to results of the BL, it can be summarised that:

- Both FHH categories are engaged in traditional cattle production activities from the beginning of the planning period, declare together 8 ha as grazing reserves and increase cattle numbers kept and labour hours invested in cattle production.
- Though calves are purchased, cattle herds of both FHH categories consist primarily of cows and bulls.
- Both FHH categories invest released labour capacities from crop production into cattle production.

6.2.4 Natural resource production and off-farm employment

Areas assigned as natural resource areas are still rather large and more or less constant and only fluctuate to a small degree over the entire planning horizon. Summed over both FHH categories and soil quality classes, they amount to 22.6 ha. An amount of 12.2 ha belongs to soil quality class ‘a’. A slightly smaller area of 10.4 ha is assigned to soil quality class ‘b’. A size of only 2.0 ha predominantly accounts for MHFHHs, and 20.6 ha accounts primarily for FHFHHs. Note that both FHH groups can use areas potentially assigned to the other FHH group. In comparison to the BL, total sizes of natural resource areas increase slightly (up to 21.0 ha in BL) based on increased extents of soil quality class ‘a’ (9.6 ha in BL). Reserves predominantly assigned to MHFHHs considerably decrease (up to 10.4 ha in BL), whereas areas declared by FHFHHs increase (up to 10.4 in BL).

Generally, total native biomass production on natural resource areas slightly increases over the entire planning horizon and is subjected to several fluctuations. Summed over both FHH categories, natural resource biomass amounts to 16,992 kg on average per year (12,342 – 26,255 kg). In comparison to the BL, total natural resource biomass production summed over both FHH categories is slightly reduced (17,129 kg per year). As described in the beginning of this section, extents of potential natural resource areas increase slightly. However, balances of areas actually in use in both scenarios show a slight decline of -1 ha on average over the entire planning horizon, both soil qualities and FHH categories.

For MHFHHs (FHFHHs) in SC2, annual production levels equal a) 3,472 kg (3,481 kg) for firewood, b) 255 kg (270 kg) for thatching grass and c) 64 kg (93 kg) for timber tree biomass. These production levels are more or less equivalent to production levels obtained in the BL (MHFHHs: 3,398 kg firewood, 260 kg thatching grass, 76 kg timber tree biomass; FHFHHs: 3,428 kg of firewood, 267 kg thatching grass and 88 kg timber tree biomass). Over the entire planning horizon, domestic consumption requirements are exactly met for both FHH categories without any over or under compensations, as are selling obligations for timber trees. Generally, results obtained for natural resource production indicate only some minor differences compared to results of the BL.

As indicated in previous sections, sale activities are rather minor, especially if compared to purchases. Nevertheless, both FHH categories seem to meet budget constraints and are not even obliged to sell surplus thatching grass or timber tree reserves. This leads to considerable explicit results with respect to off-farm employment activities. As an important aspect, both FHH groups focus on wage labour employment. MHFHHs are additionally engaged to a minor extent in casual labour activities in only nine years (1, 5, 6, 19, 20, 21, 28, 29 and 31),. With some insignificant differences, MHFHHs and FHFHHs slightly increase labour hours spent on formal employment over the planning horizon. MHFHHs meet the upper bound of possible formal employment in year 24, whereas FHFHHs meet it in year 22 and face minor decreases in remaining years. Over the entire planning horizon, MHFHHs invest on average 1,344 labour hours in wage labour. For FHFHH, wage labour consumes slightly more - 1,369 labour hours. Cash income generated by off-farm labour activities particularly shapes the general cash income balance. In comparison to the BL, both FHH categories slightly reduce labour hours spent on off-farm employment. However, such reductions amount to only 0.01 % and 1 % on average over the entire planning horizon.

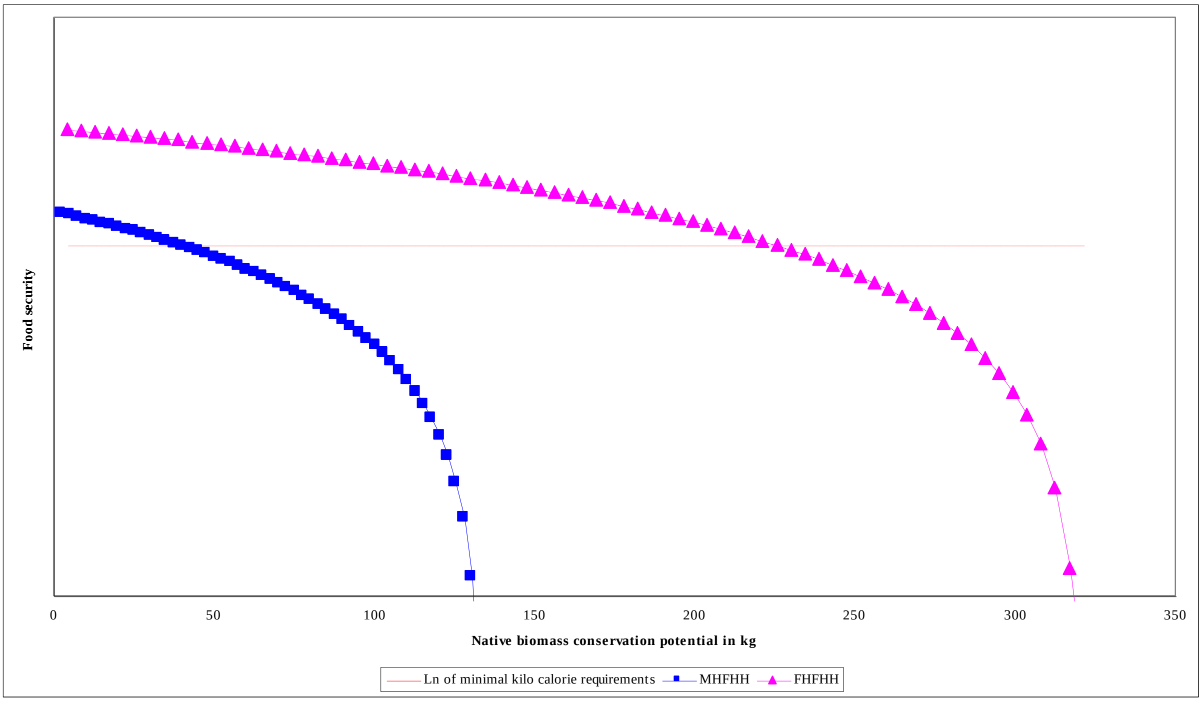
In contrast to results of the BL, it can be summarised that:

- Both FHH categories face only minor changes in terms of natural resource production and off-farm employment.

6.2.5 *Impacts on the natural resource base*

With respect to the biomass loss index, the situation compared to the BL has extremely changed. FHFHHs face a reduction in the biomass loss index of 19 % on average over the entire planning horizon. This reduction can be fully attached to changes in crop production activities. As mentioned for the BL, the biomass loss index is significantly related to the total potential areas of each FHH group. Hence, not only a reduction in crop production activities plays an important role but also an increase in total potential areas. For FHFHHs, both aspects can be observed: a) an increase in total potential areas and b) a reduction in crop production activities. Contrarily, biomass loss indices for MHFHHs increase by 17 %, of which 7 % can be attributed to changes in crop production, another 8 % to changes in cattle production and about 2% to changes in natural resource production. Generally, for MHFHHs total actual land endowments decline, compared to the BL. Contrarily, areas declared for crop production (a slight decline of about 1 ha) as well as timber, firewood and thatching grass extractions remain constant while cattle numbers increase.

Compared to the BL, the contribution of crop production to biomass loss is still striking though declining for MHFHHs to 75 % (85 % in BL) and to 90 % for FHFHHs (93 % in BL). Figures for native biomass destruction per 1,000 kilocalories are increased for both FHH categories compared to the BL (Figure 6.12).



Source: Own design based on MAPOM results.

Figure 6.12: Trade-off between food security and native biomass conservation in scenario 2

Figures for maximum kilocalorie deliveries of crop products declined (2.39 kg and 16,891,000 kcal for MHFHHs in BL; 3.85 kg and 44,696,000 kcal FHFHHs in BL). This indicates that both curves obtain lower starting points on the y-axis and are faced with a stronger decline per unit of native biomass conserved. As can be clearly seen, a maximum level of 236 kg native biomass can be possibly conserved by FHFHHs. A similar but more striking relationship can be expected for MHFHHs. Since MHFHHs produce only minor surpluses over minimum kilocalorie requirements, the area between the curve and the straight line is smaller. Consequently, they could conserve less native biomass without threatening food security (40 kg).

In comparison to the BL, both FHH categories reach maximum possible limits of biomass conservation earlier (MHFHHs 74 kg in BL; FHFHHs 354 kg in BL).In contrast to results of the BL, it can be summarised that:

- FHFHHs become less biomass destructive, since they occupy larger actual land endowments and simultaneously allocate less land to crop production, only slightly intensify cattle production and are similarly engaged in natural resource production.
- MHFHHs become more biomass destructive since they occupy smaller actual land endowments, allocate similar amounts of land to crop production, keep larger cattle numbers and are similarly engaged in natural resource production.
- Both FHH categories reach possible maximum limits of biomass conservation earlier, since quotients of biomass destruction per kilocalorie are higher and maximum kilocalorie deliveries of crop production are lower.

6.2.6 Summary of scenario 2

Results of SC2 indicate some general tendencies in terms of optimal land use strategies under important system constraints. Over all production activities, both FHH categories face limitations in actual land endowments. Limits in land endowments are reached earlier and are specifically more striking for soil quality class ‘a’. No changes are apparent in labour capacities. While FHFHHs occupy even more land, MHFHHs occupy less.

In terms of crop production, it can be summarised that both FHH categories are still a) attracted to labour-saving technologies and millet production activities which promise high yield levels, b) continuously supplementing domestic millet production with purchases and store outputs in years of peak production levels to balance insufficient production levels in following periods and c) not selling any crop products. Both FHH categories produce less millet, since average yearly production balances over the entire planning horizon are negative. Still, both FHH categories meet minimum kilocalorie requirements, but welcoming increases over minimum food energy intake rates are reduced for FHFHHs and MHFHHs.

In terms of livestock production, it can be summarised that both FHH categories a) are engaged to a specific degree in traditional cattle production activities, b) still do not sell any cattle and c) primarily keep bulls and cows obtained from purchases of calves. Herd sizes of MHFHHs are still larger than those of FHFHHs. For both FHH categories, grazing areas, cattle numbers kept and labour hours invested into cattle production are increased. Released labour capacities from crop production are invested into cattle production. MHFHHs even reduce labour hours spent on family, social and cultural obligations and invest those in cattle production.

In terms of natural resource production and off-farm employment, it can be summarised that both FHH categories are still to a similar degree a) involved in natural resource production for predominantly satisfying domestic energy and building material requirements and b) engaged in off-farm labour activities, the major source of cash income, and focus on wage labour.

With respect to impacts on the natural environment, results reveal that FHFHHs become less biomass destructive. They occupy larger actual land endowments and simultaneously allocate less land to crop production. Further, they slightly intensify cattle production and are still similarly engaged in natural resource production. Contrarily, MHFHH become more biomass destructive. They occupy smaller actual land endowments and allocate similar amounts of land to crop production. Moreover, they keep more cattle and are similarly engaged in natural resource production. Still, both FHH categories face a trade-off between native biomass conservation and food security. Maximum limits of potential biomass conservation are met earlier by both FHH categories. This is because quotients of biomass destruction per kilocalorie increase while maximum kilocalorie deliveries of crop production decline.

6.3 A scenario based on changes in policy conditions for natural resource usage

Masters and Dalton (1998: 1) discovered that a relatively low level of pasture tax per livestock unit would increase the attractiveness of more labour and capital-intensive confinement systems over free grazing livestock management in Mali. Results of the BL show that both FHH categories do not take part in the improved livestock management system, which is related to higher labour efforts and higher weaning rates. Therefore, the following scenario (SC3) aims to analyse impacts of cattle fees on participation rates of FHHs in both the traditional and improved livestock activities. Besides, such cattle fees can be evaluated as a policy instrument for counteracting future threats to pastures of becoming overgrazed. As shown by the BL, in comparison to cropping activities, cattle production has only a minor impact on biomass loss in the research area. This tendency is also confirmed by Pröpper (2009: 190) and Schneiderat (2008: 120), who calculated carrying capacities of grazing areas in Mutompo. Therefore, in SC3 cattle fees are introduced in tandem with a) fees for the use of natural resources and b) fees for the establishment of new cropping fields.

Since land was the most prominent limiting factor in the BL, this scenario additionally considers a 50 % increase of total land endowments on the village scale. Hence, total land endowments comprise 41.8 ha of soil quality ‘a’ and 59.6 ha of soil quality ‘b’.

6.3.1 Construction of fee levels

In the BL, water fees are considered by a minimum cash expenditure amount which needs to be satisfied by each FHH category per year without any differentiations. The total cash expenditure amount also includes school fees and expenditures for medical services and transport. However, in the research area water fees are often differentiated by livestock ownership. FHHs that do not own cattle have to pay 16 N$ per month (192 N$ per year). Contrarily, FHHs of livestock owners are charged 25 - 45 N$ per month (300 – 540 N$ per year) (Pröpper, 2009: 296). Thus, a difference of 9 – 29 N$ per month (108 – 348 N$ per year) is due to to livestock ownership.

With the average number of cattle owned by one FHH (revealed by the CSFS to be 18.83) a maximum water fee of cattle amounts to 18.48 N$ per head. While keeping the minimum cash expenditure amount of the BL constant in this scenario, a water fee specifically attributed to livestock of 18.48 N$ per head is added. This figure matches with findings about effective gross fees for cattle from Masters and Dalton (1998: 1). They discovered that a relatively low level of pasture tax of about 3 US$ (= approximately 25.70 N$) per livestock unit and year could increase the attractiveness of more labour and capital-intensive livestock management.

As briefly outlined in Chapter 4.5.2, in the BL of MAPOM the issuing of permits related to the use of timber trees, firewood and thatching grass was not considered due to a lacking enforcement of this regulation. However, to give an indication of a complete enforcement, SC3 additionally analyses optimal farming strategies under the assumption that permits need to be issued before trees and grasses are harvested or before firewood is collected.

Prices of permits and related fees are appointed by Pröpper (2009: 290), who refers to the Directorate of Forestry (DoF) 2007. Generally, the permit system consists of four different types. Permits are required for a) harvesting, b) transporting, c) marketing and d) exporting tree products. For the following analysis the export permit is not considered since it can be assumed that FHHs in the research area will not be engaged in any export activities, (Table 6.6).

Table 6.6: Prevailing permit system in Kavango Region

Permit type	**Product**	**Harvested amount**	**Permit price**	
			Domestic usage N$	Commercial usage N$
Harvesting				
	Poles	1,000 kg	32 1)	45 2)
	Timber trees	1 (live)	115 1)	125 2)
	Timber trees	1 (dead)	85 1)	95 2)
Transporting			5	15
Marketing			-	15

1) Includes a permit fee of 5 N$ for domestic usage. 2) Includes a permit fee of 15 N$.

Source: Own design based on figures presented in Pröpper (2009: 290).

In terms of the harvest and transport permits, differentiations are made according to the usage character. If the respective products are used domestically, lower permit prices occur which include a permit fee of 5 N$. For commercial usages, the permit price and the permit fee (15 N$) are higher. Then, a marketing permit also needs to be issued. With respect to the harvesting and selling of grasses, Pröpper (2009: 287) mentioned that villagers usually do not issue permits. However, he also reported a case where the Hompa (traditional authority) reminded the villagers of the annual flat-rate fee of 100 N$.

In MAPOM, the commercial character of natural resource products ranges from non-commercial (firewood) to semi-commercial (thatching grass) up to fully commercial (timber). Since the prevailing permit system considers other commercial characters for some products (timber, firewood), different adaptations of the permit system are necessary to improve convenience with model formulations. To avoid if-conditionals in MAPOM, transport and marketing permit fees are simplistically added to the permit prices per kg. Outcomes of the following adaptation process are summarised in Table 6.7.

Table 6.7: Constructed permit system

Products	Use specification	Harvested amount	Permit price N$	Permit price in MAPOM
Firewood	harvesting (domestic use)	per 1,000 kg	35	
	transporting (domestic use)	-	5	0.04 N$/kg
Thatching grass	harvesting (domestic use)	-	100	
	transporting (domestic use)	-	5	105 N$/year
	harvesting (commercial use)	-	100	
	transporting (commercial use)	-	15	
	marketing (commercial use)	-	15	130 N$/year
Timber trees	harvesting (commercial use)	per tree	125	
	transporting (commercial use)	-	15	
	marketing (commercial use)	-	15	0.86 N$/kg [1)]

1) With an assumed tree biomass of 180 kg.

Source: Own design based on figures presented in Pröpper (2009: 290).

Given that firewood sales are fairly uncommon in the research area and therefore not considered in MAPOM, commercial usage is not respected. A thatching grass harvesting permit consists of a flat rate of 100 N$ without any differentiations for the amount harvested or the usage character (commercially or domestically). Transport permits, on the other hand, are differentiated by the usage character. Since thatching grass can be sold, a marketing permit is compulsory. In MAPOM, the harvest of timber trees is not differentiated into 'harvesting live' or 'harvesting dead' timber trees. Therefore, a permit for timber tree harvesting relies on the permit price for live timber trees. As described in Chapter 4.5.1, one timber tree provides native biomass of approximately 180 kg. Since timber tree harvesting is assumed to be fully commercial, transport and marketing permits are added. The constructed permit system in Table 6.7 can be assumed to cover a broad variety of 'reality-conform' permit designs with its differentiation in a) commercial characters of products and b) permit characteristics (flat rates or dependent on amounts of exploitation amounts).

So far, regulations on the establishment of new fields are sorely lacking in the research area. Thus, it is rather challenging to indicate possible levels of field fees for SC3. The Namibian Communal Land Reform Act of 2002 requires that farming units for cultivation are registered with Land Boards. Land units exceeding a size of 20 ha need additional approval from the ministry (RoN, 2002) (Chapter 2.2.4). Since none of the established field sizes of the BL went far beyond this limit, another starting point needs to be found. Based on data accuracy, it seems to be most appropriate to relate fees for the establishment of new fields to the prevailing permit system for natural resources. While a linkage of crop output and fee amount does not seem to be reasonable, a flat rate per ha is suggested. According to Pröpper (2009: 127), a case study of a community forest project showed that 30 trees could be harvested on an area of 15.22 ha. Under the assumption that no additional field is established on a land unit size of one hectare, 1.97 timber trees could be possibly harvested instead. This amount of timber trees would be subjected to a harvesting fee of 246.25 N$ (Table 6.6). Consequently, for each ha of land which is cleared and hence attached to crop production, a fee of 246.25 N$ has to be paid in SC3.

6.3.2 Resource endowments

Based on higher land endowments on the village scale, both FHHs occupy higher actual land areas. Figure 6.8 illustrates the actual land endowments and areas in use for both soil quality classes and FHH categories in the BL and SC3.

Table 6.8: Actual land endowments and land areas in use by soil quality class and FHH category in scenario 3

	Actual land endowment			Land in use		
	Total	**Soil quality class 'a'**	**Soil quality class 'b'**	**Total**	**Soil quality class 'a'**	**Soil quality class 'b'**
	ha	ha	ha	ha	ha	ha
Baseline scenario						
MHFHH	23	13	10	13	4	9
FHFHH	40	13	27	19	10	9
Scenario 3						
MHFHH	50	13	36	17	8	9
FHFHH	46	27	19	24	10	14

Source: Own design based on MAPOM results.

It can be clearly seen that MHFHHs occupy slightly more land than FHFHHs and additionally occupy more land than compared to the BL. Actual land endowments equal 46 ha for FHFHHs, whereas MHFHHs occupy on average 50 ha over the entire planning horizon. Land areas in use amount to 17 ha for MHFHHs and 24 ha for FHFHHs. For both FHH groups, land set under fallow is considerably increased and amounts to 27 ha for MHFHHs (10 ha in BL) and 22 ha for FHFHHs (20 ha in BL). Though actual land endowments are increased, land is still a limiting factor and starts to become scarce after year 12 of the planning horizon (year 9 in BL). An absolute limit is reached after year 23.

With respect to the different soil quality classes, it becomes apparent that land of soil quality class ‘a’ already becomes a limit after year 6 (year 18 in BL). Land resources under soil quality class ‘b’ become scarce after year 9 and limiting after year 23 (20 in BL). Compared to the BL, MHFHHs occupy approximately equal land shares of soil quality class ‘a’ but considerably higher shares of soil quality class ‘b’. Contrarily, FHFHHs occupy considerably larger land areas under soil quality class ‘a’ and considerably lower land areas under soil quality class ‘b’.

Generally, labour capacities are similar for both FHH categories and match exactly with labour capacities from the BL.

In contrast to results of the BL, it can be summarised that:

- Limits in land endowments occur earlier and are especially more striking for soil quality class ‘a’.
- FHFHHs occupy slightly more land, whereas MHFHHs occupy considerably more land.
- No changes are apparent in labour capacities.

6.3.3 Crop production

Over the entire planning horizon, FHFHHs cultivate larger fields than MHFHHs, with a size of up to 18.4 ha on soil quality class ‘a’ and a size of up to 17.9 ha on soil quality class ‘b’. This indicates that up to 69 % of their total land endowments of soil quality class ‘a’ are entirely in use for crop production. Likewise, as much as 91 % of their total land endowments of soil quality class ‘b’ are used for crop production. Contrarily, MHFHHs cultivate cropping areas of up to 12.0 ha on soil quality class ‘a’ and up to 13.7 ha on soil quality class ‘b’. Actual land endowments in use which are employed by the crop production sector amount to a) up to 89 % of soil quality class ‘a’ and b) up to 37 % of soil quality class ‘b’. Both FHH groups alternate years of crop production processes with years of resting periods.

As outlined in Table 6.9, FHFHHs establish and cultivate bigger fields on soil quality class ‘a’ but slightly smaller fields on soil quality class ‘b’ compared to the BL. They assign significantly less land under soil quality class ‘a’ to crop production and cultivate more land under soil quality class ‘b’. In comparison to the BL, MHFHHs establish and cultivate significantly larger fields under both soil quality classes. They declare considerably more land of soil quality class ‘a’ for crop production but put slightly less land of soil quality class ‘b’ under cultivation.

No significant changes occur in terms of the preferred cropping activities. Both FHH groups a) focus on millet production under the pure cultivation mode, b) choose activities with two weeding sessions, c) usually choose activities which require row planting and consequently DAP weeding and d) even prefer two activities which also involve DAP ploughing. However, there is an obvious tendency for FHFHHs to focus on activities which do not make use of DAP ploughing. This is an important factor for identifying labour inputs.

Table 6.9: Actual land endowments and potential crop areas by soil quality class and FHH category in scenario 3

	Actual land endowment			Potential crop areas		
	Total	Soil quality class 'a'	Soil quality class 'b'	Total	Soil quality class 'a'	Soil quality class 'b'
	ha	ha	ha	ha	ha	ha
Baseline scenario						
MHFHH	23	13	10	13	4	9
FHFHH	40	13	27	31	12	19
Scenario 3						
MHFHH	50	13	36	26	12	14
FHFHH	46	27	19	36	18	18

Source: Own design based on MAPOM results.

Sizes of fields being under cultivation indicated already that production levels of millet are generally larger in comparison to the BL. MHFHHs generally produce more millet compared to the BL over the entire planning horizon. For FHFHHs, high increases are balanced by alternating high reductions. However, average production balances over the entire planning horizon are positive and amount to +599 kg per year for FHFHHs and as much as +1,726 kg per year for MHFHHs. As for the BL, both FHH categories continuously supplement domestic production with purchases and stored millet amounts from peak production years. However, purchases are reduced, especially for FHFHHs. Likewise; both FHH categories do not sell any crop products over the entire planning horizon.

As can be expected from higher production levels of MHFHHs, even the nutrition situation is improved. Nutrition levels of MHFHHs exceed minimum intake rates by a comfortable amount of 26 % (8 % in BL), resulting in 2,822 kilocalories per person and day (2,419 in BL). FHFHHs supply an average of 23 % more kilocalories than the minimum bound demands (67 % in BL). This results in an average daily energy consumption of 2,755 kilocalories per person (3,741 in BL). The apparent reduction can be explained by lower purchase volumes of FHFHHs. Contrarily, the increase in food intake rates for MHFHHs can be explained by higher land endowments considered for SC3. As indicated for the BL figures, presented are minimum kilocalorie supplies. Hence, kilocalorie deliveries can be even higher.

In contrast to results of the BL, it can be summarised that:

- FHFHHs cultivate bigger fields on soil quality class ‘a’ but slightly smaller fields on soil quality class ‘b’; they declare significantly less land under soil quality class ‘a’ but more land under soil quality class ‘b’ as being used for crop production.
- MHFHHs cultivate significantly larger fields on both soil quality classes; they declare more land of soil quality class ‘a’ but less land of soil quality class ‘b’ as being used for crop production.
- No significant changes occur in terms of the preferred cropping activities. Both FHH groups a) focus on millet production under the pure cultivation mode, b) choose activities with two weeding sessions and c) mostly choose activities which require labour-saving technology.
- FHFHHs produce slightly more millet, whereas MHFHHs produce significantly more millet; average yearly production balances over the entire planning horizon are positive.
- Both FHHs meet minimum kilocalorie requirements but welcoming increases in food energy intake rates diminish for FHFHHs and increase for MHFHHs.

6.3.4 Livestock production

In the BL, cattle production under the traditional livestock farming system was only considered to a minor degree in the optimal solution. Livestock farming under the improved system was not considered at all. This phenomenon has similar significance in SC3. A first indication can be illustrated by sizes of areas declared as grazing reserves. In comparison to the BL, grazing areas summed over both soil quality classes increased slightly from 4.0 ha to 5.68 ha accounting for both FHH categories.

Still, both FHH categories start with cattle keeping during the end of the planning horizon (MHFHHs in year 21 and FHFHHs in year 20). Cattle balances are more or less constant but show a slight decrease of -0.26 heads for MHFHHs. For FHFHHs, a slight increase of +0.05 heads can be observed. MHFHHs (FHFHHs) build up a cattle herd of 0.47 (0.38) heads of cattle (MHFHHs 0.73 heads in BL, FHFHHs 0.33 heads in BL).

In terms of the cattle category, mostly bulls and cows are kept. This is a change compared to the BL, where cattle herds consisted predominantly of calves and oxen. Comparable to the BL, both FHH categories focus on purchasing calves for building up a cattle herd but from time to time also buy oxen, bulls or cows for immediate consumption. In the BL, calves which entered the bull and cow population were immediately consumed. This is also apparent for SC3. Similar to the BL, calves which are kept are not primarily produced by FHHs themselves but are accumulated by purchases. This explains why the improved cattle farming system still is not considered in the optimal solution. Both FHH categories are not involved in any selling activities.

All three limiting factors apparent in the BL remain crucial for both FHH categories. These are a) a reduced or non-existent potential of cattle production to satisfy important consumption constraints, b) a conflict with other production sectors for the factor land and c) a conflict with other production sectors and occupations for the factor labour.

Over the entire planning horizon, FHFHHs (MHFHHs) spend per year on average a) 2,209 labour hours (1,380 labour hours) on crop production and b) 89 labour hours (92 labour hours) on livestock production. Labour hours consumed by natural resource production and daily maintenance tasks are similar for both FHH categories. These amount to 2,536 labour hours for FHFHHs and 2,532 labour hours for MHFHHs in terms of natural resource production and 1,632 labour hours for daily maintenance tasks. In comparison to the BL, both FHH categories allocate more labour hours to a) crop production (FHFHHs 1,950 man hours in BL; MHFHHs 823 man hours in BL) and b) cattle production (FHFHHs 73 man hours in BL; MHFHHs 88 man hours in BL). Contrarily, labour input remained similar for a) natural resource production (2,534 hours in BL), b) daily maintenance tasks (1,632 hours in BL) and c) off-farm labour (1,432 labour hours for MHFHHs, 1,417 labour hours for FHFHHs in BL).

In contrast to results of the BL, it can be summarised that:

- Areas declared as grazing reserves slightly increased.
- Though livestock numbers are slightly reduced, both FHH categories focus on cow and bull keeping.
- Both FHH categories start with cattle keeping at the end of the planning period.

6.3.5 Natural resource production and off-farm employment

Areas assigned as natural resource areas are rather large and more or less constant and only fluctuate to a minor degree over the entire planning horizon. Summed over both FHH categories and soil types, they amount to 33.7 ha. They belong with an extent of 9.4 ha to soil quality class ‘a’ and with an extent of 24.3 ha to soil quality class ‘b’. MHFHHs average a size of 24.3 ha, and FHFHHs average a size of 9.4 ha. Note that both FHH groups can use areas potentially assigned to the other FHH group. In comparison to the BL, total sizes of natural resource areas increase (up to 21.0 ha in BL) based on larger extents of soil quality class ‘b’ (9.4 ha in BL). Reserves predominantly assigned to MHFHHs considerably increase (up to 10.4 ha in BL), whereas areas declared by FHFHHs slightly decrease (up to 10.4 in BL).

Generally, total native biomass production on natural resource areas increases slightly over the entire planning horizon and is subjected to several fluctuations. Summed over both FHH categories, natural resource biomass production amounts to 18,977 kg per year (12,746 – 47,403 kg). In comparison to the BL, this amount is slightly increased (BL 17,129 kg per year). As described at the beginning of this section, potential areas are slightly increased. This matches with higher land endowments supplied in SC3.

For MHFHHs (FHFHHs), annual production levels equal a) 3,441 kg (3,786 kg) for firewood, b) 274 kg (347 kg) for thatching grass and c) 79 kg (110 kg) for timber tree biomass. These levels are more or less similar to production levels obtained in the BL. Some slight increases are apparent (MHFHHs: 3,398 kg firewood, 260 kg thatching grass, 76 kg timber biomass, FHFHHs: 3,428 kg of firewood, 267 kg thatching grass and 88 kg timber biomass). Domestic consumption requirements are exactly met for both FHH categories over the entire planning horizon without any over or under compensations, as do selling obligations for timber trees. Results obtained for natural resource production indicate only some minor differences to results of the BL.

As indicated in previous sections, sale activities are rather minor, especially if compared to purchases. Nevertheless, both FHH categories seem to meet budget constraints plus induced fee levels and are not even obliged to sell surplus thatching grass or timber tree reserves. This leads to considerable explicit results obtained from MAPOM with respect to off-farm employment activities. As an important aspect, both FHH groups focus on wage labour. MHFHHs are also engaged to a minor extent in casual labour activities in only nine years (1, 20, 21, 22, 23, 25, 26, 30 and 31). With some insignificant differences, both FHHs slightly increase labour hours spent on formal employment over the planning horizon. MHFHHs meet the upper bound of possible formal employment in year 23; FHFHHs meet it in year 25. While MHFHHs are involved in formal employment with on average 1,440 labour hours, FHFHHs invest on average 1,413 labour hours in wage labour activities. Cash income generated by off-farm labour activities significantly shapes the entire income balance.

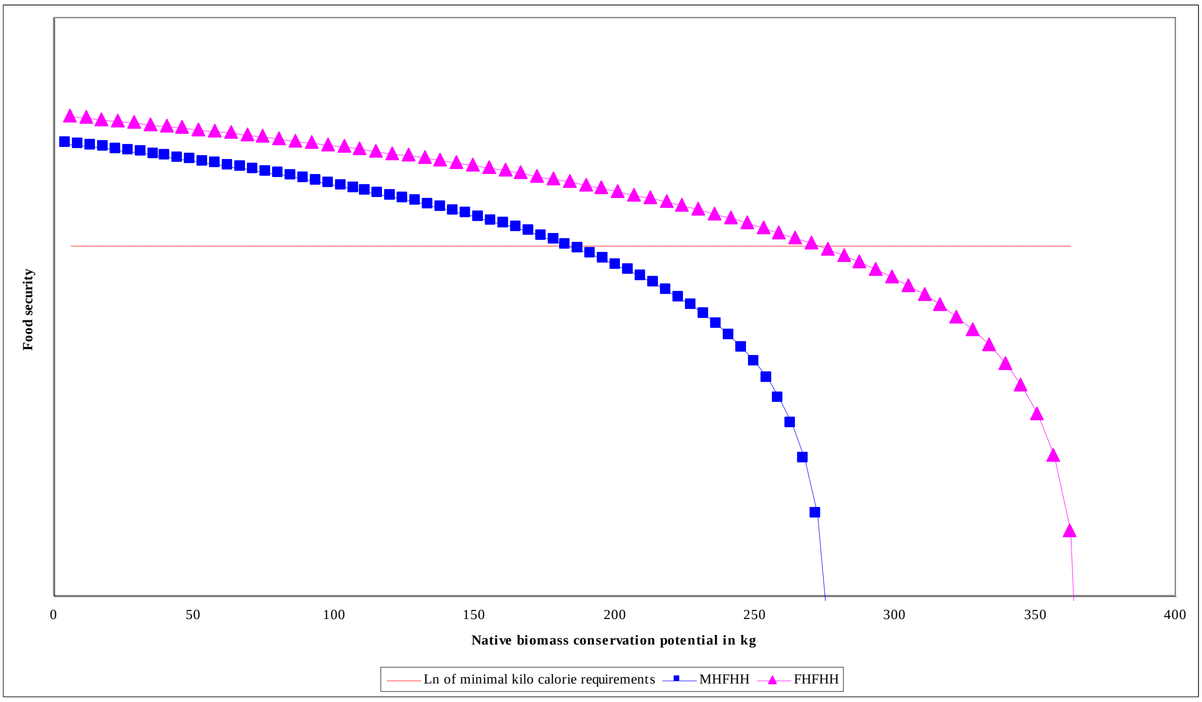
In contrast to results of the BL, it can be summarised that:

- Both FHH categories face only minor changes in terms of natural resource production and off-farm employment.

6.3.6 *Impacts on the natural resource base*

With respect to the biomass loss index, the situation compared to the BL has not significantly changed. On average over the entire planning horizon, FHFHHs face no change in the biomass loss index. For FHFHHs, only minor changes could be observed in terms of potential area endowments and crop production activities. Hence, all minor changes could be balanced over the entire planning horizon. Contrarily, biomass loss indices for MHFHHs slightly increase. These increases are predominantly assigned to natural resource production. At this point, the biomass loss index again shows its weakness. MHFHHs enlarge their areas in use for crop production considerably. Simultaneously, they increase total potential land endowments. Hence, increased crop production activities are predominantly not reflected. In comparison to the BL, the contribution of crop production to biomass loss is still striking and even increased for MHFHHs to 91 % (85 % in BL). On the other hand, it slightly declined to 92 % for FHFHHs (93 % in BL).

For both FHH categories, figures of the native biomass destruction per kilocalorie increased compared to the BL. Further, maximum kilocalorie deliveries of crop products for MHFHHs increased (2.39 kg and 16,891,000 kcal in BL). However, they declined for FHFHHs (3.85 kg and 44,696,000 kcal in BL). This indicates that trade-off curves of FHFHHs obtain lower starting points on the food security axis and are faced with a stronger decline per unit biomass conserved (Figure 6.13).



Source: Own design based on MAPOM results.

Figure 6.13: Trade-off between food security and native biomass conservation in scenario 3

Contrarily, MHFHHs reach a higher starting point on the food security axis but are also faced with a stronger decline per unit biomass conserved. As depicted by Figure 6.13, a maximum level of 187 kg native biomass could be potentially conserved by MHFHHs. A similar situation can be observed for FHFHHs. However, their trade-off curve is even more relaxed. Consequently, they could conserve a maximum of 275 kg native biomass without threatening food security.

In comparison to the BL, MHFHHs meet maximum limits of possible biomass conservation at a later state; FHFHHs meet it earlier. However, the difference between both FHH categories is reduced (MHFHHs 74 kg in BL, FHFHHs 354 kg in BL).In contrast to results of the BL, it can be summarised that:

- MHFHHs meet maximum limits of possible biomass conservation later, since higher kcal deliveries of crop production over-compensate the higher biomass destruction per kcal.
- FHFHHs meet maximum limits of possible biomass conservation earlier, since maximum kilocalorie deliveries of crop products declined.
- MHFHHs do not produce at but considerably above limits of kilocalorie requirements, hence their trade-off curve is more relaxed and less striking.
- Both FHH categories could conserve native biomass to a more or less similar degree at costs of lower kilocalorie deliveries.

6.3.7 Summary of scenario 3

Results of SC3 indicate some general tendencies in terms of optimal land use strategies under important system constraints. Note that land endowments are increased at the village scale, but FHHs face higher cash expenditures due to an enforced fee system on natural resource usage, cattle keeping and crop production. Though equipped with higher actual land endowments, both FHH categories face limitations in actual land endowments. Limits in land endowments occur earlier and are more striking on soil quality class ‘a’. FHFHHs and MHFHHs occupy about equal area sizes. No changes are apparent in labour capacities.

In terms of crop production, the following tendencies become apparent. Both FHH categories are still a) attracted to labour-saving technologies and millet production activities which promise high yield levels, b) continuously supplementing domestic millet production with purchases and store outputs in years of peak production levels to balance insufficient production levels in following periods and c) not selling any crop products. Especially for FHFHHs, purchase volumes are reduced. FHFHHs produce slightly more millet, whereas MHFHHs produce significantly more millet. Average yearly production balances over the entire planning horizon are positive. Both FHHs meet minimum kilocalorie requirements. However, welcoming increases of food energy intake rates diminished for FHFHHs and increased for MHFHHs.

In terms of livestock production, the following tendencies can be observed. Both FHH categories are to a minor degree engaged in traditional cattle production. Hence, they do not sell any cattle products. Both FHH categories primarily keep bulls and cows obtained from purchases of calves. Herd sizes of both FHH categories are slightly reduced and are still higher for MHFHHs than for FHFHHs.

In terms of natural resource production and off-farm labour, it becomes evident that both FHH categories are still a) to a similar degree involved in natural resource production and b) to a similar degree engaged in off-farm labour activities, the major source of cash income, and focus on wage labour employment.

With respect to impacts on the natural resource base, it can be summarised that FHFHHs are still more engaged in native biomass destruction activities. They meet maximum possible limits of biomass conservation earlier, since quotients of biomass destruction per kcal are higher and maximum kcal deliveries of crop production are lower. Contrarily, MHFHHs do not produce at limits of kilocalorie requirement, but above. Hence, their trade-off curve is more relaxed and less striking. Both FHH categories can to a similar degree conserve natural resource biomass.

6.4 A scenario based on changes in weighting factors in the objective function

According to Kruseman (2000: 29) and Brown (2000: 3/4), the specification of an adequate objective function which respects for competing and complementary goals has not always received sufficient attention in existing modelling approaches. In the Kavango region, FHHs are often composed of a number of different individuals. Their needs might differ from needs and interests of the FHH head (Matsaert et al. (1998: 2/ 51).

Bearing these two aspects in mind, this study empirically identified objectives of peasant farmers, simultaneously regarding gender specification of objectives. However, in order to show the importance of including such empirical findings, this scenario (SC4) presents optimal farming strategies neglecting objectives of peasant FHHs under prevailing system constraints. This is achieved by changing weighting factors in the objective function.

As outlined in Chapter 4.7.2.2, different weights are attached to different on and off-farm activities of MHFHHs and FHFHHs. In SC4, such weights are either completely ignored or not respecting for gender specification. For one FHH category in MAPOM, each production sector obtains an equal weighting factor. In the following, this FHH category is called the ‘equal weighting farm household’ (EWFHH). For the second FHH category, each production sector obtains average weighting factors without respecting for gender differentiation. In the following, this FHH category is called the ‘average weighting farm household’ (AWFHH).

6.4.1 Resource endowments

As already apparent in the BL, maximum land endowments are a limiting factor for both FHH groups. Absolute limits are reached in year 24 of the planning horizon. Table 6.10 illustrates actual land endowments and areas in use for both soil quality classes for MHFHHs, FHFHHs, EWFHHs and AWFHHs.

Table 6.10: Actual land endowments and areas in use by soil quality class and FHH category in scenario 4

	Actual land endowment			Land in use		
	Total ha	Soil quality class 'a' ha	Soil quality class 'b' ha	Total ha	Soil quality class 'a' ha	Soil quality class 'b' ha
Baseline scenario						
MHFHH	23	13	10	13	4	9
FHFHH	40	13	27	19	10	9
Scenario 4						
MHFHH	38	19	19	20	7	13
FHFHH	23	7	16	10	7	3

Source: Own design based on MAPOM results.

Compared to EWFHHs, actual land endowments, or land declared as potential areas for crop, livestock and natural resource production, are higher for AWFHHs and amount to 38 ha on average. Both FHH categories do not cultivate these potential areas completely. Land in use exceeds 30 ha only once for AWFHHs but amount to an average of 20 ha. Generally, EWFHHs use less land. Their crop, grazing and natural resource areas in use add up to 10 ha.

In comparison to the BL, limits of land endowments are striking three years later. AWFHHs occupy more land than MHFHHs and less than FHFHHs but use on average more than both. Contrarily, EWFHHs occupy similar land endowments as MHFHHs but use less than both. With respect to different soil quality classes, the following tendencies become apparent. The absolute limit of soil quality class ‘a’ is reached in year 20, though it declines to 2 ha as early as after year 7 of the planning horizon. For soil quality class ‘b’, a total bound is reached three years later (24). AWFHHs do not show a preference for one or the other soil quality class. They declare about 19 ha of each soil quality class as being potentially in use for farming activities. Contrarily, EWFHHs occupy only about 7 ha of soil quality class ‘a’ and 16 ha of soil quality class ‘b’.

In comparison to the BL, relative (declining under 2 ha) and absolute limits of land endowments become striking with a slight time delay. Again, AWFHHs occupy a) more land of both soil quality classes than MHFHHs, b) more land of soil quality class ‘a’ than FHFHHs and c) less land of soil quality ‘b’ than FHFHHs. Contrarily, EWFHHs mostly occupy less land of both soil quality classes than all other FHH categories (an exception is land under soil quality class ‘b’ compared to MHFHHs).

Generally, labour capacities are similar for both FHH categories and comprise on average 83 % family and 17 % hired labour. Both FHH categories take full advantage of hiring external labour and consume it up to its imposed maximum.

In contrast to results of the BL, it can be summarised that:

- Land limits of both soil quality classes become generally striking with a slight time delay.
- FHFHHs occupy on average the highest land endowments, followed by AWFHHs, MHFHHs and EWFHHs.
- AWFHHs use on average the most land endowments followed by FHFHHs, MHFHHs and EWFHHs.
- No changes are apparent in labour capacities.

6.4.2 Crop production

Over the entire planning horizon, AWFHHs cultivate larger fields with a size of up to 10.2 ha on soil quality class ‘a’ and up to 18.3 ha on soil quality class ‘b’. This indicates that up to 54 % of their total land endowments of soil quality class ‘a’ and up to 98 % of their total land endowments of soil quality class ‘b’ are entirely used for crop production. Contrarily, EWFHHs cultivate only up to 5.1 ha on soil quality class ‘a’ and up to 6.1 ha on soil quality class ‘b’ (Table 6.11). Actual land endowments under use by the crop production sector amount for them to a) up to 73 % of soil quality class ‘a’ and b) up to 37 % of soil quality class ‘b’. Both FHH groups alternate years of crop production processes with years of resting periods.

Table 6.11: Actual land endowments and potential crop areas by soil quality class and FHH category in scenario 4

	Actual land endowment			Potential crop areas		
	Total	Soil quality class 'a'	Soil quality class 'b'	Total	Soil quality class 'a'	Soil quality class 'b'
	ha	ha	ha	ha	ha	ha
Baseline scenario						
MHFHH	23	13	10	13	4	9
FHFHH	40	13	27	31	12	19
Scenario 4						
MHFHH	38	19	19	28	10	18
FHFHH	23	7	16	11	5	6

Source: Own design based on MAPOM results.

In comparison to BL, AWFHHs use the most of their actual land endowments of soil quality class ‘b’ for crop production followed by MHFHHs, FHFHHs and EWFHHs. Contrarily, FHFHHs use most of their actual land endowments of soil quality class ‘a’ for crop production, followed by EWFHHs, AWFHHs and MHFHHs. Hence, FHFHHs and EWFHHs predominantly prefer land under soil quality class ‘a’ for crop production. Contrarily, MHFHHs and AWFHHs use mainly soil quality class ‘b’.

In comparison to the BL, no changes occur in terms of the preferred cropping activities. Even AWFHHs und EWFHHs a) focus on millet production under the pure cultivation mode, b) choose activities with two weeding sessions, c) usually choose activities which require row planting and consequently DAP weeding and d) even prefer two activities which also involve DAP ploughing.

Sizes of fields under cultivation indicate that production levels of millet are higher for AWFHHs than for EWFHHs. In comparison to FHFHHs and MHFHHs of the BL, it is obvious that average production levels per year over the entire planning horizon are highest for FHFHHs (5,358 kg), followed by AWFHHs (5,077 kg), MHFHHs (2,284 kg) and EWFHHs (1,788 kg). For all FHH groups, similar interactions of peak and zero production levels are apparent. Zero production levels are predominantly balanced by stored products from previous periods, though purchases supplement domestic production in several years. Further, all FHH groups show a zero production level in year 20. Though weighting factors of the objective function are attached to consumption amounts of FHHs, the following tendency becomes apparent for production levels. A ranking of the production levels according to the FHH category predominantly follows a possible ranking pattern of weighting factors attached to crop production. Weights for FHFHHs are the highest (0.23), followed by AWFHHs (0.19) and MHFHHs (0.16). EWFHHs are the exception (0.20). For this FHH category, effects of the absolute weighting factor for crop production are overshadowed by the relative equality of weighting factors for all other considered farming activities.

In terms of utilisation patterns, two aspects become apparent. First, AWFHHs and EWFHHs do not sell any crop products over the entire planning horizon. This matches with findings for FHFHHs and MHFHHs from the BL. Second, both FHH categories meet minimum kilocalorie needs of all their FHH members over the entire planning horizon. AWFHHs exceed minimum kilocalorie intake rates in several years (4, 8, 10, 14, 15, 16, 19, 21, 23, 25, 27) and supply an average of 16 % more kilocalories than the minimum bound demands. This results in 2,598 kilocalories per person and day. This welcoming nutrition improvement is not apparent for EWFHHs. Daily dietary energy rates include on average only a 1 % increase over minimum bounds. This averages 2,262 kilocalories per person and day. In comparison to the BL, equal tendencies could be observed for FHFHHs and MHFHHs.

In contrast to results of the BL, it can be summarised that:

- All FHH categories are attracted to labour-saving technologies and millet production activities which promise high yield levels.
- All FHH categories continuously supplement domestic millet production with purchases and store outputs in years of peak production levels to balance insufficient production levels in following periods.
- All FHH categories do not sell any crop products.
- FHFHHs generate the highest production levels on average per year, followed by AWFHHs, MHFHHs and EWFHHs.
- A ranking of the production levels according to the FHH category predominantly follows a possible ranking pattern of weighting factors attached to crop production. An exception occurs for EWFHHs.
- FHFHHs provide their members with maximum food energy intakes over minimum bounds, followed by AWFHHs, MHFHHs and EWFHHs.

6.4.3 Livestock production

Generally, cattle production produced by either the traditional or improved livestock system does not seem to be a promising farming strategy even in SC4. This can be indicated by actual grazing area sizes, which amount to 4 ha summed over both FHH categories and soil types. Only some cattle under the traditional livestock farming system are kept during the end of the planning horizon. AWFHHs start with cattle keeping in year 22, whereas EWFHHs start three years later. On average over the entire planning horizon, AWFHHs keep 0.65 heads of cattle, while EWFHHs keep 0.52 heads of cattle.

In comparison to BL, both AWFHHs and EWFHHs start slightly later with their traditional cattle production activities than MHFHHs and FHFHHs. AWFHHs and EWFHHs keep fewer cattle than MHFHHs (0.73) but more than FHFHHs (0.33). Two general tendencies can be distinguished: a) all FHH categories build up their herds predominantly by purchases of calves, which either enter the bull and cow population after three years or are immediately consumed, and b) all FHH categories are not involved in any selling activities.

As outlined in more detail for results of the BL, similar limiting factors are also crucial for AWFHHs and EWFHHs. These are a) a reduced or non-existent potential of cattle production to satisfy important consumption constraints, b) a conflict with other production sectors for the factor land and c) a conflict with other production sectors and occupations for the factor labour.

Utilisation of hired external labour to the limit imposed by the system and results in terms of crop production indicate that labour might be a limiting factor. Both FHH categories focus on crop production activities with a high level of labour-saving technologies.

In comparisons to results of the BL, it can be summarised that:

- MHFHHs are the earliest starters of cattle production under the traditional regime, followed by FHFHHs, AWFHHs and EWFHHs.
- MHFHHs keep the largest cattle herds followed by AWFHHs, EWFHHs and FHFHHs.
- A ranking of the cattle numbers kept according to FHH category predominantly follows a possible ranking pattern of weighting factors attached to livestock production. An exception occurs for EWFHHs.
- All FHH categories a) build up their herds predominantly by purchases of calves, which after three years either enter the bull and cow population or are immediately consumed, and b) are not involved in any selling activities.
- For all FHH categories, livestock production is constrained by a) a reduced or non-existent potential of cattle products to satisfy important consumption constraints and b) a conflict with other production sectors or occupations for the factors labour and land.
- EWFHHs spend the largest time resources on family, social and cultural activities, amounting to on average 47 %, followed by MHFHHs (45 %), AWFHHs (37 %)

and FHFHHs (37 %). This fact reflects the relative higher weighting factor of EWFHHs for such activities.

6.4.4 Natural resource production and off-farm employment

Areas assigned as natural resource areas are rather large and more or less constant and only fluctuate to a minor degree over the entire planning horizon. Over both FHH categories, they amount to 23.8 ha. They belong with an amount of 10.6 ha to soil quality class ‘a’ and with an amount of 13.2 ha to soil quality class ‘b’. AWFHHs have an average size of 10.6 ha, while EWFHHs have an average size of 13.2 ha. Note that both FHH groups can use areas potentially assigned to the other FHH group.

Generally, total native biomass production on natural resource areas slightly increases over the entire planning horizon and is subject to several fluctuations. Summed over both FHH categories, natural resource biomass amounts to 18,054 kg per year (12,753 – 37,744 kg). Annual production of firewood amounts to 3,560 kg (3,454 kg) for AWFHHs (EWFHHs). Likewise, 1,495 kg (1,579 kg) of thatching grass and 1,012 kg (891 kg) of timber tree biomass are produced. Compared to the BL, the following slightly changed tendencies can be observed: AWFHHs produce on average the highest amounts of firewood per year, followed by EWFHHs, FHFHHs and MHFHHs. FHFHHs produce on average the highest amounts of thatching grass per year, followed by EWFHHs, AWFHHs and MHFHHs. AWFHHs produce on average the highest amounts of timber trees per year, followed by FHFHHs, MHFHHs and EWFHHs.

Over the entire planning horizon, domestic consumption requirements are exactly met for both FHH categories without any over or under compensations. Similarly, obligations for timber tree selling activities are considered. However, MHFHHs, FHFHHs and AWFHHs start with timber tree selling activities in year 21; EWFHHs start with a slight time delay in year 26. Though respecting considerably higher weighting factors for natural resource production, EWFHHs (0.20) do not consume higher amounts of firewood or thatching grass than AWFHHs (0.06). At this point, again, the relation to other weighting factors seems to outweigh effects of a higher weighting factor for natural resource usage.

As indicated in previous sections, all sale activities are rather minor, especially if compared to purchases. Nevertheless, both FHH categories seem to meet budget constraints and are not even obliged to sell surplus thatching grass reserves. This leads to considerable explicit results with respect to off-farm employment activities. As an important aspect, both FHH groups focus on wage labour employment. AWFHHs even participate in casual labour for 12 years of the planning horizon. With some insignificant differences, AWFHHs and EWFHHs slightly increase hours spent on formal employment up to the year 21, when both reach the upper bound of 1,516 hours. Cash income generated by off-farm labour activities significantly shapes the general cash income balance.

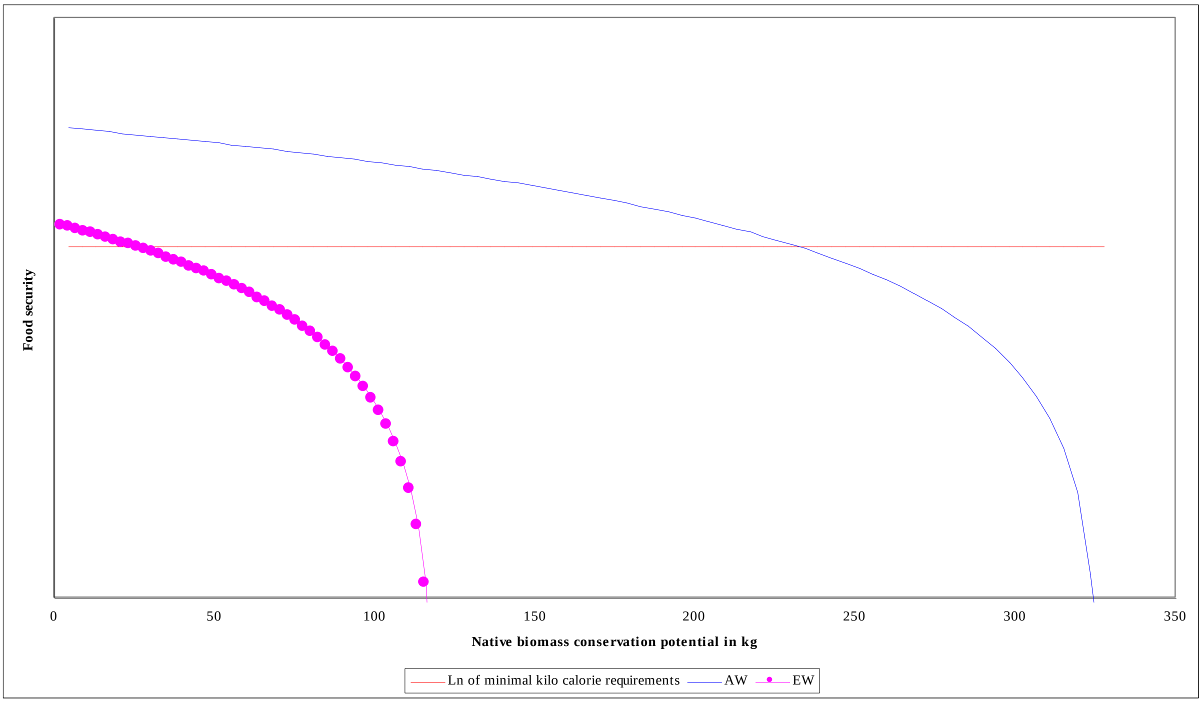
In comparisons to results of the BL, it can be summarised that:

- All FHH categories are to a more or less equal degree involved in natural resource production for predominantly satisfying domestic energy and building material requirements.
- All FHH categories are to an equal degree engaged in off-farm labour activities, the major source of income, and focus on wage labour employment.
- EWFHHs (0.20) do not consume higher amounts of firewood or thatching grass than AWFHHs (0.06), although they attach a higher weight to natural resource production.
- Both FHH categories with the highest weighting factors for off-farm employment, which are AWFHH (0.29) and MHFHH (0.31), are also engaged in casual labour.

6.4.5 Impacts on the natural resource base

With respect to the native biomass loss index, AWFHHs seem to focus on farming activities which are significantly more destructive for native biomass. Though a simplified indicator, biomass loss signifies a clear relationship between native biomass loss and crop production even for AWFHHs and EWFHHs.

Summed over the entire planning horizon, results of MAPOM for AWFHHs show that a production of 1,000 kilocalories destroys an average of 4.25 kg native biomass. For EWFHHs, this figure amounts to 2.36 kg. A maximum of 32,653,000 kcal can be supplied by crop production in one year for AWFHHs. For EWFHHs, this maximum amounts to 11,862,000 kcal. Assuming that these amounts are produced without any conservation measures delivers the intersection with the y-axis. This means that native natural resource conservation equals zero where a maximum of kilocalories can be supplied by crop production and vice versa. Reducing this amount continuously by 4.25 kg delivers the intersection with the x-axis. As can be seen in Figure 6.14, a maximum level of 234 kg native biomass can be conserved by AWFHHs. As can be expected, the assumed relationship for EWFHHs is similar but on the other hand more striking. Since EWFHHs produce at the very limit of minimum kilocalorie requirements, the area between the curve and the straight line is considerably smaller. Hence, they could conserve less native biomass without threatening food security (26 kg).



Source: Own design based on MAPOM results.

Figure 6.14: Trade-off between food security and native biomass conservation in scenario 4

In contrast to results of the BL, it can be summarised that:

- FHFHHs and AWFHHs are more engaged in native biomass destruction activities than EWFHHs and MHFHHs.
- All FHH categories face a trade-off between native biomass conservation and food security.
- FHFHHs generate the highest amounts of kilocalories by crop production, followed by AWFHHs, MHFHHs and EWFHHs.
- For AWFHHs, a production of 1,000 kcal is related to the highest native biomass destruction, followed by FHFHHs, MHFHHs and EWFHHs.
- For EWFHHs and MHFHHs, the potential of conserving native biomass is more limited, since they already produce at the limit in terms of kilocalorie deliveries.

6.4.6 Summary of scenario 4

Results of the SC4 indicate some general tendencies in terms of optimal land use strategies under important system constraints. Overall, production activities of AWFHH and EWFHH face limitations in actual land endowments, but limits in land endowments occur with a slight time delay. All FHH categories frequently alternate periods of usage with periods of resting. FHFHHs occupy on average the largest land endowments followed by AWFHHs, MHFHHs and EWFHHs. Contrarily, AWFHHs use on average the largest land endowments followed by FHFHHs, MHFHHs, and EWFHHs.

In terms of crop production, all FHH categories are a) similarly attracted to labour-saving technologies and millet production activities which promise high yield levels, b) continuously supplementing domestic millet production with purchases and store outputs in years of peak production levels to balance insufficient production levels in following periods and c) not selling any crop products. FHFHHs obtain the highest production levels per year followed by AWFHHs, MHFHHs and EWFHHs. A ranking of the production levels according to FHH category predominantly follows a possible ranking pattern of weighting factors attached to crop production. An exception occurs for EWFHHs. FHFHHs provide their members with the highest food energy intake rates, followed by AWFHHs, MHFHHs and EWFHHs.

In terms of livestock production, it can be summarised that MHFHHs are the earliest starters of cattle production under the traditional regime, followed by FHFHHs, AWFHHs and EWFHHs. They additionally keep the largest cattle herds, followed by AWFHHs, EWFHHs and FHFHHs. A ranking of the cattle numbers kept according to FHH category predominantly follows a possible ranking pattern of weighting factors attached to livestock production. An exception occurs for EWFHHs. All FHH categories a) build up their herds predominantly by purchases of calves, which after three years either enter the bull and cow population or are immediately consumed, and b) are not involved in any selling activities. All FHH categories face a reduced or non-existent potential of cattle products to satisfy important consumption constraints, followed by constraints on land and labour.

In terms of natural resource usage and off-farm employment, it becomes evident that all FHH categories a) are to a more or less similar degree involved in natural resource production, b) are to a similar degree engaged in off-farm labour activities, the major source of income, and c) focus on wage labour employment. Both FHH categories with the highest weighting factors for off-farm employment, which are AWFHHs and MHFHHs, are also engaged in casual labour.

With respect to impacts on the natural environment, it can be summarised that FHFHHs and AWFHHs are more engaged in native biomass destruction activities than EWFHHs and MHFHHs. All FHH categories face a trade-off between native biomass conservation and food security. FHFHHs generate the highest amounts of kilocalories by crop production, followed by AWFHHs, MHFHHs and EWFHHs. For AWFHHs, a production of 1,000 kcal is related to the highest native biomass destruction, followed by FHFHHs, MHFHHs and EWFHHs. For EWFHHs and MHFHHs, the potential to conserve native biomass is more limited, since they already produce at the limit in terms of kilocalorie deliveries.

6.5 Summary and conclusions

In general, results of the BL indicate that land is a limiting factor, caused predominantly by the fact that FHHs apply continuous resting periods. Additionally, labour is limiting, since FHHs take full advantage of labour hiring activities. With respect to crop and livestock production, FHHs are attracted to labour-saving technologies or systems demanding little labour. They supplement domestic production with purchases. They do not take part in any selling activities. Generally, they satisfy minimum consumption constraints for nutrition, energy and building materials. In this context, nutrition levels are partly overcompensated and based on an induced system constraint. This is predominantly served by crop production. Consequently, cattle production plays a minor role in optimal farming strategies. The major cash income generation activity is participating in off-farm employment. Nevertheless, income balances equal zero for several years. A trade-off between food security and native biomass conservation is apparent. To some degree, native biomass could be conserved without tremendously threatening food security. This potential is higher for FHFHHs, since overcompensations of nutrition levels are higher.

Based on a modification of the cattle keeping element in the objective function, some changes in optimal farming strategies become apparent. Cattle production is slightly intensified at the cost of crop production activities. Consequently, overcompensations of nutrition requirements and potentials of native biomass conservation without threatening food security are reduced.

The introduction of fees for cattle keeping, field clearing and natural resource exploitation coupled with higher land endowments only lead to significant changes in optimal farming strategies for MHFHHs. They produce considerably more millet. Consequently, overcompensations of nutrition requirements and the potential to conserve native biomass without threatening food security are increased. However, these effects are based on the higher land endowments. Contrarily, the behaviour of FHFHHs can be partly attributed to the enforcement of the fee system. They produce only slightly more millet but reduce on the other hand their purchasing volumes. Higher cash income is needed to pay for the fees and purchases need to be reduced. Generally, the enforcement of the fee system has only minor impacts on optimal farming strategies. With respect to MHFHHs, they even lead to the fact that more land is put under cultivation instead of conserving native natural resources.

Based on a modification of weighting factors in the objective function, some effects on optimal farming strategies become apparent. Generally, average weighting factors which do not consider gender specification in objectives are suitable to represent optimal farming strategies of both genders to some degree. Contrarily, equal weighting factors for all production sectors underestimate (crop) or overestimate (cattle) optimal production levels. By definition this has no impacts on model-induced constraints, and the focus is still on crop production activities. Based on the underestimations of optimal crop production levels, equal weighting factors underestimate impacts on the natural resource base.

This study shows that embedding empirically identified objectives of peasant FHHs in a multi-annual programming model is a suitable approach to identify optimal farming strategies under conditions in the research area. It could be revealed that a promising farming strategy for the research area consists of crop production activities combined with off-farm employment, minor cattle production and constant usage of natural resources. Food security is a predominant impacting factor on these strategies. It is noteworthy that labour-saving technologies or low labour demanding farming systems are primarily preferred. For crop production, these labour-saving devices focus on weeding and ploughing labour. Hence, findings of this study support suggested labour-saving potentials proposed by Hange et al. (1999: 14). Even in terms of cattle production, management systems with lower labour inputs belong to optimal farming strategies. In this context, it could be revealed that some innovative farming strategies do not reflect a suitable alternative to prevailing farming strategies. Notably, the improved livestock management activity is not considered in any solution. This is predominantly based on its higher cash and labour inputs. Moreover, the optimal livestock system is based on purchasing calves to build up cattle herds. This phenomenon outweighs the advantage of the improved system, which is characterised by higher weaning rates.

In this study, ratios of producers to dependents within a FHH are assumed to be constant, though increasing in absolute numbers over time. This ratio can be negatively influenced by the HIV/AIDS epidemic, which is suggested to decrease the general labour pool (World Bank, 2001: 4). The fact that under unchanged 'producer to dependents' ratios, optimal farming strategies are based on labour-saving technologies, shows their potential importance in future years for the research area.

Optimal strategies include in all instances formal employment to its system-imposed limits. This indicates that if formal employment offers could be increased in the research area, FHHs might release even more family labour from farming activities. Crop production has a major impact on the destruction of native biomass, which leads to biodiversity loss in the long run. Simultaneously, crop production is one major activity delivering nutrition. To counteract this trade-off by creating incentives to 'pay' for natural resource usages does not seem to be a suitable solution in the research area. Indeed, opposite effects can be expected.

In terms of the used modelling approach, three aspects are highly important. First, elements included in the objective function and their compositions have an impact on identified optimal farming strategies. Second, levels of weighting factors of the objective function arguments and their relation to one another influence optimal farming strategies to a similar degree. Hence, outcomes of this study support recommendations on a more adequate identification process of the objective function, suggested by Brown (2000: 3/4) and Kruseman (2000: 29). Third, a further specification of weighting factors between certain groups, for instance between genders, impacts identified farming strategies to a lesser degree. Hence, general tendencies can be revealed without further differentiations.

6.6 Policy recommendations and future research

Bearing summarised conclusions in mind, it seems to be of high relevance to promote labour-saving technologies for the different farming activities in the Kavango Region. In terms of crop production, such technologies are mostly needed in terms of saving weeding labour. Though row planting consumes more labour than the traditional method during the planting process, it saves higher amounts of weeding labour. Generally, the promotion process needs to be addressed to both genders. This is based on two important aspects. First, weeding is not gender-specific (Matsaert et al., 1995: 20). Second, for managing DAP, the absence of male FHH members, in case of ploughing, is already a serious constraint on crop production (Mutwamwezi, Matsaert, 1998: 10). Hence, both genders need to be in the position to handle DAP for both processes.

Additionally, labour-saving technologies could be addressed to daily maintenance tasks like water fetching. Such technologies need to be specifically tailored to women, since they are predominantly responsible for daily maintenance. Released labour could then be invested into productive farming activities. In terms of natural resource production, more effective stoves which can be used with less firewood could possibly offset some labour for firewood collection.

Instead of creating incentives to 'pay' for natural resource usage, policy measures need to create incentives to 'value' natural resources. A starting point in this direction is already made in the Kavango Region, in terms of supporting the development of community forests (Pröpper, 2009: 127). Users of such forests are permitted to extract natural resources but under a sustainable setting. In connection with labour-saving technologies, a promotion of 'slightly' intensified farming activities could be another starting point. Investments into soil fertility by promoting the usage of manure could prevent continuous establishment of new fields, which was observed by Pröpper (2009: 172). Creating incentives in this direction could conserve native natural resources. However, such a promotion needs to be highly connected with labour-saving technologies.

Another recommendation of this study addresses the creation of off-farm employment facilities for peasant FHHs. Formal employment can reduce incentives to extract more natural resources than are domestically demanded, since cash income does not need to be supplemented (Reardon, et. al, 1996: 20). Creating off-farm employment directly in rural areas can be assumed to be a rather difficult task. However, as evidenced by present and past phenomena, FHHs in the Kavango Region are highly willing to take up formal employment even in nearby towns or other regions of Namibia (Matsaert, 1996: 17). Generally, men face better chances to get involved in formal employment. They would then be absent from farming activities (Mutwamwezi, Matsaert, 1998: 10). Since men are responsible for managing DAP in crop production processes, incentives to create off-farm employment would then need to be coupled with 'DAP managing training courses' for women. Again, a reduction of the family labour pool by off-farm employment requires promotion of labour-saving technologies. Besides, off-farm employment can support a sustainable intensification process. This can be achieved by generating cash income for investments into soil fertility. Hence, it can conserve native natural resources by preventing new fields from being cleared continually (Reardon, et. al, 1996: 20).

Unavoidably, this study could not address all relevant factors related to optimal farming strategies in the Kavango Region, and there is more work for future research. Though addressing risk aversion in some instances by incorporating a manifold set of farming activities, this study does not tackle risk and uncertainty directly. This could be achieved by a) reformulating the implied utility function and incorporating 'expected' utility, b) making rainfall events stochastic or c) considering the timing of rainfall events.

Another limitation of this study is related to its database. An inclusion of time-series data for all relevant economic parameter levels could improve the consistency. Moreover, ecological data which a) reflect environmental interdependences in the Kavango Region and b) are suitable to be encompassed in an economic model are so far missing. Hence, the bio-physical component of MAPOM was rather small. Specifically, coefficients which describe the relationship between soil quality, its degradation and related crop yields could improve the outcomes. This study focuses on millet production and cattle production activities. An improvement at rather ‘low’ costs would be an additional inclusion of other crop production activities and goat rearing. A consideration of, for instance, cash crops or Yathropha, as a crop which delivers biofuels, could test the commercialisation potentials of the prevailing farming system.

Summary

Farming activities can be assumed to be one of several driving forces which lead to continuous deterioration processes of tree and bush savannahs in the Kavango Region of northeastern Namibia. However, these farming activities can be assumed to be closely connected with securing subsistence needs of peasant farmers. In this context, the present study aims to a) empirically identify objectives of peasant farmers, b) quantify their most prevailing and other possible on-farm and off-farm activities, c) identify optimal farming strategies under important system constraints and their impacts on environmental and socioeconomic aspects and d) identify policy-induced changes to the previously identified optimal farming strategies. Results of this study are intended to a) serve as a solution point for similar problems in related ecological or economic systems and b) be relevant for policy makers to investigate policy impacts on peasant farming strategies.

Chapter 2 addresses some major challenges of the Namibian economy. In particular, the agricultural sector and the peasant farming system of the Kavango Region are described. In this environment, agricultural activities are predominantly subsistence-oriented and embedded in a semi-commercial system of imperfect markets. The prevailing farming-system comprises of three major elements: a) crop production, b) livestock production and c) natural resource production. By a varying degree, all elements contribute to food security, cash income or domestic usage patterns. Hence, an important internal driving force which causes (over)usage or depletion of natural resources is the obligation to secure substantial living needs. This aspect is further discussed by giving an outline of a) environmental and socioeconomic threats as well as b) possible coping strategies.

Chapter 3 illustrates the theoretical background of the present study by discussing two different methodological approaches. Peasant farmers in the research area can be assumed to be both producers and consumers. This aspect determines the first considered methodological approach. Several concepts of farm household (FHH) models reflect non-separability under specific assumptions and imply certain benefits and limitations. This study uses a FHH model which is primary based on *Barnum and Squire*. However, it is supplemented by features from *Chayanov* and *Low*. Economic farm activities are influenced by the natural resource base and vice versa. This aspect determines the second considered methodological approach. In order to reflect economic and environmental dynamics, bio-economic models (BEM) are well-known tools. Hence, important facets of BEMs and their applications to various research tasks and areas are briefly outlined. This study develops a multi-annual programming optimisation model (MAPOM) which is based on

theories of FHHs and BEMs. MAPOM represents a typical village with two non-separable and non-interacting gender-specific FHH categories and includes some bio-physical features. Both FHH categories are equally equipped with several farm assets but follow different objectives.

Utility is maximised for both FHH categories by consuming several goods and services which are generated by participating in different farm and off-farm activities. One major constraint which needs to be respected is food security. Biophysical dynamics are addressed by a) including rainfall in all on-farm production functions, b) updating the resource base each year and c) calculating a 'native biomass loss' index for each farming element.

Chapter 4 consists of two parts which describe the data base of MAPOM. Primary data is predominantly obtained by a case study on farming systems (CSFS). Outcomes of the CSFS build the basis of all relevant parameter calculation processes (e.g. static input-output relationships). Moreover, a review of region-specific publications is supplemented to validate calculation outcomes and to fill data gaps. In a second part, this chapter depicts the methodological approach of a traditional conjoint analysis (TCA). This method is used to identify objectives of peasant farmers. A brief outline of the research design is specified after a description of the theoretical foundation of TCAs and their applications in developing countries. Results of this analysis generated weighting factors for the arguments of the objective function used in MAPOM. Since these results showed some gender specifications, MAPOM distinguishes in this point between female and male-headed FHH.

Chapter 5 presents the model framework and the mathematical model formulations. Generally, it embeds the previously determined static input-output combinations in dynamic ecological and economic relationships, in terms of equations. These equations are specified for each farming element and off-farm activity in MAPOM. Moreover, the most important consumption patterns are outlined along with production functions. As an example, equations are specified for cattle dynamics, annual growth of native biomass and population dynamics. Linkages of the different farming system elements become apparent in exchange relationships specifically between livestock and crop production. In addition, attention is paid to the description of system-related constraints. They are implemented in MAPOM to mirror the prevailing conditions in the research area. A final section presents the development of the objective function.

Chapter 6 illustrates the results of four different scenarios simulated by MAPOM. In general, all different farming elements and off-farm activities are represented to a varying

degree in the optimal solution of the baseline scenario. Cattle production plays a minor role in optimal farming strategies. Results indicate that land and labour are limiting factors. A trade-off between food security and native biomass conservation is apparent. To some degree, native biomass could be potentially conserved without tremendously threatening food security. Scenario 2 involves a modification of the cattle-keeping element in the objective function. Then, cattle production is slightly intensified at the costs of crop production activities. Simultaneously, overcompensations of nutrition requirements and potentials of native biomass conservation are reduced. Scenario 3 addresses the enforcement of a fee system for natural resources usage and considers an increased land endowment. Impacts of these changes on optimal farming strategies are rather small. However, in some cases farmers use even more land for cultivation, instead of conserving native natural resources. In a final scenario, weighting factors in the objective function are modified. Generally, average weighting factors (over both genders) are suitable to reflect optimal farming strategies of both genders to some degree. Contrarily, equal weighting factors underestimate or overestimate optimal production levels. Hence, they do not reflect actual native biomass destruction potentials. Results of all scenarios indicated that FHHs are highly attracted to labour-saving technologies or activities which demand little labour. Hence, family labour is one of the most prominent limiting factors. This factor might, however, be threatened in the future by several socioeconomic developments. Therefore, it seems to be of high relevance to promote labour-saving devices for the different farming activities of peasant farmers in the research area.

References

Araya B (2005) Poverty and natural resource management in the Central Highlands of Eritrea. Dissertation. University of Groningen. Groningen, Netherlands

Ashley C (1996) Incentives affecting biodiversity conservation and sustainable use: the case of land use options in Namibia. Research Discussion Paper. Directorate of Environmental Affairs. Ministry of Environment and Tourism. Windhoek, Namibia

Backhaus K, Erichson B, Plinke W, Weiber R (2006) Multivariate Analysemethoden: Eine anwendungsorientierte Einführung. 11. Auflage, Springer. Berlin, Deutschland

Backhaus K, Frohs M (2008) Die Messung von Zahlungsbereitschaften für produktbegleitende Dienstleistungen im Industriegütermarketing –ein konzeptioneller Vorschlag. http://www.escpeap.net/conferences/marketing/2008_cp/Materiali/Paper/Fr/Frohs_Backhaus.pdf Retrieved at 25.05.09

Barbier B, Bergeron G (1998) Natural resource management in the hillsides of Honduras: Bio-economic modelling at the micro-watershed level. EPTD Discussion Paper No. 32. International Food Policy Research Institute. Washington, USA

Barbier B, Carpentier C (2000) The conditions for sustainability of tropical agriculture. Bio-economic models applied to five contrasting farming systems. Paper presented at the International Association of Agricultural Economists (IAAE) Conference. Berlin, Germany

Barnum H, Squire L (1979) A model of an agricultural household. Theory and evidence. Johns Hopkins University Press. USA

Bender A (1992) Meat and meat products in human nutrition in developing countries. Food and Nutrition Paper 53. Commissioned jointly by the Animal Production and Health Division and the Food Policy and Nutrition Division of FAO. Rome, Italy

Benson J (1979) Rural labour use and development strategies in east Africa and India. In: Ryan, J.G., Thompson, I.L. eds. Socioeconomic Constraints to Development of Semi-Arid Tropical Agriculture (p. 333-346). Hyderabad, India

Bester F, Els J, Jessen P, Reed E (2000) The Sanga Cattle: Manual for extension officers and farmers. Ministry of Agriculture, Water and Rural Development. Directorate of Agricultural Research and Training. Division of Research (Livestock). Windhoek, Namibia

Börner J (2006) A bio-economic model of small-scale farmers' land use decisions and technology choice in the eastern Brazilian Amazon. Dissertation. Rheinische-Friedrich-Wilhelms-Universität. Hohe Landwirtschaftliche Fakultät. Institut für Betriebslehre. Bonn, Deutschland

Brown D (2000) A review of bio-economic models. Paper prepared for the Cornell African Food Security and Natural Resource Management (CAFSNRM) Program. Cornell University. New York, USA

Buß H (2006) Land Use Options of Namibian Farms. Optimal Management Strategies proposed by Bio-economic Models. Dissertation. Agrarökonomische Studien. Wissenschaftsverlag Vauk Kiel KG. Kiel, Deutschland

Byerlee D (1979) Rural labour markets in west Africa with emphasise on the semi-arid tropics. In: Ryan J., Thompson I eds. Socioeconomic Constraints to Development of Semi-Arid Tropical Agriculture (p. 348-355). Hyderabad, India

Cacho O (2000) The role of bio-economic models in renewable resource management and assessment of solution techniques. Paper presented at the International Conference of Agricultural Economists (IAAE). Berlin, Germany

Chen M, Dunn E (1996) Household economic portfolios. Assessing the Impact of Microenterprise Services (AIMS). Harvard Institute for International Development and the University of Missouri. Missouri, USA

Chirwa R (2007) Consumer preferences for beans in Malawie and its influence on price. In: Highlights CIAT (Centro Internacional de Agriculture Tropical) in Africa 2007. No. 37

De Janvry A, Fafchamps M, Sadoulet E (1991) Peasant household behaviour with missing markets: Some paradoxes explained. The Economic Journal, 101, p. 1400-1417

De Janvry A, Sabbarao K (1986) Agricultural price policy and income distribution in India. Oxford University Press

De Janvry A, Sadoulet E, Fafchamps M, Raki M (1992) Structural adjustment and peasantry in Morocco: A computable household model. European Review of Agricultural Economics, Volume 19, Number 4, p 427-53

De Viers P (1992) A Research Journey: on Actors, Concepts and the Text. In: Long R and Long A (ed.) Battlefields of Knowledge: The Interlocking of Research and Practice in Social Research and Development. London: Routledge

Deniau L, Mukuhu O, Iyambo H, Blanc F (1997) Livestock production in Omusati and Ohagwena Regions, Namibia. Proceedings of the 7th Annual Congress of the Agricultural Scientific Society of Namibia. Windhoek, Namibia

Domptail S, Popp A, Nuppenau E (2009) A trade-off analysis between rangeland health and income generation in southern Namibia. In: Agrobiodiversity conservation and economic development. Routledge Explorations in Environmental Economics. University of Stirling. United Kingdom

Drechsler M, Grimm V, Mysiak J, Wätzold F (2005) Differences and similarities between ecological and economic models for biodiversity conservation. UFZ Discussion Papers. Department of Ecological Modelling, Department of Economics. Centre for Environmental Research. Leipzig-Halle, Germany

Ellis F (1992) Peasant economics: Farm households and agrarian development. Cambridge University Press. Cambridge, USA

Emongor R (2008) The impact of South African supermarkets on agricultural and industrial development in the Southern African Development Community. Dissertation. Department of Agricultural Economics, Extension and Rural Development, Faculty of Natural and Agricultural Sciences, University of Pretoria. Pretoria, South Africa

Fischer I, Buchenrieder G (2008) Insurance preferences of smallholders: Results from an Adaptive Conjoint Analysis in Northern Vietnam. Discussion Paper No. 05/2008. University of Hohenheim, Department of Agricultural Economics and Social Science in the Tropics and Subtropics. Stuttgart, Germany

Food and Agriculture Organisation (FAO) (1992) Food, Nutrition and Agriculture. International Conference on Nutrition. Issue 5/6. FAO Report. Rome, Italy

Food and Agriculture Organisation (FAO) (1995) Sorghum and millets in human nutrition. FAO Nutrition series, No. 27. Rome, Italy

Food and Agriculture Organisation (FAO) (1996) The world Sorghum and Millet Economics: Facts, Trends and Outlook. A joint study by the Basic Foodstuffs Service FAL Commodities and Trade Division and the Socioeconomics and Policy Division International Crops Research Institute for the Semi-Arid Tropics. FAO Report. Rome, Italy

Food and Agriculture Organisation (FAO) (1998) Large gap in food availability between rich and poor countries. New map on nutrition released. Press release 98/70. Rome, Italy

Food and Agriculture Organisation (FAO) (2000) Wood fuels review and assessment: Namibia country report. FAO Report. Rome, Italy

Food and Agriculture Organisation (FAO) (2001) Global Forest Fire Assessment 1990 – 2000. FAO Report. Rome, Italy

Food and Agriculture Organisation (FAO) (2006) The State of Food Insecurity in the World. Eradicating world hunger - taking stock ten years after the World Food Summit. FAO Report. Rome, Italy

Food and Agriculture Organisation (FAO) (2009) Map of Namibia
http://www.fao.org/fi/oldsite/FCP/en/NAM/PICS/Map%20Namibia.jpg
Retrieved at 25.05.09

Fuller B and Van Zyl D (2006) Silently starving: A new form of famine among small scale farming households affected by the HIV epidemic? NEPRU Working Paper No. 107. The Namibian Economic Policy Research Unit. Windhoek, Namibia.

Hange A, Kakakuru E, Low A, Bagnell-Oakley H (1999) The impact of HIV/AIDS on gender burdens and household incomes in Kavango: technology and policy implications. Discussion Paper No 4. Ministry of Agriculture, Water and Rural Development, Division Agricultural Planning, Directorate of Planning, Department of Agriculture and Rural Development. Windhoek, Namibia

Hengua A, Bovell R (1997) Communal Livestock in Okavango: A literature review. Report of the Kavango Farming System Research and Extension (KFSR). Rundu, Namibia

Holden S (2004) Bio-economic modelling for NRM impact assessment. Discussion Paper # D-13/2004. Department of Economics and Resource Management. Agricultural University of Norway. Norway

Holden S, Shiferaw B, Pender J (2004) Non-farm income, household welfare, and sustainable land management in a less-favoured area in the Ethiopian highlands. Food Policy 29, pp. 369-92

Holtz U (2003) The United Nations Convention to Combat Desertification (UNCCD) and its political dimension. Paper prepared for the 5th Parliamentary Round Table in the context of the implementation of the UNCCD

International Fund for Agricultural Development (IFAD) (2007) Assessing farmer's preferences for improving the provision of livestock health services. Report and technical advisory notes of an IFAD supported research carried out by the International Livestock Research Institute (ILRI)

Jones B, Cownie D (2001) Socio-ecological survey report for the Kavango Region (Namibia – 2001). Report produced for the Every River Has Its People Project. Windhoek, Namibia

Kakukuru E, Matsaert H, Mutwamwezi E (1998) KSFR/E Case study monitoring 1995 - 1997 report on trees and forest products. Kavango Farming System Research and Extension (KFSRE) Working Document 30. Rundu, Namibia

Klein M (2002) Die Conjoint-Analyse. Eine Einführung in das Verfahren mit einem Ausblick auf mögliche sozialwissenschaftliche Anwendungen. In ZA-Information, 50, 2002, p. 7-45. Zentralarchiv für Empirische Sozialforschung. Universität Köln. Köln, Deutschland

Klink C (2004) Development of communal grazing resources of a Northern Namibian village. Trend extrapolation with GAMS based on conjoint measurement. Masterarbeit. Philipps Universität Marburg. Wirtschaftswissenschaften. Institut für Kooperation in Entwicklungsländern. Marburg, Deutschland

Kojwang H (2000) Country Report Namibia. Forest Outlook Studies in Africa (FOSA). FAO. Forestry Department. Rome, Italy

Krusemann G (2000) Bio-economic household modelling for agricultural intensification. Dissertation. Wageningen University.Wageningen, Netherlands

Lopez R (1986) Structural models of the farm household that allow for interdependent utility and profit-maximisation decisions. In: Agricultural Household Models: Extensions, Applications and Policy. Singh I, Squire L, Strauss J, Johns Hopkins University Press. Baltimore, Maryland, USA

Low A (1986) Agricultural development in Southern Africa: Farm household theory and the food crisis. James Currey. London, United Kingdom

Masters W, Dalton T (1998) Pasture taxes and agricultural intensification in southern Mali. Agricultural Economics Volume 19, Issue 1-2, pages 27-2

Matsaert H (1996) Kavango Region socio-economic overview: A preliminary report. Kavango Farming System Research and Extension (KFSRE) Working Document WD 9. Rundu, Namibia

Matsaert H, Hatutale K, Simbombo J (1995) Survey of an inland community of Kavango Mbora Village. Working Document WD7. Rundu, Namibia

Matsaert H, Mutwamwezi E, Kakukuru E (1998) Getting to know rural livelihoods in Kavango through case study monitoring. Kavango Farming System Research and Extension (KFSRE) Working Document 26. Rundu, Namibia

Mendelsohn J, El Obeid S (2003) Sand and water. A profile of the Kavango Region. Struik Publishers and RAISON for the Ministry of Environment and Tourism. Cape Town, Windhoek, Namibia

Ministry of Agriculture, Water and Rural Development (Mawrd) (1996) Farm management survey of the Kavango Region. Analysis Report 1. Directorate of Planning. Windhoek, Namibia

Ministry of Agriculture, Water and Rural Development (Mawrd) (1997) Spotlight on agriculture: The Sanga -the underrated breed. Ministry of Agriculture, Water and Rural Development. Directorate of Agriculture Research and Training. Spotlight on agriculture No 3. Windhoek, Namibia

Ministry of Agriculture, Water and Rural Development (Mawrd) (2003) Baseline survey of the impact of agricultural extension services in the Kavango Region. Ministry of Agriculture, Water and Rural Development. Rundu, Namibia

Mmopelwa G (2006) The value of the Okavango-delta: A natural resource accounting approach. Dissertation. Faculty of Natural and Agricultural Sciences. Department of Agricultural Economics, Extension and Rural Development. University of Pretoria. Pretoria, South Africa

Mutwamwezi E, Matsaert H (1998) Crop production in Kavango: Findings of case study monitoring 1995 – 1997. Kavango Farming System Research and Extension (KFSRE) Working Document Number 29. Rundu, Namibia

Myers N (2002) Biodiversity and bio depletion: The need for a paradigm shift. In: Biodiversity, Sustainability and Human Communities. Protecting beyond the Protected. O'Rioradan, Stoll-Kleemann. Cambridge University Press p. 46 – 60. Cambridge, United Kingdom

Okumu BN, Jabbar MA, Colman D, Russel N, Pender J (2001) Bio-economic modelling for ex ante assessment of technology and policy impact at watershed level: A case study. Paper presented at the workshop of Integrated Management for Sustainable Agriculture, Forestry and Fisheries. August, 2001. Ciat, Cali, Colombia.

Petersen A (2008) Pedodiversity of Southern African Drylands. Dissertation. Institute of Soil Science. University of Hamburg. Hamburg, Germany

Pröpper M (2009) Culture and Biodiversity in Central Kavango, Namibia. Dissertation. Kulturanalysen Band 10. Dietrich Reimer Verlag

Pröpper M, Gruber M (2007) Wiza Wetu! Our Forest! Ethnographic awareness film. Rukwangali with English subtitles. Running time: 50 minutes. Gruberfilm. Produced by the Institute for Social Anthropology. University of Hamburg, Germany

Reardon T, Crawford E, Kelly V, Diagana B (1996) Promoting farm investment for sustainable intensification of African agriculture. Technical Paper No. 26. Office of Sustainable Development Bureau for Africa. SD Publication Series.

Republic of Namibia (RoN) (2002) Communal Land Act. Windhoek, Namibia

Rooyen van B, Gartside A (1999) Livestock Report: Findings of a survey about animal husbandry and management practices in five riverine villages. Kavango Region. Kavango Farming System Research and Extension (KFSR/E) Working Document 31. Rundu. Namibia

Schneiderat U (2008) Livestock farming in communal areas in northern and central Namibia: Rangeland resources and their users. Dissertation *submitted* to the Department of Agricultural Science, Home Economics and Resource Management. Justus-Liebig University. Giessen, Germany

Senahoun J, Heidhues F, Deybe D (2001) Structural adjustment program and soil erosion: A bio-economic modelling approach for Northern Benin. In: Sustaining the Global Farm. Selected papers from the 10th International Soil Conservation Organization Meeting. May 1999. Purdue University

Shiferaw B, Holden S (1999) Soil erosion and smallholders' conservation decisions in the highlands of Ethiopia. World Development, Vol. 27, No. 4, pp. 739-752

Singh I, Squire L, Strauss J (1986) Agricultural household models: Extensions, Applications, and Policy. Johns Hopkins University Press. Baltimore, Maryland, USA

Singh I, Subramanian J (1986) Agricultural household modelling in a multi-crop environment: Case studies in Korea and Nigeria. In: Agricultural household models: Extensions, Applications and Policy. Singh I, Squire L, Strauss J, Johns Hopkins University Press. Baltimore, Maryland, USA

Standard Bank (SB) (2009) Interest rates for the 'One Account' and 'Pure Save' account in 2009. http://www.standardbank.co.za/SBIC/Frontdoor_02_05/0,2358,3447_1091713_0,00.html (Retrieved at 15.05.09)

Strauss J (1986) Estimating the determinants of food consumption and caloric availability in rural Sierra Leone. In: Agricultural household models: Extensions, Applications and Policy. Singh I, Squire L, Strauss J, Johns Hopkins University Press. Baltimore, Maryland, USA

Strohbach B (2000) Vegetation degradation in Namibia. Paper presented at the 75th Aniversary Congress of the Namibian Scientific Society. 2-3 June 2000. Windhoek, Namibia

Strohbach B, Strohbach M (2004) An annotated plant species list for Mile 46 LDC and surrounding area in central Kavango, Namibia with some notes on species diversity. Dintreria No 29: 55-78. Windhoek, Namibia

Sweet J (1998) A rainfall model for estimating carrying capacity. NOLIDEP Northern Region Development Project. Ministry of Agriculture, Water and Rural Development (MAWRD). Windhoek, Namibia

Sweet J, Burke A (2002) Country pastures/ Forage resource profiles: Namibia. FAO Agricultural Department Crop and Grassland Service. Country Pasture Profiles. FAO Report. Rome, Italy

Tano K, Kamuango M, Faminow M, Swallow B (2003): Using conjoint analysis to estimate farmer's preferences for cattle traits in West Africa. Ecological Economics Vol. 45 Issue 3: 393-407.

Taylor E, Adelman I (2003) Agricultural household models: Genesis, evolution, and extensions. Review of Economics of the Household, Vol. 1: 33-58.

Teichert T (2001) Nutzenschätzung in Conjoint-Analysen. Theoretische Fundierung und empirische Aussagekraft. Dt. Universitätsverlag. Band: 282. Reihe: neue betriebswirtschaftliche Forschung (nbf). 342 Seiten

Teer J (1996) Conservation of living resources in a changing world. Environmental Management. Vol. 20 No. 6: 925 -931.

The Pennsylvania State University (TPSU) (2006) Health harvest: Enhancing educational and economic opportunities for women agriculturalists in Namibia. Report of the College of Agricultural Sciences. The Association Liaison Office for University Cooperation in Development Promoting Higher Education Partnerships for Global Development. Pennsylvania, USA

Twine W, Moshe D, Netshiluvhi T, Siphugu V (2003) Consumption and direct-use values of savannah bio-resources used by rural households in Mametja, a semi arid area of Limpopo province, South Africa. South African Journal of Science. 99:467-473

Upton M (1987) African farm management. Cambridge University Press. Cambridge, USA

Vigne and Associates (2005) The feasibility of commercial Mahangu production in the Namibian communal areas. Namibian Agronomic Board. Windhoek, Namibia

Voeth M (2000) Nutzenmessung in der Kaufverhaltensforschung: Die Hierarchische Individualisiert Limit-Conjoint-Analyse (HILCA). Gabler, Wiesbaden, zugleich Habilitationsschrift. Münster, Deutschland

Vogel M (2006) Erfassung von Vegetationsveränderungen in Namibia mit Hilfe von Fernerkundungs-Change-Dection-Verfahren und unter Berücksichtigung rezentrer Niederschlagsereignisse. Dissertation. Institut für Geographie. Würzburg. Julius-Maximilians-Universität. Würzburg. Deutschland

Wiegand S (1992) Die Conjoint-Analyse als Instrument zur Nutzenmessung: Ergebnisse einer Befragung in den neuen Bundesländern. Frankfurt am Main. Johann-Wolfgang-Goethe-Universität, Fachbereich Wirtschaftswissenschaften. Frankfurter volkswirtschaftliche Diskussionsbeiträge 35

Wildner R, Dietrich H, Hölscher A (2006) HILCA: Ein neues Conjoint-Verfahren zur verbesserten Abbildung von Kaufentscheidungen komplexer Produkte. GfK. Jahrbuch der Absatz- und Verbrauchsforschung 4/2006

World Bank (2001) Namibia selected development impact of HIV/AIDS. Macroeconomic Technical Group, Africa Region. Report No. 22046-NAM

World Bank (2007) Country Brief

World Bank (2008) Namibia at a glance

World Bank B (2007) Millennium Development Goals

World Health Organization (WHO) and Food and Agriculture Organisation (FAO) (2003) Diet, Nutrition and the prevention of chronic diseases: report of a joint WHO/FAO expert consultation. WHO technical report series 916

Yaron G, Janssen G, Maamberua U. (1992) Rural Development in the Okavango Region of Namibia: An assessment of needs, opportunities and constraints. Gamsberg Macmillan Publishers. Windhoek, Namibia

Appendix

Appendix A1: Equation listing of the MAPOM GAMS code

Appendix A2: Information sheet for crop production activities

Appendix A3: Parameter levels embedded in MAPOM

For a copy of Appendix A1, A2 and A3 or the complete model code please contact:

Justus-Liebig-Universität Giessen

Institut für Agrarpolitik und Marktforschung

Professur für Agrarpolitik und Umweltpolitik

Senckenbergstrasse 3

35390 Giessen, Germany

or

Judith Hecht

Davidsbodenstrasse 28

4056 Basel, Switzerland

Judith.Hecht@gmx.net

Judith Hecht

Decision Making of Rural Farm Households in Namibia

ISBN 978-3-86955-505-8

9 783869 555058