Evaluation of biomass enhancing practices in the Yatenga region of Burkina Faso

MSc Thesis – Plant Production Systems


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MSc Thesis Report

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For quality of life

Preface

Over the course of the last year I learnt a lot about my thesis subject but also gained many new insights fuelling my personal development. The trip to Mali has been an eye opener, as I found myself face to face with a different world and new ways of thinking. The field work in Mali confronted me with 'real farmers', which changed their static role on paper to real and live people. This fed my enthusiasm to do my best at this thesis. I am very grateful towards all the respondents who had patience and time for answering my questions, gave me new information and raised interesting questions related to my project. In many cases, however, I also got questions about what I was going to do and how I was going to help them. Those exchanges made me question my role as a plant sciences student and made me wonder about how I/we can contribute to the improvements in 'the quality of life'.

Hereby I would like to thank Issa and Bakary, who made my stay at the guest house much more comfortable and pleasant and who introduced me to all the nice places in Koutiala. Also many thanks for the introduction to Malian cooking and for taking the time to make and drink tea, which lead to nice exchanges teaching me about our cultural differences. After being in Koutiala for a month, I stayed in Bamako for a week, where I was warmly welcomed by Fily in her family home. Being her guest gave me the opportunity to discover how it is to live in Mali for a Malian family and allowed me to be part of their daily routines. Here again the cooking amazed me and being able to cook a 'European' meal in a pot on coals was a great experience. Fily also showed me around in the headquarters of the IER (Institut d'Economie Rurale) and ICRISAT, which I really appreciated as it showed me how research is performed in practice, in a different location from the university.

In this way I would like to thank the ILRI team in Burkina Faso, especially Viviane Yameogo and Augustine Ayantunde, for their input. Thank you for collecting and arranging data and providing information, without which it would not have been possible to perform this thesis. I am grateful for the support from the WLE Biomass project, enabling data collection. A big thanks also goes to CCAFS for the provision of household data.

Of course I owe much to everyone at A.M.E.D.D., especially Bougouna, Ousmane and Arouna, who spent time and energy helping me in setting up the fieldwork and getting around in Koutiala. Sory, Michel and Bakary have been a great help, without them it would have been much more difficult to perform the interviews. I especially appreciated the discussions about farming in Mali and in the Netherlands, where I learned that what is normal for me is often different from what is normal in Mali, and the other way around. I am also grateful for the time taken to make sure we were all on one line before starting the interviews and organising the fieldwork, this gave me confidence in conducting my first ever interviews.

I also owe much to Mink, who has been a great help and has provided answers to my unending list of questions related to the use of FARMSIM. Finally, I would like to thank Katrien and Wim, who supported me throughout the whole thesis process. Thank you for supporting me in my wish to go abroad, even with the impediments and the impossibility to go to Burkina Faso. This lead to an experience which I will not soon forget. I am also grateful for all the help you gave during the thesis and the great feedback I have received. It has helped me in going further, digging deeper and improving my work.

Summary

In the Yatenga region of Burkina Faso agriculture is the main source of livelihoods. However, farmers are poor and vulnerable due to erratic rainfall. This leads to the need to produce food while thinking of the maintenance or improvement of soil quality, to ensure future food production. For the project 'Realising the full potential of mixed crop-livestock systems in rapidly changing Sahelian agro-ecological landscapes' (WLE Volta and Niger Focal Region), several suggested interventions are evaluated based on their impact on food and feed production and on soil fertility. The adoptability of these interventions for farmers is also assessed, as this influences the reach and impact of the project. The aim of this thesis was to build a decision-tool to help (among others) extension agents in choosing the right interventions to promote per farm. Six farm types are distinguished based on their resource endowment, as resource endowment influences farming constraints and goals and alters the impacts of interventions on the farming system.

For the impact evaluation of the interventions, the NUANCES-FARMSIM (Nutrient Use in Animal and Cropping systems – Efficiencies and Scales, FARM SIMulator) model was used, an integrated crop livestock model adapted to African smallholder farming systems. The model was adapted to the local situation (e.g. rainfall, soil and household characteristics) and a baseline scenario was run for 12 years. The different interventions were then simulated and the model was run again. The indicators taken into account were total farm calorie production (averaged over the years), livestock productivity (milk production and cattle weight, averaged over the years) and farm average soil organic carbon (SOC, for the last simulation year). The outcomes for the different interventions were compared to the outcomes of the baseline scenario to monitor changes. For all farm types the outcomes for the different interventions followed the same trends, although the magnitude of the impacts varied. This depended mainly on the crops grown and on the area of farm land available per cattle head.

Farmer constraints, goals and attitudes were assessed through conducting interviews in the villages Ziga, Ninigui and Thiou in the Yatenga region. Per type the strength of the constraints limiting agricultural production (cropping land, pasture area, livestock, capital, education and technology) were measured and combined to expert opinions on the inputs of these elements needed for the implementation of interventions. From there it was possible to retrieve which interventions had the least constraints limiting adoption and which interventions had the strongest constraints limiting adoption. A difference in strength of present farming constraints was discerned based on resource endowment. Farmers were also asked about their farming goals, which also influence adoption potential. Farmer goals turned out to be dependent on resource endowment, similarly to the farming constraints. It was hypothesized that farmer attitude (positive or negative view on farming) would also influence intervention take-up. In this thesis it was however impossible to discern clear attitude groups.

From the information collected in this thesis a decision tool was made to help in the process of choosing the best suited interventions for different farm types. The following steps should be taken for finding those interventions. Households should be classified based on resource endowment. Then the constraints present for the household should be noted. This determines which constraints might limit intervention adoption or which constraints should be alleviated for the implementation of the interventions. The impact of the interventions on the farming system should then be found (impact on SOC, food production and livestock productivity). With the information about farming constraints and intervention impact, the user of the decision tool should consider which intervention to promote and implement. Once one or several interventions are chosen it should be checked whether the interventions lead towards the goal(s) of the farmer, as when this is the case the rate of adoption of the intervention will be increased.

Contents

1 Introduction

1.1 General introduction

Agriculture is the principle source of livelihood in the Sahel, employing more than half of the working population and contributing to close to 40% of the gross domestic product (Mortimore and Adams, 2001). However, farmers in the Sahel are one of the poorest in the world (Zorom et al. 2013) and they also are vulnerable, due to the erratic rainfall and the frequent long dry spells, creating an unpredictable natural production potential (the World Bank, 2013; Dreschel et al. 2005).

Farmers in the Yatenga province of Northern Burkina Faso are no exception. This province has problems of environmental deterioration; a great part of the land is degraded or eroded (Critchley, 1991). Many households suffer from yearly hunger periods during the dry periods, lasting from 3 to 5 months (WLE, 2014).

1.2 Present challenges

Besides water as a limiting factor to agricultural production in Burkina Faso, low soil fertility and nutrient limitation are also strong. It limits plant production and restricts the vegetation use of water to 10-15% of the rainfall (Bationo & Buerkert, 2001; Bationo & Mokwunye, 1991; de Ridder et al., 2004). Low soil fertility has been blamed to cause chronic hunger for 28% of the African population and to lead to more than 50% of the population surviving on less than 1$ a day (Bationo et al., 2007). The increasing population pressure leads to a reduction in the amount and the duration of fallow periods, causing a shift to permanent cultivation and a following decrease in soil quality. The use of external inputs is still marginal, with the yearly nitrogen plus phosphate fertilizer use in Burkina Faso in the year 2010 averaging only 8 kg of $N+P_20_5$ total nutrients per hectare. In the same year this value was 120 and 227 kg $N+P_2O_5$ total nutrients for France and the Netherlands respectively (FAOSTAT, 2013). For these various reasons insufficient nutrients are returned to the soil, resulting in soil depletion (de Ridder et al. 2004). Therefore the rate of soil degradation in the Sahel is high (Mando & Stroosnijder, 1999).

1.3 Future challenges

Next to the existing challenges, it is expected that climate change will strongly affect Africa, especially the drier regions such as the Sahel. Rainfall will become even more irregular, both in amount and distribution (Barbier et al 2009). Panthou et al. (2014) found that the frequency of extreme rainfall events has increased in the last decades. These changes have and will have repercussions on ecosystem services, agricultural production and livelihoods (Mertz et al. 2009).

Combined with this, the population growth rate in the Sahel is one of the highest in the world, reaching 3.1% in Burkina Faso (Haub and Kaneda, 2014). This population increase had led to a decreasing per capita food production over the past thirty years, even though the overall food production in the country has increased (Bationo et al., 2007).

The interplay and additional challenges of soil degradation, population growth and climate change lead to the already scarce natural resources and biomass production being under increasing pressure. There is a need to enhance food and feed production, while keeping soil quality as optimal as possible.

There are several different ways for increasing food and feed production and promoting soil fertility. Potential avenues for improving these aspects are specific interventions aimed at improving soil fertility (e.g. manure management), genetic improvements in crops to increase the food and feed production, practices to reduce erosion, to optimize growing conditions, to conserve water, etc. In this thesis the focus is on biomass enhancing activities because biomass production serves many purposes in farming systems. It is important as a source of food, feed, fuel and fibre and increasing biomass production could therefore lead to decreasing the hunger period and increasing income.

Biomass is an important player in regulating and supporting ecosystem services (ES). Regulating ES are benefits received by the regulation of ecosystem processes, such as pollination, erosion control, water regulation. Supporting ES are necessary for providing the other ES and have only indirect effect on people (such as soil formation processes which indirectly affect people through improved food production). Biomass plays a role in these two ES as it provides organic matter (OM) for the soil and it can act as a protective soil cover. Returning OM to the soil improves soil fertility and structure through many different pathways (MEA, 2003), including the provision of nutrients, the provision of habitat for soil organisms and the improvement of soil water holding capacity. A greater soil cover decreases erosion and traps sediments, thus keeping nutrients in place and available for uptake by plants (Zhang et al., 2007). Next to this a soil cover also stimulates biological activity, changes soil temperature and reduces water evaporation (Mando & Stroosnijder, 1999). On the long term, enhanced biomass production could therefore lead to improved plant nutrient provision and better soil water retention (Power, 2010). This then increases plant production and leads to improved food and feed availability.

Biomass is also an important player in the provisioning ecosystem services. Crop biomass production leads to the availability of food and feed, while the biomass is also a source of raw materials which can be used for construction and fuel (Valbuena, 2015). The presence of biomass also affects the flow and the purification of fresh water, influencing the quantity and quality of fresh water available. Forests and grassland can also be a source of plants used in medicine.

The optimal situation is attained when food and feed production are improved and the amount of OM returned to the soil has increased. This means that both the provisioning and the regulating and supporting ecosystem services would improve. However, trade-offs are often found between maximizing provisioning services on the one hand and maximising regulating, cultural and supporting services on the other hand (MEA, 2003 and Elmqvist et al., 2013). Therefore optimizing food production in the short term might not lead to highest amount of biomass available for soil cover and soil organic matter in the long term. At the same time, it is not impossible to improve both the provisioning and the regulating ES, as cases are found where the implementation of new agricultural techniques have led to the reduction of the trade-off between the two ecosystems services (Elmqvist et al., 2013). Examples are the introduction of integrated pest management and the implementation of integrated nutrient management (Pretty et al., 2006).

1.4 Using a model to quantify the impact of interventions

To be able to reduce the trade-off it is important to understand the role of biomass in farming systems, as different interventions will affect the nature or the magnitude of the trade-off in a different way (MEA, 2003).

One way to understand the impact of interventions is through the use of a model. A model can give insight into the complexity and the conflicts in agro-ecosystems, through the simulation of different system components, their interactions and the effects of processes at various levels (field, farm, landscape) (McCown, et al., 1996). Not only information can be gained about the yearly impact of the interventions, a model can also give insight about the long-term consequences of interventions and the sustainability of a system. The level chosen for this thesis is the farm level, enabling the following of on-farm food and feed production while keeping track of the soil fertility in different fields. This makes it possible to simulate the impact of different management options.

A model can also be used to perform an exploratory research, by simulating the impact of potential interventions. It hereby gives insight in the underlying reasons for observed effects, the key constraint and opportunities in agricultural systems (Whitbread et al., 2010). Next to this the use of a model can also directly engage farmers, inviting them in the design of farming system, leading to the designing of on-farm experiments and changes in the farming practices. (Whitbread et al., 2010). In addition to this a modelling exercise is fast once it is set up, compared to a field trial.

The NUANCES FARMSIM model (Nutrient Use in Animal and Cropping systems – Efficiencies and Scales, FARM SIMulator) is a model adapted to the African smallholder farming systems, which can help understanding the role of biomass in farming systems through simulation exercises. It is possible to use NUANCES-FARMSIM to analyse the effect of various interventions within farming systems.

1.5 Need for adaptation of interventions to farm types

Next to understanding the role of the biomass, it is also important to think about the drivers and constraints which influence the practice of biomass enhancing measures, or how well interventions are adapted to the context in which farmers operate. Any innovation must answer the goals of farmers and their short-term will to increase income, food production and reduce risks (Bationo & Buerkert, 2001). Two main paradigms exist on the explanation of the adoption of technologies (Bidogeza, 2009):

- The economic paradigm. It states that resource endowment determines adoption of interventions. In this paradigm no emphasis is put on the heterogeneity in preference among farmers.
- The innovation diffusion paradigm. This paradigm puts weight on the role of information, risk factors and social positions in the adoption of interventions. Households have different roles; they can for example be innovators or followers and therefore more or less promptly adopt new interventions. No emphasis is put on the practical ability of the farmers to perform the intervention.

In this thesis elements from the two paradigms are used. Resource endowment is taken into account in determining the adoption of interventions. Farmer constraint, goals and attitudes, which correspond more to the diffusion paradigm are also considered.

1.5.1 Resource endowment

Land, livestock, capital and labour resources differ between farmers and gender. These differences will determine soil fertility management practices, farm management and the type of investments made (Defoer et al., 2000). Resource endowment will also influence the farmer's perception of a new intervention and play a role in the adoption of interventions. The role of biomass will also be different on the different farms, as available resources (land, livestock, etc.) vary. Thus the repercussions of interventions on food production, livestock productivity and SOC are unique. For this reason it is necessary to tailor biomass interventions to specific contexts, by exploring the role of biomass for farmers with varying resource endowments.

1.5.2 Constraints

It is also important to review farming constraints, defined here as the limitations present reducing potential agricultural production. Where no limitations are present, the constraints restricting adoption are the lowest and the adoption potential could be increased. Production constraints can be felt at farm level (e.g. land shortage) or beyond the farm level (e.g. no access to seeds). The farmer's resources will partly define what the constraints for biomass production are, as the constraints often depend on socio-economic conditions (Defoer et al., 2000). Examples of potential constraints are capital, education, technology, land and livestock.

1.5.3 Goals and attitudes

Two other important points in determining the suitability of an intervention to farmers are farming goal (what the farmer intends to attain through farming) and the farming attitude (the farmer's disposition towards farming). They influence the adoption rate of the intervention as they determine which practices are most relevant to farmers. For example, if crop yield production is very important, measures which strongly increase soil organic carbon (SOC) but for which the increase in yields is only slight and visible after several years will not be prioritized by the farmers and adoption rates may be low.

1.5.4 Examination of farm heterogeneity

An important step in analysing the suitability of interventions for farmers is the examination of farm heterogeneity. Failing in doing this can lead to the promotion and implementation of a 'one-size- fits-all' intervention which does not fulfil the farmer's requirements (Woolverton, 2014). In the aim of creating biomass enhancing interventions, not only one solution should be manufactured but a “basket of options”, should be proposed and reviewed. For each group of farmers the best suitable options can then be suggested (Defoer et al., 2000).

1.6 Problem Analysis

There is an increasing pressure on biomass in the Yatenga province of Burkina Faso. The ‘basket of options’ available for increasing biomass production has to be reviewed, to quantify the potential of interventions to increase food production, livestock productivity and promote soil fertility. The heterogeneity of farmers should be taken into account to select and promote the interventions best suited for each farmer and with the greatest chance of adoption.

1.7 Aim of study

The aims of this project are the following:

- Understanding farm heterogeneity, through the creation of a farm typology
- Assessing the effects of interventions on SOC, food production and livestock productivity (milk and livestock weight) for different farm types through a modelling exercise
- Understanding farming constraints, attitudes and goals with the help of an interview
- Developing a decision support tool to enable the matching of the best suitable and most easily implemented interventions to farm types

2 Materials and methods

2.1 Description of the overall project

This thesis is situated within the project 'Realising the full potential of mixed crop-livestock systems in rapidly changing Sahelian agro-ecological landscapes', WLE Volta and Niger Focal Region. This project is led by the International Livestock Research Institute (ILRI), through a consortium with several partners. The aim of this project is to: 'investigate the gender gap and assess how women and youth can contribute and benefit from improved biomass production and productivity of crop-livestock systems'. It also investigated 'the effect of improved biomass production and management on soil and water related ecosystem services'. Within this project a lot of attention is drawn towards the impacts of interventions on agricultural productivity, natural resource sustainability, food security and livelihoods.

The role of Wageningen University (WUR) within this project is to assess the impacts and trade-offs related to intervention adoption at different scales (farm scale, regional scale, etc.) through modelling and participatory tools. This is done for two main aims: designing technologies adapted to households and farmers and creating decision support tools.

Within the project, this thesis assesses the impact of interventions on food security, income and soil quality through a modelling exercise, for the Yatenga region of Burkina Faso. Through interviews the adoptability of the interventions for different farm types in this region is analysed. From this information a decision tool is made to help extension agents in choosing the most suitable interventions for different farmers.

2.2 Environment

The location of this project is in the Yatenga region, around the city Ouahigouya. This region is situated in the northern part of Burkina Faso, a land-locked country in West Africa (Figure 1).

Figure 1: Map of Africa with Burkina Faso in red (a) (source: History & Maps, 2015) and the map of Burkina Faso with all major cities (b) (source: Bambara, 2010).

Burkina Faso itself is situated in the Sahel, the semi-arid region forming the transition between the Sahara desert and the more humid savannas. This ecological zone extends from the Atlantic coast in West Africa to Sudan in the east (de Ridder et al, 1982) and is delimited by the 100mm and 600mm isohyets, with rainfall strongly increasing from North to South. There is one rainy period during summer, lasting two to four months. It usually starts in June and lasts until September (Figure 2). This period is followed by extremely dry conditions during the rest of the year (de Ridder et al, 1982).

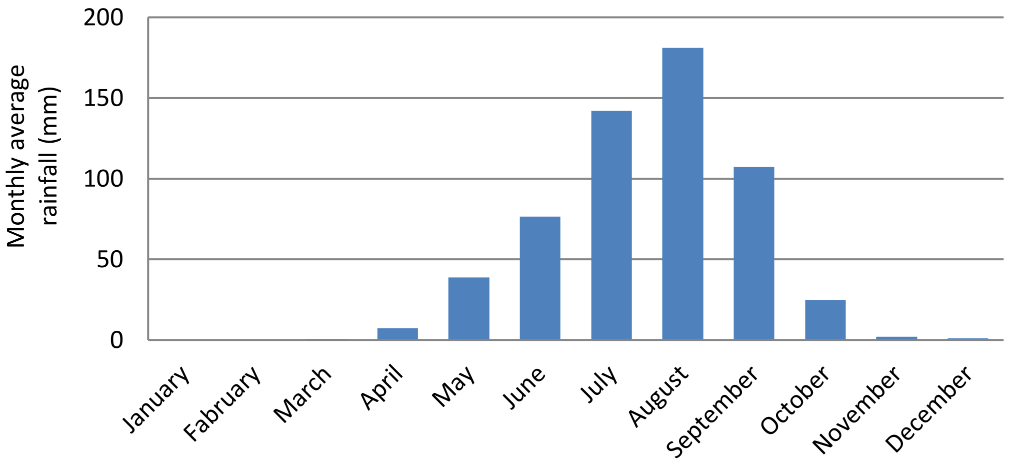

Figure 2: Monthly average rainfall (mm) in Ouahigouya for the years 1981 to 1992. From FAO weather station placed at 13.75 latitude, -2.42 longitude and an elevation of 336m.

In the study area, the year can be divided in three following three seasons (Figure 3): the rainy season (June to October), the early dry season (November to January) and the late dry season (February to May). These three seasons define biomass availability: in the wet season the crops are grown and a lot of biomass is available in the rangelands, in the early dry season there is still some vegetation present, while at the end of the dry season biomass availability is lowest and there is a shortage of grazing resources and crop residues for animal feed. At that time in the year the quality of the pasture is also lowest (Breman & de Ridder, 1991).

Figure 3: Schematic representation of the seasons in Burkina Faso. Green represents the wet season, orange the early dry season and red the late dry season.

Soils in the Sahel region range from sandy to sandy loam, soils with a good permeability. The levels of organic matter, total nitrogen and cation exchange capacity are low, leading to inherent low soil fertility (Bationo & Mokwunye, 1991). Most soils are also low in phosphorus. Table 1 shows an example of a typical soil in the Ouahigouya region (A. Ayantunde, personal communication; Leenaars et al., 2014)

Table 1: Typical soil properties for top soils in the Yatenga region.

Bulk density (kg/m^3)	Top soil depth (m)	Clay (%)	Silt (%)	pH H2O	SOC (%)	Mineral N (%)	Olsen P (mg/kg)	Exch. K (mmol(+)/kg)
1550	0.2	10	10	5.2	0.8	0.08	3.93	4.8

Agriculture is important in Burkina Faso, as it represents around 30% of the countries' GDP and employs more than 90% of the working population (FAO, 2014). Most farms are small scale farms, the area they occupy usually being less than 5 ha (FAO, 2014). The main crops produced are sorghum, millet and maize as staple food and cotton and groundnut for cash crops (Mortimore and Adams, 2001). Crops are grown once a year, during the rainy season. Yields are generally low.

The Yatenga region (with the capital Ouahigouya) has one of the highest population growth rates of Burkina Faso. Until the 1970s, there was enough land available and it was possible for farmers to expand agriculture on marginal land. The traditional agricultural practices caused erosion but long fallow periods restored the soil fertility. Population pressure led to reduction and elimination of fallows. Since the 1980s, to avoid the decline in agricultural production, agriculture is intensified through the introduction of zaï and stone bunds, improving soil and water conservation (Douxchamps et al., 2004). Thus far the efforts to enclose livestock to collect better manure and reduce grazing pressure have not been successful (Ouedraogo et al., 1996). Therefore livestock (cattle and small ruminants) graze in the vicinity of the villages throughout the year and feed mainly from the rangelands (de Ridder et al., 1982). In the dry season, when there is feed shortage in the rangelands, the livestock depend mainly on crop residues (Rattunde, 1998). Livestock plays an important role as it serves multiple functions, such as milk provision, draft power provision and the role of insurance in case of failed crop (Herrero et al., 2003).

2.3 Overview of steps taken

The flow chart in Figure 4 is a schematic overview of the methodology followed to create a decision tool helping in the choice of the best suited interventions.

Firstly a short literature search was performed, to understand what the interventions consist of and what possible impacts they can have on farming system, while also learning what possible constraints could limit the adoption of the interventions.

Secondly a farm typology was used to study farm heterogeneity to get an overview of the situation of farmers in the Yatenga region of Burkina Faso.

Thirdly the NUANCES-FARMSIM model was used to explore the impact of specific interventions for different farm types. The impact of the interventions was scored on the following points: food production, livestock productivity and soil organic carbon, used as an indicator for soil fertility.

Fourthly interviews were held in the Yatenga region to collect information about farmer's constraints, goals and attitudes. This information was matched to information received from experts about the strength of constraints limiting the adoption of several interventions.

Lastly a decision tool was made, showing which interventions are most adapted to different farm types. This information can then be used within the WLE-Volta project to match the interventions to farmers but it can also be used by extension officers, to find the best interventions for different farm types.

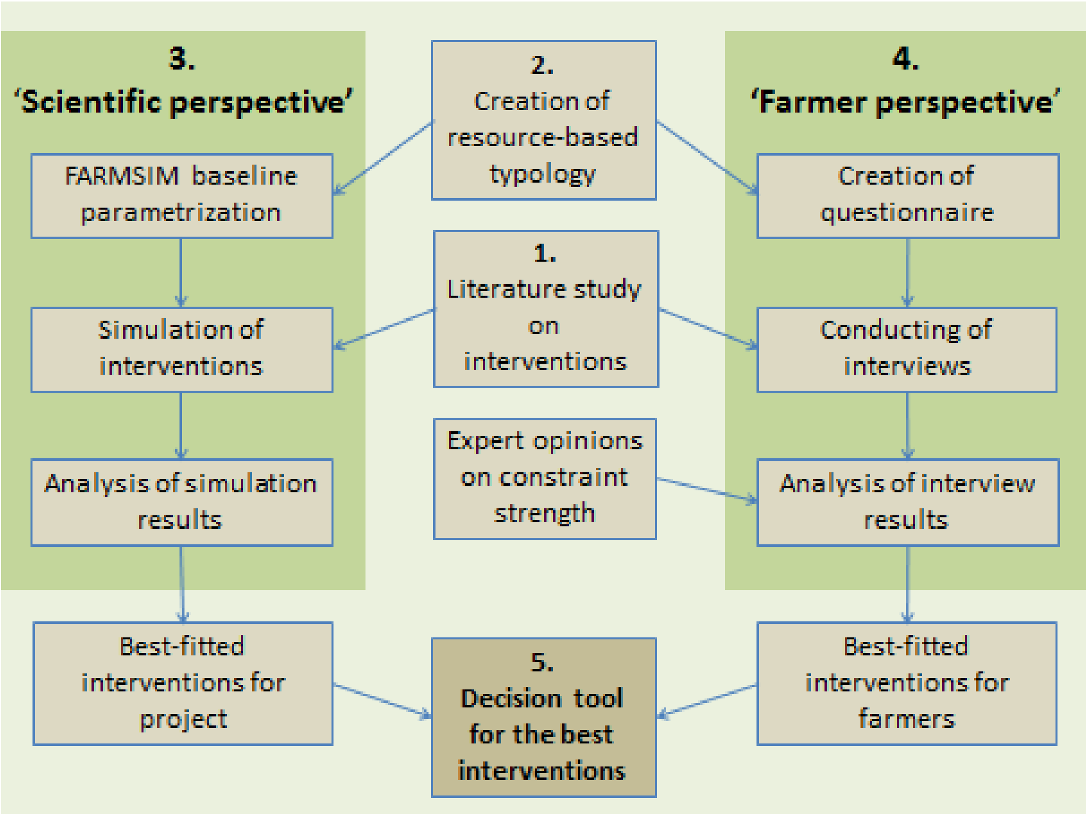

Figure 4: Flow chart of the steps taken during the thesis.

2.4 Data sources

In this thesis, two main sources of data were used for the parametrization of the baseline modelling scenarios and for the definition of the farm types. Each time one of the two databases was used in this thesis, it was mentioned in the methodology.

The farm types were based on information from the Detailed Household Characterization Survey, collected by CCAFS (CGIAR's research program on Climate Change, Agriculture and Food Security). This was done as data from the WLE-Volta project was released only later. The main aim of this survey was to collect standard indicators as well as key livelihood indicators, with the aim of standardizing analyses. The survey was held in July and August 2012, in the villages Barga, Titao and Namissiguima in the Yatenga and Loroum states of Burkina Faso.

The input data for the baseline scenarios was mainly based on the household survey data made available from within the WLE-Volta project (survey held in June and July 2015). The objectives of the survey were to characterise the types of farms, describe the opportunities and constraints for biomass production, as well as collecting information about the farmer's perception of the effects of the biomass enhancing intervention. The villages included in the data set are Ziga, Thiou, Ninigui and Pogoro-silmimossin, all villages in the Ouahigouya district.

2.5 Literature review of assessed interventions

The selected interventions (Table 3) were assessed based on a short literature review. The research was done in google scholar, Scopus and through Wageningen library, with the following search terms: key words of the intervention, coupled to "impact", "effect", "Sub-Saharan Africa", "SOC", "yield" and a combination of these keywords.

The literature information was summarized in a quick explanation of the intervention, its' impacts on the farming system and on the requirements in terms of labour, education, equipment and access and availability of inputs.

Within the WLE-Volta project several interventions were offered (Table 3). Only a set of interventions was selected for this thesis, based on the possibility to simulate the intervention in the current version of FARMSIM.

Table 3: Overview of interventions in the WLE-Volta project, separated whether included in the thesis or not.

Interventions included in the thesis	Interventions excluded from thesis
Pasture planted with native or exotic species	Establishment firewalls
Forage planted as live hedge	Collection of wood for fire
Planting of trees with multiple uses	Clearing and pruning
Planting of forage cover crop	Planting of vegetation bands
Planting of improved, dual-purpose varieties	Gardens for food
Planting of drought tolerant crops	Irrigated forage
Fallow	Corridor planting with crops in between rows or trees
Collection herbaceous biomass for animal feed	Afforestation
Collection and storage crop residue for animal feed	Communal forest set-up
Leaving crop residues on field for animal browsing	Burning of residues in the field
Mulching	Early fire
Physical treatment crop residue	Assisted Natural Regeneration
Chemical treatment crop residues	Composting
	Grazing rotation
	Deferred grazing
	Collection herbaceous biomass for selling
	Collection crop residue for selling
	Use of crop residue for building

2.6 Impact indicators

Biomass in this thesis had two main purposes; the improvement of livelihoods and the improvement of soil fertility. Indicators were chosen to measure the goals of livelihood and soil fertility. Livelihood was measured through food production and livestock productivity and soil fertility was measured through soil organic carbon (SOC) content. The impact of the different interventions gave information about the most beneficial interventions for these indicators. Hereunder different indicators used in this thesis are further explained and a recapitulation can be seen in Table 4.

2.6.1 Food production

As there is a yearly shortage of food in the Sahel region, it is crucial to increase food production.

In the baseline there were two ways of expressing food production: crop production and food self-sufficiency. Crop production (kg/ha) was followed from years 1 to 12, enabling the visualisation of yield evolution over time. The fraction of food self-sufficiency was calculated by comparing calorie production to calorie need on a yearly basis. Vitamins or proteins were not taken into account. The amount of calories needed for the household during the year was calculated by multiplying the number of household members by their yearly calorific needs. The following was assumed: boys aged 1 to 10 needed 1 300 kcal per day, while girls of the same age required 1 200 kcal, adult men required 2 200 kcal per day and women needed 1 800 kcal per day (HHS/USDA, 2010). Calorie production was calculated by multiplying annual crop yields by the area of the crops grown and the calorific values of the crop (Annex 1, Table 1 for the nutritional value of crops). Food originating off-farm was not taken into account. When calculating the average value of food self-sufficiency over the years the first year of simulation was not taken into account.

When comparing the outcomes of the interventions to the outcomes of the baseline scenario, the average calorie production (over years 2 to 12) was taken into account. The average calorie production under the intervention was divided by the average calorie production under the baseline scenario and this outcome was multiplied by 100, giving the percentage of increase or decrease of average calorie production under the interventions compared to the baseline scenario..

2.6.2 Livestock productivity

Livestock also suffer from the yearly drought through feed shortage (quality and quantity). Survival of livestock depends on the amount and quality of feed available (pasture grass, external feed and crop residues). Livestock bodyweight and milk production were analysed.

For the baseline scenario milk production (kg/year) and livestock body weight, summed over the animals (kg body weight/month) were followed over the 12 simulation years.

When comparing livestock productivity under the different interventions to livestock productivity for the baseline scenario, milk production was averaged over the years 2 to 12 and cattle weight, summed over all the cattle head of the farm, was averaged over these 132 months. Average milk production and average cattle weight under the interventions were divided by average milk production and average cattle weight in the baseline scenario. The outcome was then multiplied by 100. This enabled to find the percentage of increase or decrease in milk production and weight gain due to the intervention, compared to the baseline scenario.

2.6.3 Soil Organic Carbon

Soil organic carbon (SOC) is a component of soil organic matter, decomposed plant and animal organic matter in the soil (Wang, 2013). SOC is important in chemical, physical and biological soil fertility (Chan, 2010) as SOC increases soil fertility through improving plant nutrient availability, soil structure, water holding capacity and providing food for soil organisms. Increasing SOC levels has been shown to increase yields in many cases (Körschens et al., 1998). Therefore the maintenance of SOC is an effective way to counteract land degradation while increasing food production (Bationo et al., 2007). Carbon inputs depend mainly on biomass productivity and the return of biomass to the soil. Major carbon outputs are mineralization, leaching, erosion and run-off. At this moment the amount of SOM in soils of the Sahel is very low, ranging from less than 1% to around 2% (Beal at al., 2015). The aim of implementing the interventions is to increase the SOC by increasing the amount of organic matter going to the soil. Other possibilities to increase SOC in soils, not explored here, are changing the quality of the OM input, placing the OM in deeper soil layers and enhancing the soil physical production of the OM through the formation of complexes (Gobin et al., 2011).

For the baseline scenario SOC (%) was followed over the 12 simulation years. To get the value of average SOC for a farm, the SOC of the different fields was multiplied by the area of the fields, summed across the fields and the result was then divided by the total area of the farm.

When comparing the SOC outcomes for the baseline scenario with the SOC outcomes of the interventions, only the SOC value for the last year of simulation were taken into account (year 12), as SOC is a long-term impact indicator. The average SOC for the farm was calculated for this year, for the baseline scenario as well as for the intervention. The value of SOC for the intervention was divided by the value of SOC for the baseline scenario and the outcome was multiplied by 100. This gave the percentage increase or decrease in SOC of the intervention after 12 years of simulation.

Table 4: Indicators used in the analysis of the impact of interventions.

Category	Food production	Animal production	Soil quality
Impact indicator	Calories produced	Animal body weight and milk production	Soil Organic Carbon
Unit for the baseline scenario	Annual crop yields (kg/ha). Annual food self-sufficiency (fraction).	Annual animal body weight (kg), summed across animals. Annual milk production (kg).	Annual SOC on farm (%).
Unit when comparing to the base line scenario	Gain or loss of calorie production (%), averaged over 11 simulation years	Gain or loss of livestock productivity (%), averaged over 11 simulation years.	Gain or loss in farm SOC (%), averaged over 11 simulation years.

2.7 Farm typology

With data collected by CCAFS a farm typology was made by W. Paas.

The resulting structural typology was based on resource endowment (Alvarez et al., 2014). The key variables used to separate farmers in different classes were the following:

- Household size (the number of household members per farm; "the household include people who live and share meals at least one season per year and income generated with farming." (Quiros, 2013))
- Total area (total area of farm fields, hectare)
- Cereal area (area of the farm planted with cereals, hectare)
- Number of cattle (zebu, cow, camel)
- Number of small ruminants (sheep, goat, etc.)

This resulted in 6 different farm types. Type 5 did not possess livestock, while type 6 possessed the most cattle. As according to the farmers cattle is very important, type 5 was considered the least resource endowed farm type and type 6 was considered the wealthiest type. Type 1 had a small amount of land and livestock, type 2 had a greater area of land and type 4 had some animals but only little land. Type 3 was average with some land and some animals.

2.7.1 Decision tree

The information about the types was used to make a decision tree, enabling the classification of the farms in the right types (Figure 5). The first criterion used was the number of cattle, as this enabled the segregation of the farm types 5 and 6 from all other farm types.

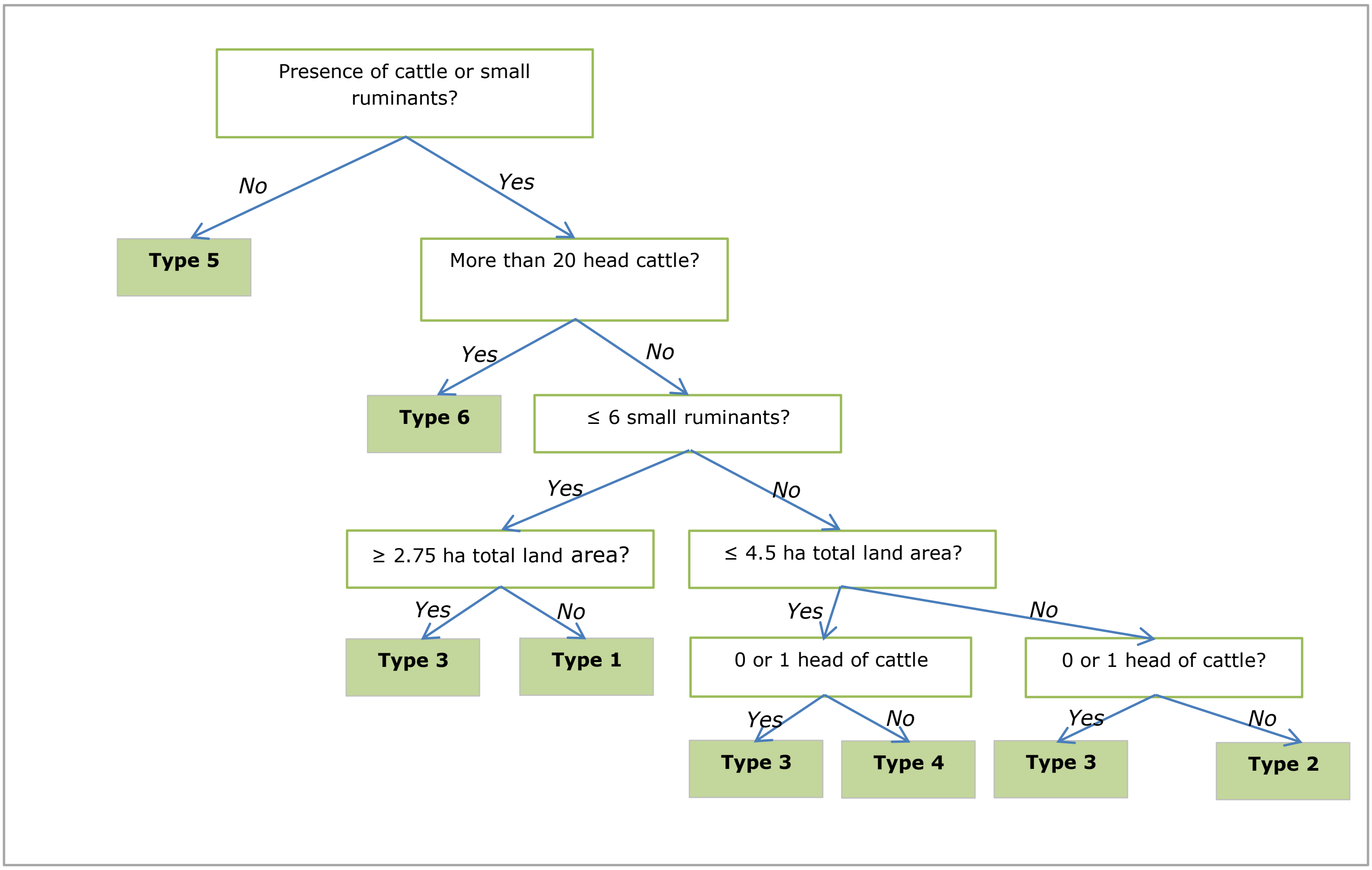

Figure 5: Decision tree for the classification of farmers in the right type.

2.8 Model study

2.8.1 Model introduction

The impact of introducing the technologies was assessed for each farm with the use of the NUANCES FARMSIM model (Nutrient Use in Animal and Cropping systems – Efficiencies and Scales, FARM SIMulator). The nuances framework is developed specifically for understanding of the complexity of African farming and for discovering of best-fit technologies (van Wijk et al., 2009). NUANCES-FARMSIM is an integrated crop livestock model, adapted to the African smallholder farming systems.

NUANCES FARMSIM is a model constituted of three sub-systems:

- FIELD (Field-scale resource Interactions, use Efficiencies and Long-term soil fertility Development), which calculates the crop production per season (depending on soil fertility and inputs), simulates water and macronutrient dynamics and monitors indicators of resource degradation (e.g. SOM and soil erosion). Crops and soil types can be defined, as well as the rainfall and the nutrient inputs into the system.
- LIVSIM (LIVEstock SIMulator), which is a livestock productivity model simulating animal production (body weight, milk production) based on breed-specific potential, feed requirements and actual feed availability. Different animal types can be chosen (breed, weight, age, sex, etc.). The model has a time step of a month.
- HEAPSIM (HEAP SIMulator), which simulates the nutrient cycling through manure collection, storage and application. This module also has a time-step of a month.

A user interface is used to insert the input conditions. The different interventions are simulated with the help of the model and the impact on food production, livestock productivity and SOC is followed over the seasons. A duration of 12 years is chosen to be able to see the evolution in the outcomes.

2.8.2 Modelling approach

A baseline scenario was made for each farm type: this was the starting point situation. The model had to be adapted to the environmental situation in the Ouahigouya district (rainfall), to the soil properties and the different farm types were constructed. This baseline scenario was the situation to which the impact of the different interventions was compared.

2.8.2.1 Input data

2.8.2.1.1 Monthly rainfall

Rainfall data were from a meteorological weather station in Ouahigouya (latitude 13.57°, longitude -2.42° and elevation 336m). The total dataset contained information about rainfall over 60 years (1950-2010) but only the data from 1981 to 1992 was used, as this was the most complete. The associated rainfall data can be seen under Appendix II, Table 1.

2.8.2.1.2 Soil characteristics

Two sources describing soil quality were used:

- Personal communication by A. Ayantunde, about soils in the proximity of Ouahigouya, in the villages Sabouna and Ziga
- Africa Soil Profile Database version 1.2., by ISRIC. Two representative soil samples, close to Ouahigouya, are chosen (reference numbers BF2877_RPROFIL40 and BFVALSOL_CN-47) (Leenaars et al., 2014).

The soil bulk density was determined according to soil texture. Soil texture was between a sandy loam and a loamy sand, consisting of 10% silt and 10% clay (USDA, n.d., a). This led to a bulk density of approximately 1,550kg/m³ (USDA, n.d., b). The chosen soil parameters for this thesis are shown in Table 1.

2.8.2.1.3 *Livestock characteristics*

It was chosen to work with the cattle breed Méré, as this breed is kept in West Africa. The Méré breed is a cross between Zébu Peulh (Fulani, Bos indicus) and N'Dama (Baoulé, Bos taurus) (Sanogo, 2011). This breed is used for traction, milk, manure, as investment and as insurance in case the crops failure. FARMSIM parametrization for this breed can be found in de Ridder at al. (2015) and in Appendix II, Table 2.

2.8.2.1.4 *Livestock ownership*

From the WLE Volta database it was found that in small herd mostly bulls were present. When the herd size increased the fraction of females in the herd also increased Table 6 represents the typical herd composition used to generate livestock input data for the model. If the farm owned only 1 head of cattle, this was the animal with ID number 1. When the farmer owned 5 head of cattle, the simulated cattle had the ID's 1, 2, 3, 4 and 5. If more than 10 cattle heads were owned, the table was repeated, until the required number of animals was reached.

No information was available about age or weight of the cattle, therefore it was attempted to represent a typical herd composition. The maximum weight of a male Méré adult is of 400kg, while for a female this is of 300kg. When making the table it was assumed cattle had not reached maximum weight.

The average amount of livestock available in the farm was defined by the average number of cattle in the farm type.

Table 6: Characteristics of the cattle in a typical herd of 10 cattle head.

Cattle ID	1	2	3	4	5	6	7	8	9	10
Sex (Female/Male)	M	M	F	F	F	F	F	F	F	M
Age (year)	6	4	6	4	2	7	5	3	1	5
Weight (kg)	300	300	250	250	150	250	250	200	100	300
Lactation (yes/no)	x	x	n	n	n	n	y	n	n	x
Gestation (yes/no)	x	x	n	n	n	n	n	n	n	x
Pregnancy (month)	x	x	-	-	-	-	-	-	-	x
Time since calving (month)	x	x	24	12	-	36	12	-	-	x
Lactating (month)	x	x	-	-	-	-	12	-	-	x

2.8.2.1.5 *Livestock feed*

No information was available about the amount of biomass grazed by the livestock in the WLE-Volta or in the CCAFS databases. The parameters for the quality of grass were adapted for a decrease in pasture quality in the early dry season and an even greater decrease in pasture quality in the late dry season (Descheemaeker, personal communication) (Appendix II, Table 4). The quality of the pasture declined in the dry season; dry matter content increased, but metabolisable energy (ME) and crude protein (CP) contents decreased.

Livestock lose weight during the dry season, due to a lower availability and quality of feed, but a part of the weight gained during the wet season and should enable the cattle to survive during the dry season (Sanogo, 2011; de Ridder et al., 1991). From this information for all farm types a "basic" amount of feed was set (pasture + concentrates + roughage, Table 5) so that the seasonal weight change was present. This basic amount of feed was given throughout the year. In the early dry season 80% of crop residues are also given as feed and during the late dry season the remaining 20% of crop residues remaining are offered.

Table 5: Feed given to bulls, calves, default cows and gestating of lactating cows throughout the year.

Feed category	Bulls	Calves	Default cows	Gestating and lactating cows
Concentrates (kg/head/day)	1	0.5	0.5	0.75
Pasture (kg/head/day)	2	2	2	2
Roughage (kg/head/day)	3	2.5	2.5	2.5

2.8.2.1.6 Crop characteristics

The crops used in this modelling exercise were millet, sorghum, maize, groundnut and cowpea. The characteristics of these crops can be seen in Appendix II, Table 3.

2.8.2.2 Parametrization of different farm types

One virtual farm was built for every farm type, with the information about the area of cropping land and cattle ownership (average values of farm type). Cattle ownership was already known, as these are the values for the average of the farm type. To complete the baseline scenario, the following information was retrieved from the WLE database:

- Crops grown and area of crops grown,
- Livestock ownership
- Manure use,
- Fertilizer use,
- Crop residue use,
- Off-farm livestock feed fed,
- Livestock grazing quality

The following paragraphs explain how these model settings were defined.

2.8.2.2.1 Crops grown (use of WLE database)

The following steps were taken to calculate the averages for the areas of crops grown in the different farm types. The data used comes from the WLE-Volta survey.

1- The frequency of the cultivation of crops by farmers within a type was calculated. Only when crops were grown by more than 50% of the farmers were they included in the baseline scenario (except for sesame, as this crop cannot be simulated in FARMSIM).
2- The average area of cultivation for all retained crops was calculated for the farmers growing the crops.
3- With information about the average crop areas the area ratio of every crop was calculated. For example, if the average areas found were 2ha of sorghum and 1ha of millet, the ratio was of 2:1. This means that 66% of total farm land was planted with sorghum and 33% was planted with millet.
4- The total cropping area of the farm was the average farm area for the farm type. Together with information about the area ratio of each crop, the area of each crop was calculated. For example, an average farm area of 4ha. Continuing the previous example, 66% of the farm was covered with sorghum and 33% of the farm was covered with millet. Therefore in total 2.66ha was under sorghum cultivation and 1.33ha was under millet cultivation.

2.8.2.2.2 Manure and fertilizer use (use of CCAFS database)

For the calculation of fertilizer and manure use, the frequency of the fertilizer and manure use within the different farm types was calculated, using data from the CCAFS survey. When less than 50% of farmers within a farm type used manure or fertilizer, it was assumed that manure and fertilizer were not applied in the baseline scenario. In cases where 50% or more of the farmers used manure or fertilizer, the average quantity applied was calculated through averaging the amount of fertilizer applied by farmers using fertilizer, for the specific crop. This amount was then used in the baseline scenario. In the baseline scenario it was assumed manure was kept in the open air.

No information was available about the way manure is kept (e.g. use of a plastic sheet to cover the heap).

2.8.2.2.3 Crop residue use

For farms with and without livestock it was assumed that all crop residues were used as livestock feed. This was due to the fact that there is pressure on the crop residue resource, which is used as livestock feed, fuel, construction material, can be sold, etc. (Powell et al., 2004; Bationo and Mokwunye, 1991). Therefore there are little to no crop residues available as soil amendment. Even for farmers without livestock the crop residues can be eaten, as freely-roaming livestock from neighbours has access to crop residues left on fields.

The quality of the crop residues was based on the data available in the model and from the PhD thesis of O. Sanogo (2011).

2.8.2.2.4 External feed

Livestock feed in FARMSIM was composed of crop residues, pasture and external forage and concentrates. The use of the crop residues was explained in the paragraph above. Information about the feeding of livestock with external forages and concentrates during the three seasons was available in the WLE database. The proportion of farmers feeding their livestock with external feed was calculated for every season. If more than 50% of the farmers fed the livestock with external feed, it was included in the baseline scenario.

No information was available about the composition of concentrates or the frequency or quantity of the concentrates fed. Therefore the following composition was assumed (Sanogo, 2011):

a. Dry matter (DM) 916 g/kg
b. Metabolisable energy (ME) 12.3 (MJ/kg DM)
c. Crude protein (CP) 276 k/kg DM
d. Dry matter digestibility (DMD) 710 g/kg DM

2.8.2.3 Simulation of interventions

The baseline scenario described above was altered so as to simulate the interventions. The way in which this was done is explained in the following paragraphs.

2.8.2.3.1 Improvement of livestock forage

2.8.2.3.1.1 Increasing grass quantity available

This intervention was built to simulate a potential effect of pasture planted with native or exotic species. Pasture quantity available to the livestock was increased by adding 1kg grass/head/day to the cattle diet throughout the year in a first instance, followed by the addition of 2kg grass/head/day to cattle diet throughout the year in a second instance.

2.8.2.3.1.2 Improvement of grass quality

This intervention was also simulated as a potential effect of pasture planted with native or exotic species. Pasture quality was improved through the increase of 10% and later 20% of the ME and CP content of grass.

2.8.2.3.1.3 Increasing external forage in the form of legumes

Forages planted as live hedge and the planting of trees with multiple uses were assumed to add legumes to the cattle diet. Therefor these interventions were simulated through the addition of legumes to the cattle diet. Three different levels of legume feeding were assumed: the addition of 0.5kg legume/head/day, 1kg legume/head/day and 2kg legume/head/day.

2.8.2.3.2 Dual-purpose varieties

Two different scenarios were constructed, where either cowpea or sorghum were used as dual-purpose crops.

Firstly the area of cowpea was increased, as cowpea is a dual-purpose crop of itself. The area of the farm under cowpea cultivation was increased from 0% to 25%, 50%, 75% and 100% total farm area.

Secondly the crop parameters of sorghum were altered in two different ways, to mimic a dual-purpose sorghum variety:

- Increased potential crop residue yield by 10% in a first run and by 20% in a second run, while keeping the grain yield at the original level. This was achieved through increasing light determined yields while reducing the harvest index. The increase of crop residue production by 10% and 20% was chosen as increased stover production ranged from 0-75% (Bossuet, 2010)
- Crop residue quality was increased by increasing CP and ME content of the sorghum forage by 10% in a first run and 20% in a second run. As the idea was to change crop residue quality not only the forage given to the livestock should increase in ME and CP, also the crop residues produced on farm should become higher in quality (as setting forage quality only influences the feed given to the livestock and not the crop characteristics). This was accounted for by increasing the minimum and maximum amount of N in crop stover 10% and then 20%. This increased crop residue quality but reduced the quantity of grain and crop residues produced.

2.8.2.3.3 Drought tolerant crops

To increase drought tolerance of crops water conversion efficiency was altered, in a first run by 10% and in a second run by 20%. This was done for both sorghum and millet (in different runs), as they are currently two existing drought-tolerant crops (CGIAR, n.d.).

2.8.2.3.4 Fallow

Fallow was simulated through the growing of crops with a harvest index (HI) of 0 (no grain production) and 100% of biomass staying on the field. Two crops that were used for the simulation of fallow were sorghum and cowpea.

First 10% and then 20% of the farm areas was converted to this fallow system. These proportions were chosen because there was no information available about the farm surface fallowed or the frequency of fallowing. Also, a general trend in sub-Saharan Africa is the reduction in fallows, which even sometimes completely disappear (Sanogo, 2011).

This gave rise to four scenarios:

- 10% fallow with sorghum as fallow crop
- 20% fallow with sorghum as a fallow crop
- 10% fallow with cowpea as fallow crop
- 20% fallow with cowpea as a fallow crop

The area of the farm which was not converted to fallow was used to grow the crops. The areas over which the crops were grown kept the same ratios in the fallow interventions as in the baseline intervention (e.g. if 50% of land was under sorghum cultivation in the baseline scenario, also 50% of land not under fallow was under sorghum cultivation during the fallow intervention).

2.8.2.3.5 Mulching

Mulching was simulated through the addition of the crop residues to the field. It was therefore similar to the situations where crop residues were left on the field. The impact of mulching legume residues (cowpea and groundnut) and cereal residues (sorghum, maize and millet) was analysed.

2.8.2.3.6 Crop residue management

The amount of crop residues allocated to the livestock was reduced, leading to more crop residues being left on the fields. The following fractions of crop residues were used:

- 100% crop residues left on field, 0% used as livestock feed

- 75% crop residues left on field, 25% used as livestock feed
- 25% crop residues left on field, 75% used as livestock feed
- 0% crop residues left on field, 100% used as livestock feed

2.8.2.3.7 Manure Management: Collection and storage and application

Manure collection was varied from 0% to 100%, by steps of 25% (0%, 25%, 50%, 75%, and 100%). The amount of collected manure applied was assumed to be 100%, with the amount of manure spread proportional to the size of the field. In a first simulation exercise manure was kept in an open heap, while in a second simulation exercise manure was kept in a heap covered by a plastic sheet.

2.8.2.3.8 Physical and chemical treatment of crop residues

The crude protein and metabolisable energy content of all crop residues was increased by 10% and then 20%. This situation was therefore similar to the sorghum dual-purpose intervention, with the difference that not only sorghum but all the crop residues increased in quality.

2.9 Interview

2.9.1 Conducting the interview

Interviews were conducted to understand the constraints, goals and attitudes of farmers. These were also the three subjects which made up the different parts of the interview.

Interview contents:

- Firstly broad questions about the constraints in agricultural production were asked. Then more emphasis was put on land shortage, labour shortage, livestock shortage, capital shortage and a shortage in education and technology. The farmer stated if he or she thought the constraint was present and how strong this constraint was. The strength of the constraint was scored on a Likert-type scale of importance from 1 to 5, from 'very low' to 'very strong' importance. An explanation was asked to clarify the given answer.
- Then the farmer was asked about his or her goals in agriculture. Specific statements were made and the farmer had to state if he or she agreed to the statement and how strong his or her feeling of agreement was. An explanation for the answer was asked. As for the constraints the answers were scored on a Likert-type scale, ranging from 1 to 5, from 'not important' to 'very important'. The score 3 stood for a neutral answer.
- Lastly the farmer was asked about his or her attitude towards agriculture. This was done through the grading on a Likert-types scale of answers on statements (scale of 1 to 5, from total disagreement to total agreement, with 3 a neutral answer).

The interview was conducted in three villages in the region of Ouahigouya: Pogoro-silmimossin, Ninigui and Thiou. When possible, four farmers from every type, randomly selected per village, were interviewed.The detailed protocol for the interview can be found in Appendix III. This contains the set-up of the interview, the questions asked and the selection of the farmers.

2.9.2 Data analysis

The first step was to verify if the farms were still situated within the right farm type (WLE Volta data was collected in 2015 and this interview took place in 2016). If this was not the case the farms were re-classified in the current farm type.

2.9.2.1 Analysis of association between type or gender with constraints and goals

A fisher exact test was used to discover if there were significant differences in the proportion of respondent considering the elements as a constraint, between the types and per gender. The same test was used to find if the proportions of answers given for the goals were different depending on type and gender. A fisher test was chosen as sample sizes were small and the Likert type ranking led to the obtaining of categorical answers (Ott & Longnecker, 2015). A significance level of 0.05 was chosen.

2.9.2.2 Analysis of farmer attitude

The distribution of the answers over the scale was calculated and discussed. The weighted averages were given.

Then an agglomerative hierarchical cluster analysis (HCA) was performed, with an average linkage within groups method (as linkage criterion) to construct a dendogram (Köhn, & Hubert, 2006). This means the clusters were arranged in such a way that the average distance between all the individuals in the resulting cluster was minimised. From this dendogram clusters in farmer attitude were defined.

2.9.3 Matching of constraints

2.9.3.1 Calculating strength of agricultural constraints

Firstly the percentage of farmers within a type who thought the resource was a constraint was calculated and reported.

Secondly the average weighted importance of the constraint was calculated (when the resource was not seen as a constraint the score was not taken into account). For example, if 20% of people say the importance is 3 and 40% say the importance is 4 and 40% say the importance is 5, the weighted average will be 0.2*3+0.4*4+0.4*5 = 4.2

Thirdly this average was multiplied by the percentage of farmers saying the resource is a constraint. The outcome is then given a score following (Table 7), following a fuzzy logic.

Table 7: Conversion of scores to 'score equivalents' enabling the matching of interventions.

Outcome calculated	Score equivalent
0-0.99	0
1-1.99	0.25
2-2.99	0.5
3-3.99	0.75
4-5	1

2.9.3.2 Expert opinion

A questionnaire was made, to ask experts about their opinion on requirement of cropping land, grazing land, livestock, education, capital and technology for the implementation of the different interventions (Appendix IV).

The received answers were compared and the most frequently given answer was taken into account. If two scores ended up with the same frequency, the strongest score (e.g. 2 instead of 1) was taken into account. The resulting scores were 0, 1 or 2 (see Table 8, row 1). A 0 (green) answer meant there was no input needed of the specific element. A 1 (orange) meant there was some input needed, while a 2 (red) meant a lot of input was required.

The cost of implementation given by the experts was multiplied by the score equivalent given by the farmers (Table 8, row 2). When the final outcome was under 0.25, it was coloured green (Table 8, row 3), while if outcome was below 0.5 it was coloured orange and above that the outcome was coloured red.

Green interventions faced no or little constraints for adoption, orange interventions faced medium constraints for adoption, while red outcomes signalled a strong constraint for the adoption of interventions.

Table 8: Scoring equivalents to match farmer constraints to expert constraints and come to the final constraints.

Sources and outcome for constraint strength	Scoring equivalents														
Cost of implementation (information from experts)	0					1					2				
Score equivalent (information given by farmers)	0	0.25	0.5	0.75	1	0	0.25	0.5	0.75	1	0	0.25	0.5	0.75	1
Final outcome	0	0	0	0	0	0	0.13	0.25	0.38	0.5	0	0.25	0.5	0.75	1

3 Results

3.1 Literature study

3.1.1 Improvement of livestock forage

In this thesis the following interventions are assumed to have as a main aim the increase of the quantity and/or quality of livestock feed and/or the timing of feed availability.

3.1.1.1 Pasture planted with native or exotic species

Depending on the species planted grazing intake differs. If the changed species composition leads to increased biomass, increased digestibility or a better spreading of the feed throughout the year, livestock is positively affected.

To implement this intervention there is a need to plant the species, requiring labour and knowledge about the species to plant, as well as access and availability of the seeds or plantlets required.

3.1.1.2 Forage planted as live hedge

Hedges reduce wind and water erosion (Ayuk, 1997). Depending on the species used, a live hedge may be able to access water from different soil layers. The shedding of leaves can lead to an increase in soil organic matter around the hedge. In this project the hedges are considered as a measure to provide extra feed for the livestock, improving livestock productivity.

For this intervention hedges need to be planted and maintained, requiring seeds or plantlets and labour for planting and maintenance.

3.1.1.3 Planting of trees with multiple uses

Trees can improve soil fertility by increasing nutrient supply, through nitrogen fixation and/or the retrieval of nutrients from lower layers in the soil. Trees can also increase nutrient availability through the enhanced cycling of nutrients and the conversion of nutrients to more labile forms. (Buresh & Tian, 1998). Trees can also improve water infiltration and storage. Depending on the tree species they may also play a role as livestock feed, the role of main importance in this thesis.

There is a labour need for planting, protecting, maintaining and propagating the trees. Feed for livestock has to be harvested. When the tree is grown close to the crops it can also lead to competition with the crop.

3.1.1.4 Collection of herbaceous biomass

Herbaceous biomass may be collected and fed fresh to the livestock when corralled. Biomass may also be collected and dried, to serve as hay fed during the dry season. This increases the amount of feed available to the livestock around the year, improving livestock productivity.

In both cases labour is involved for the collection of biomass and the biomass should be available.

3.1.2 Dual-purpose varieties

Dual-purpose varieties yield both grain and stover in good quantities. The grain is used as food or seed, while stover is used for animal feed or as organic amendment to the soil. The grain and stover yields should be evaluated in terms of both quality and quantity (Singh et al., 2003; Kristjanson et al., 2005). Depending on the crop, the improvement of crop residue quality may or may not occur at the expense of yield (Zerbini & Thomas, 2003). The dual-purpose crops most used in sub-Saharan Africa are cowpea and a special variety of sweet sorghum.

Dual-purpose varieties can alleviate the pressure on land for the production of grains and stover. Income can be increased through the sale of extra grain and stover. The soil can be enriched through the return of more residues to the soil or the production of more crop residues may lead to the enhancement of animal performance (Descheemaeker et al., 2010), as 45 to 80% of the livestock diet consists of crop residues (Rattunde, 1998).

For the implementation of dual-purpose crops seeds have to be available and accessible. There is also a requirement for knowledge about the crop, so as to manage it well (Kristjanson et al., 2005).

3.1.3 Drought tolerant crops

Drought tolerant crop are crops which give a higher yield than the normal crop under drought conditions (CGIAR, n.d.). Either new varieties can be bred with a higher drought tolerance, or crops or varieties which are inherently drought tolerant can be taken into production, such as cassava. When breeding a new variety drought tolerance can be achieved through the improved efficiency of water capture, or through the improved efficiency of water conversion (Schafleitner et al., 2007).

When crops are more drought tolerant farmers have more security about their yield, through the reduced chance of a failed crop as crop production in the dry years is assured. To be able to cultivate drought-tolerant crops, there is a need for seed access and availability (Cairns et al., 2000). There is no change in labour requirement.

3.1.4 Fallow

Fallow is a traditional means of increasing soil fertility in West-Africa (Bilgo et al., 2007) by taking land out of production. This can last from one season to many years depending on land use, population pressure and soil qualities (Corbeels, Shiferaw & Haile, 2000). Due to the increasing population and an increased need for fertile land, a decrease in fallows has occurred in sub-Saharan Africa.

Fallows can break weed and pest and disease cycles. They can also improve soil fertility, reducing erosion and increasing soil organic matter and biological activity through the input of organic matter from primary production into the soil (Styger & Fernandes, 2006; Aguilera, 2013). Usually there is less nutrient mining in areas where fallows are still common (Drechsel et al., 2001). Fallows can also be used for the provision of medicinal plants and fibres, timber, etc., to improve livelihoods, or be used as pasture (Styger and Fernandes, 2006).

However, if the fallow is not well managed (organic matter input smaller than organic matter outputs from the system, including mineralization and erosion), SOC may decrease, reducing soil fertility. Fallowing takes land out of production and thus reduces the potential food and feed production of the farm. The impact of the fallow depends on the duration and production during the fallow (Langyintuo & Dogbe 2005) and knowledge is needed on how to maximise and maintain soil productivity (what crops to plant, for how long, etc.).

3.1.5 Mulching

Mulching is a technology whereby the soil surface is covered by organic matter (OM), often applied in association with zero or reduced tillage. There are many different ways of mulching: the mulch can be dead (e.g. straw) or alive (e.g. low growing intercrop), it can be produced on the field or it can be acquired from outside (Erenstein, 2003).

The benefits obtained from mulching are multiple. Organic matter is added to the soil, improving soil fertility. Mulch acts as soil cover, reducing erosion, run-off and water evaporation. Through these functions it can play a role in increasing yields. Mulching increases moisture retention by buffering the soil against extreme temperatures (Twomlow et al., 2008). It also can reduce weed infestation through shading weeding (Erenstein, 2003; Twomlow et al., 2008).

Mulching can be a complicated technology. The user needs knowledge about the application of a good amount of mulch and in the case of live mulch, the system should be managed so as not to compete with the main crop. It is usually stated that mulch cover should be at least 30% to act as effective soil protection (SSSA, 1986). This may be difficult in sub-Saharan Africa due to many alternative uses for the mulch (livestock feed, construction materials, composting, etc.). When the mulching material comes from outside the field or farm labour is required to transport and apply the mulch. Tillage needs to be altered, so as to minimise the amount of residues being incorporated into the soil (Erenstein, 2003).

3.1.6 Crop residue management

Once the crop residues are produced, there are often competing claims on them. There is a pressure on the crop residue resource as low yields in addition to a growing population and a reduction of communal resources have led to a dependence on the use of crop residues for livestock feed, selling, fuel, construction and soil amendment (Valbuena et al., 2015). Two potential uses explored in this project are the use of crop residues as animal feed and the use of residues as soil amendment.

At this time the crop residues are mostly used as livestock feed (Valbuena et al., 2012), increasing the availability of draught power, meat and manure and fulfilling a function as insurance and savings. Livestock are very dependent on the crop residue feed source, especially in the dry season and in case of droughts (Rattunde, 1998).

When crop residues are left on the soil they play a role in the improvement of soil fertility in the long term, through the addition of organic matter to the soil (Omotayo & Chukwuka, 2009). They also act as a cover, protecting the soil from erosion. Leaving crop residues on the field does however not suffice to counter the loss of nutrients due to grain harvesting.

When the crop residues are left on the field no labour is needed. However, when the residues are transported and handled labour is needed.

3.1.7 Manure management

Manure management contains three important steps influencing the quantity and quality of manure returned to the soil: collection, storage and application. Manure is used to return organic matter and nutrients to the soil, in the aim of increase crop yields. Manure is part of an internal flow of nutrients within the farm. It can add nutrients to the farming system when livestock graze outside the farm but manure is collected. However, as feed is scarce and the number of animals is limited, this is often not the case (Bationo et al., 2001). The quantity and quality of manure is often low and inadequate to meet the crop requirements (Vanlauwe & Giller, 2006; Bationo et al., 2001).

3.1.7.1 Manure collection

The more manure is collected, the more manure is available for the next handlings and the more will be available as an organic amendment. Housing (e.g. corralling or not) also influences the amount of manure collected (Rufino et al., 2007).

Manure collection is labour intensive, depending on the way the cattle is kept (cattle kept in a corral or allowed to roam). Faster and more frequent manure collection leads to less C and N losses and higher manure quality (Rufino et al., 2007).

3.1.7.2 Storage

Manure can be stored in many ways: in open or closed compartments, manure can be turned over or left as it is, organic material can be added, etc. The conditions of storage affect decomposition and nutrient losses, as aerobic conditions allow a faster decomposition of carbon than anaerobic conditions (Rufino et al., 2007). Rufino et al. (2007) state that even the size of the manure heap influences decomposition process, due to heat distribution within the heap.

Labour and knowledge are needed to store manure in a way to maintain quality.

3.1.7.3 Amount applied to the field

The more manure is applied to the fields and the higher the manure’s quality, the more positive the effect on the soil fertility. Spreading manure is labour intensive and there is a need for farming equipment (Vanlauwe & Giller, 2006).

3.1.8 Physical and chemical treatment of crop residues

Treatment of crop residues is done to improve the quality of crop residues as animal feed.

3.1.8.1 Physical treatment of CR

Physical treatments of crop residues include grinding, chopping, shredding and pelleting. These lead to an increased area of the feed exposed to air, resulting in a greater activity of digesta, followed by a greater voluntary intake of crop residues (Lawrence, 1993). This can potentially increase livestock productivity. Digestibility of crop residues is usually not affected (Balch, 1977).

There is a need to collect the crop residues and to process them, requiring power and equipment.

3.1.8.2 Chemical treatment of crop residues

Treating the crop residues with chemicals such as hydroxide, ammonium hydroxide, anhydrous ammonia or hydrogen peroxide enhances fibre digestion, resulting in a higher digestibility of the crop residues and enhancing the voluntary crop residues intake (Lawrence, 1993; Owen, 1994; Zerbini & Thomas, 2003).

Crop residues need to be collected, transported and processed, requiring labour and chemicals, which are not prevalent in West Africa (Lawrence, 1993). There is also a need for knowledge for the handling of chemicals.

3.2 Typology

Type 5 did not own livestock, type 6 had the most cattle and ruminants, type 2 had the most land and the biggest number of household members, type 4 had some animals and a small piece of land and type 1 had the smallest land area (Table 9). In FARMSIM, the maximum number of cattle heads (20 instead of 33) was used for type 6.

Table 9: Characteristics of the farms used for the modelling exercise.

	Type					
Type	1	2	3	4	5	6
Household members (#)	8	13	8	9	6	15
Area (ha)	1.5	10.6	4.8	2.3	3.0	17.9
Cattle (#)	2	5	1	5	0	33
Small ruminants (#)	3	20	9	15	0	36

3.2.1 Crops grown

All farm types cultivated millet and groundnut. Except for type 5 all types grew sorghum and except for type 6 cowpea was grown everywhere. Type 3 was the only type where maize was taken up in the baseline scenario. Refer to Appendix V, Table 1, for a detailed account of percentages of farmers growing particular crops within each farm type.

With the exception of type 3, millet was the crop which was grown over the largest area. The legume areas were the smallest, except for farm type 3, where maize the maize area was even smaller (Table 10).

Table 10: Area of crops (ha) per farm type and used in the baseline scenario of the modelling exercise.

	Type					
Crop	T1	T2	T3	T4	T5	T6
Millet	0.6	5.2	1.3	0.9	1.9	10.5
Sorghum	0.4	3.2	1.8	0.6	0.0	4.8
Maize	0.0	0.0	0.5	0.0	0.0	0.0
Cowpea	0.2	1.0	0.6	0.5	0.0	0.0
Groundnut	0.3	1.2	0.6	0.3	0.3	2.5
Total area	1.5	10.6	4.8	2.3	3.0	17.9

3.2.2 Manure and fertilizer use

From the CCAFS database it was inferred that less than half of the farmers from all farm types used manure or fertilizer on their fields (Appendix V, Table 2). For this reason manure and fertilizer application was assumed to be 0 in the baseline scenario

3.2.3 External livestock feed

With the exception of type 6, less than 50% of the farmers gave extra feed to their livestock during one or more seasons. In farm type 6, 60% of the households fed concentrates to the livestock during the early dry season (Appendix V, Table 3). It was therefore assumed that the livestock of type 6 were fed with an extra daily ration of 0.5kg of concentrates during the early dry season (November, December and January).

3.3 Modelling

3.3.1 Baseline scenario

In the baseline scenario there was an exponential decrease of crop yields over time, nearing a plateau at the end of the simulation period around 500kg/ha (Figure 6: Evolution of crop yields (kg/ha) over time.). A big jump in yields from the first to the second year was observed. Similarly to the yields, SOC also decreased over time. The decrease in SOC decelerated over time and was similar for all crop fields, going from approximately 0.75% to 0.6% (Figure 7).

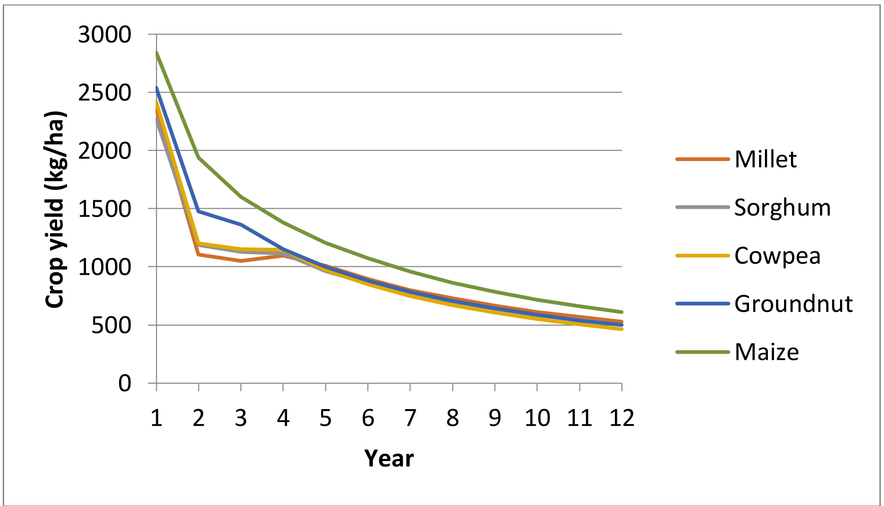

Figure 6: Evolution of crop yields (kg/ha) over time.

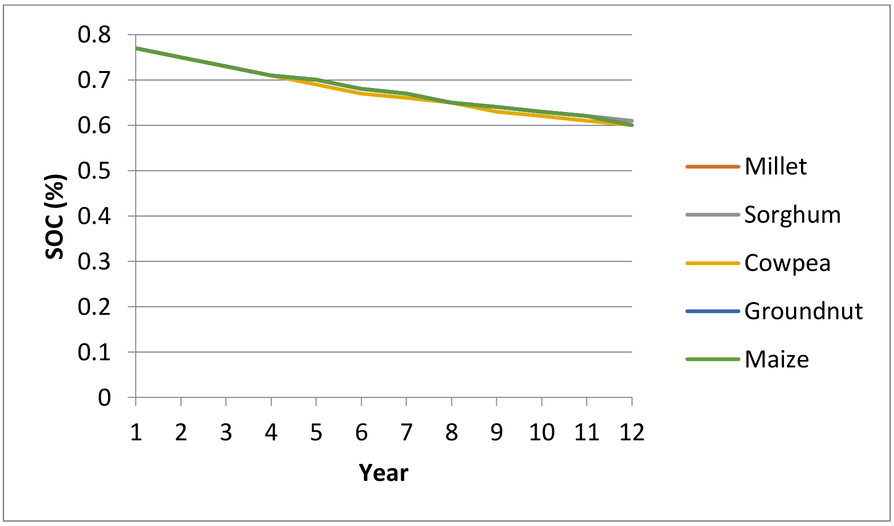

Figure 7: Evolution of SOC (%) in the different fields over time.

Milk production was highest in the first years of simulation, after which it went to 0 (Table 11). There was no milk production in farm types 1 and 3, as bulls were the only cattle present. Milk production was highest for type 6, which had the highest number of animals. Similar to the trend in milk production there was a decrease in livestock weight: cattle quickly lost weight and deceased (Figure 8). As the total livestock weight of the herd was summed across the animals, farmers with more livestock had a higher livestock weight. The seasonal variation in weight of the livestock is illustrated by the wavy pattern in Figure 8. Livestock weight decreasing fastest in the dry seasons but even in the wet season there was a loss of cattle weight.

Table 11: Amount of milk (kg/year) produced by the cattle for the different farm types.

	Type				
Year	T1	T2	T3	T4	T6
1	0	395	0	355	1483
2	0	101	0	124	199
3	0	0	0	2	0
4	0	0	0	0	0
5	0	0	0	0	0
6	0	0	0	0	0
7	0	0	0	0	0
8	0	0	0	0	0
9	0	0	0	0	0
10	0	0	0	0	0
11	0	0	0	0	0
12	0	0	0	0	0

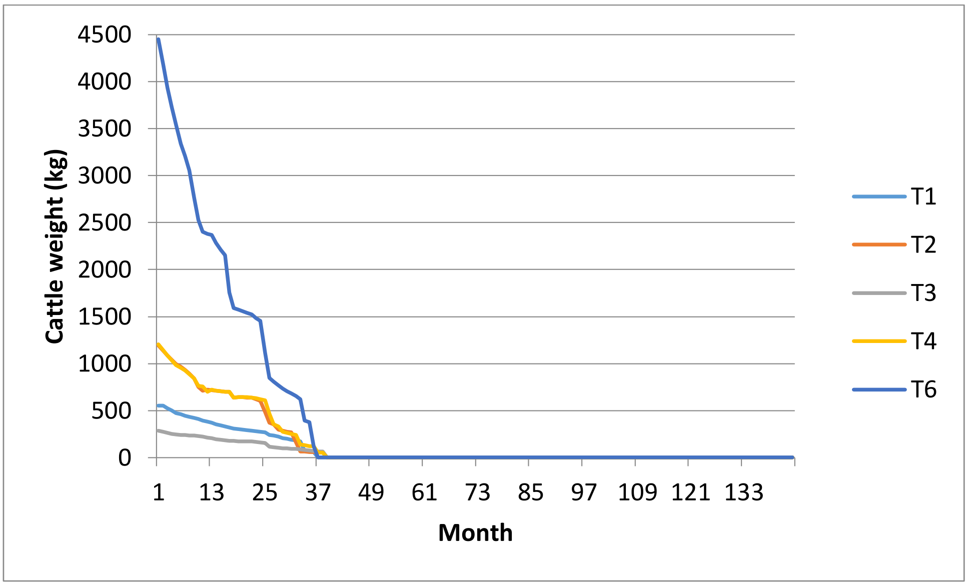

Figure 8: Monthly total cattle weight of the herd (kg, summed across the animals) for the farm types.

The average yearly amount of crop calories produced over the 11 simulation years (first year of simulation not taken into account) was highest for type 6, the farm type with the most cropping land, while it was lowest for farm type 1, which had the least land (Figure 9). Except for farm type 1 all the farms produced on average enough food to feed their household. For types 2 and 6 respectively, the calorific production was approximately 4 and 6 times higher than the calorific needs. This was related to the ratio of cropping land per household member.

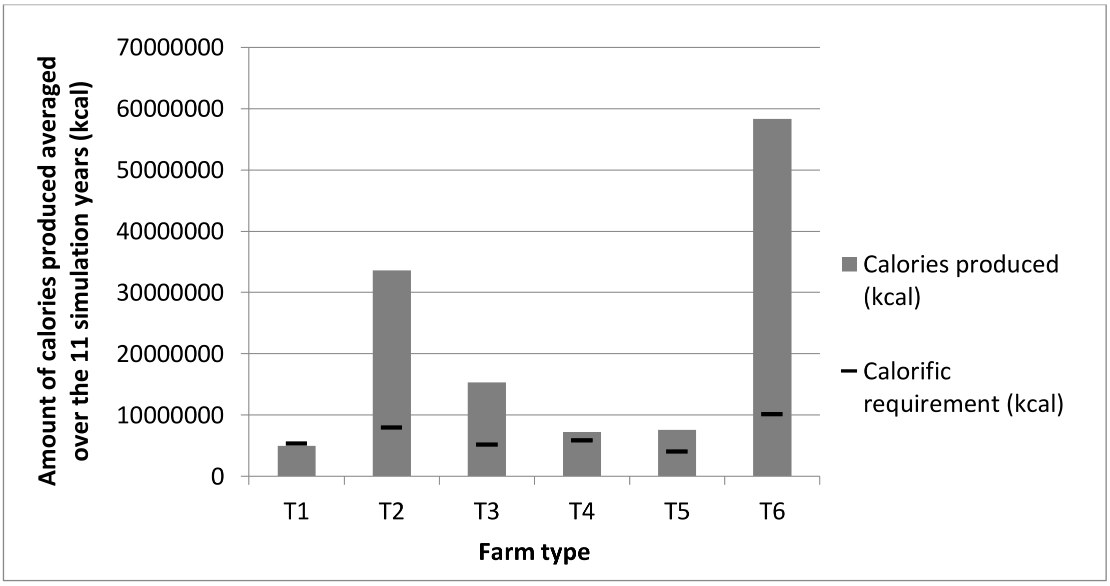

Figure 9: Amount of crop calories (kcal) produced on farm, averaged over 11 years of the simulation, compared to the amount of calories needed within the household.

Similarly to crop yields, the yearly calorific production of the farms decreased over the years (Figure 10). Type 1 and 4 ended with a calorific production which was not sufficient to feed the household, while type 5 was close to reaching the same situation. Type 6 was the farthest away from insufficiently producing enough calories to feed the family, followed by types 2 and 3.

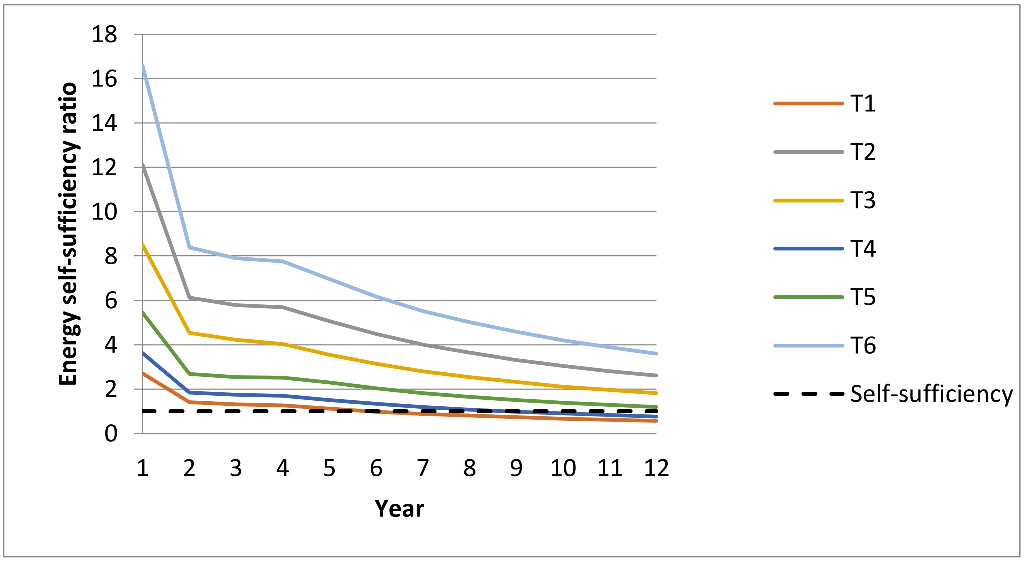

Figure 10: Fraction of calorific food self-sufficiency for the farm types over the years.

3.3.2 Impact of interventions

The percentage change in calorific yield production, livestock productivity and SOC for the interventions compared to the baseline scenario, are reported in Appendix VII, Tables 1 and 2. The number of the interventions given in the following paragraphs can be used to navigate in the table in annex (Appendix VII, Tables 1 and 2).

3.3.2.1 Improvement of livestock forage (interventions 1 to 7)

3.3.2.1.1 Increasing grass quantity available (interventions 1 and 2)

Increasing the quantity of grass fed led to higher livestock productivity as the overall quantity and quality of the feed increased. In type 1 the increase in livestock weight reached 26.6%. This intervention had no effect on crop yield or SOC, as there was no feedback mechanism (because in baseline settings manure application was set at 0).

3.3.2.1.2 Improving grass quality (interventions 3 and 4)

Improving grass quality improved livestock productivity. The increase found depended on the ratio of cropping land: number of cattle (the lower the ratio the stronger the effect) and on crops grown.

3.3.2.1.3 Increasing external forage in the form of legumes, live fences and/or trees (interventions 5 to 7)

Increasing the amount of legumes fed improved livestock weight. An increase in weight by 36% compared to the baseline was reached for type 6 when 2kg of legumes were fed per day. This was related to the improvement of overall feed quality. There was no effect on food production or SOC, as there is no feedback mechanism (in the baseline settings manure application was set at 0).

3.3.2.2 Dual-purpose varieties (Interventions 6 to 14)

3.3.2.2.1 Dual-purpose cowpea (interventions 6 to 10)

A trade-off was visible between the optimization of livestock productivity and calorie production (Figure 1112). The increase of the area under cowpea cultivation increased livestock productivity but reduced calorie production. Livestock weight and milk production were increased thanks to the elevated fodder quality (higher ME, MP and DMD). The rise in livestock productivity was dependent on the number of cattle (e.g. type 3 owns only one male cattle head which does not have the possibility to reproduce while type 2 owns 5 cattle head with the possibility to reproduce) and on the ratio land area : cattle head. When this ratio was higher the increase in livestock productivity when enlarging cowpea area was larger. The livestock still only survives in the first couple of years.

Enlarging cowpea area lowered farm calorie production due to the low calorific content of cowpea than millet, groundnut and maize and a lower yield per hectare than all the other crops. The decrease in amount of calories produced was dependent on the percentage of farm area under groundnut cultivation, as groundnut was the crop with the most calories per kilogram yield and the crop with the second highest yield, after maize (Figure 11, b). Reducing the area of groundnut therefore strongly affected farm calorie production.

No significant changes in SOC were observed, as the difference between the SOC in a cowpea field or in any other field was of 0.01% at most.

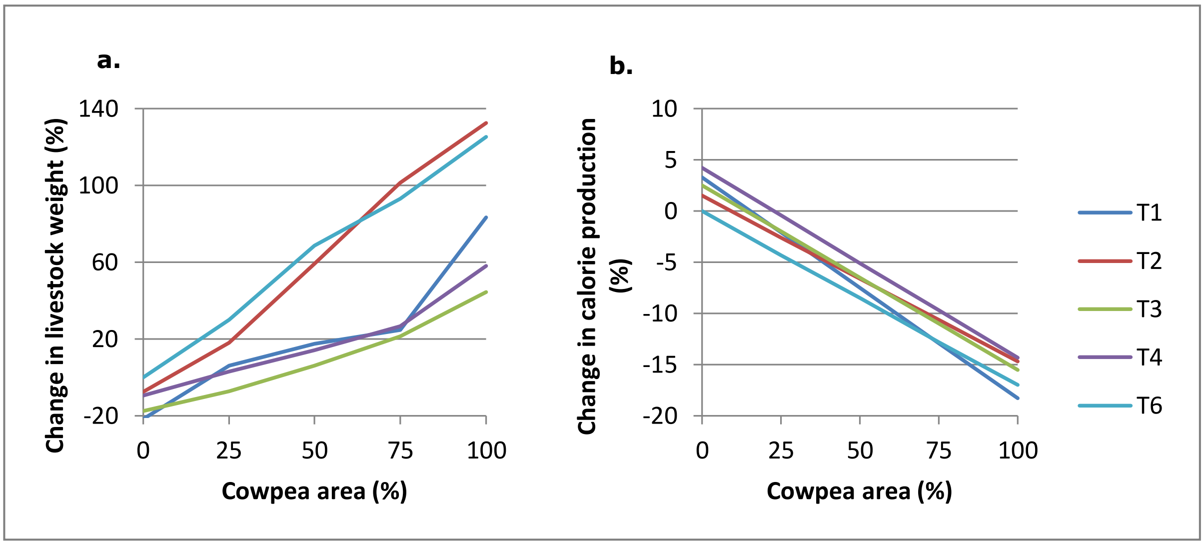

Figure 11: Change in livestock weight (a) and calorie production (b) relative to the baseline scenario, depending on the percentage farm area dedicated to cowpea.

3.3.2.2.2 *Implementation of dual-purpose sorghum*

3.3.2.2.2.1 *Increasing sorghum crop residue availability (interventions 11 and 12)*

Increasing sorghum crop residue production was negative for livestock productivity, especially for type 3 (up to 13.6% loss of cattle weight), as this was the type where the ratio of arable land: livestock is the greatest, followed by type 2. Type 3 was also the type with the highest proportion of land under sorghum cultivation. For the other types the decrease was negligible. This is due to the fact that sorghum residues are of low quality and therefore increasing the amount of sorghum crop residues decreases overall fodder quality. Farm calorific production was slightly reduced.

3.3.2.2.2.2 *Improving sorghum crop residue quality (interventions 13 and 14)*

Improving the quality of sorghum crop residues was positive for livestock productivity as the overall quality of feed was increased. In types 2 and 6 increases of more than 15% of livestock weight were reached. The effect on livestock productivity was dependent on the area of sorghum on the farm, on the ratio of farm area: livestock head and on the possibility of the livestock to reproduce. The greater the ratio of land under sorghum cultivation and the greater the ratio farm area: livestock head, the greater the increase. When cows are present on farm they can produce offspring, explaining a greater increase in livestock weight.

The improvement of the crop residue quality led to a small decrease in yields but had no significant effect on SOC.

3.3.2.3 Drought-tolerant crops (interventions 15 to 18)

Improvement of water conversion efficiency (WCE) was associated with a trade-off between food and livestock productivity. Improving WCE raised yields slightly (a maximum increase of 2.9% for type 6 at a WCE increased by 20%). This intervention was negative for livestock, as the amount of millet or sorghum crop residues increased, decreasing overall forage quality in the dry seasons. The magnitude of the effects depended on the proportion of the farm under cultivation of millet and sorghum. Therefore the farm calorific production increased most in farm types 5 and 6 for millet and types 2 and 3 for sorghum. SOC was not affected as there was no change in the amount of crop residues going to the soil.

3.3.2.4 Fallow (interventions 19 to 22)

Increasing the amount of fallow reduced the size of arable land, decreasing farm calorific production and the amount of crop residues produced. The percentage decrease in calories produced was equal to the percentage of land taken out of production.

The fallow interventions did not impact SOC in the fields; whether sorghum was fallowed or not the SOC at year 12 was of 0.61 and whether cowpea was fallowed or not the SOC at year 12 was of 0.60. This meant that increasing the area of sorghum (crop + fallow) slightly increased SOC while increasing the amount of cowpea (crop + fallow) slightly decreased average farm SOC.

Increasing the amount of fallow decreased the amount of crop residues available for feed and livestock productivity.

3.3.2.5 Mulching / crop residue management (interventions 23 to 27)

More crop residues on the field led to negligible higher yields and SOC but lower cow productivity. The increases in yield and SOC were of no more than 0.1% and 0.4% respectively compared to the baseline. Animal body weight decreased by 13% in some of the farms (Figure 12), while milk yield was reduced by more than 50% in farm type 4, due to the reduction of feed available. Cattle weight changes were similar for all farm types, with the exception of type 6. Livestock weight loss when no crop residues were fed was less for this type because livestock receive a daily ration of 0.5kg of concentrates.

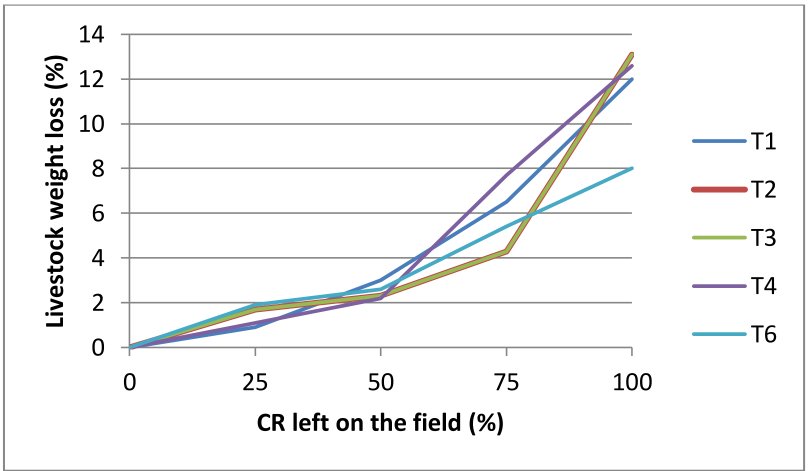

Figure 12: Percentage cattle weight loss relative to the baseline scenario depending on the percentage of crop residues left on the field as soil amendment.

3.3.2.6 Manure management (interventions 28 to 37)

The more manure was applied to the fields, the higher the SOC, increasing by 2% compared to the baseline for type 1. The higher SOC became, the more calories were produced. The increase in calorie production is related to the ratio of cattle head per land area, as more manure applied per field led to a higher increase in SOC and calorie production. For this reason the greatest increase was found for type 4, followed by the types 1, 6, 2 and 3.

Using a plastic sheet to cover the manure heap further improved these results slightly, as carbon and nutrient losses were reduced. There was no a substantial impact on livestock productivity.

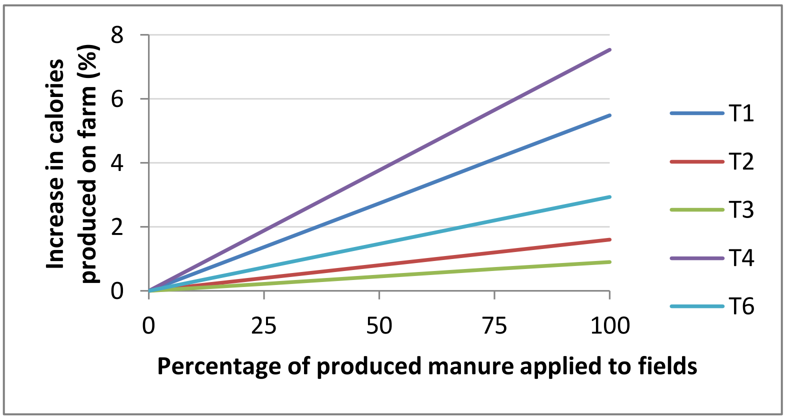

Figure 13: Relative increase of calories (%) produced on farm compared to the baseline scenario, depending on the application of manure to the fields. Manure stored in an open heap.

3.3.2.7 Physical and chemical improvement of crop residues (interventions 38 and 39):

Improving the quality of crop residues improved livestock weight gain and milk production up to respectively 520% (in type2) and 642% (in type3), through the increased availability of MP and ME. More cows live on all farms and the duration of life of the cows is prolonged.

There were no negative effects on food production or SOC, as this intervention had no effect on the soil (because in the baseline scenario it was defined that manure was not collected and applied to the fields).

3.4 Interview

3.4.1 Basic farm typology

There was a temporal space between the collection of the data collected for the WLE-Volta project (June 2015) and the data collected for this thesis (June 2016). During this time changes occurred leading to households shifting from type (Appendix VIII, Table 1). There were no more farms in type 6, therefore this type was no longer included in the analysis of the interview answers. The number of farmers in types 5, 1 and 2 increased. The main cause for changes in farm types was the loss of livestock (14 out of 39 households experienced livestock losses, moving the household into other farm types). In four cases the change was due to a gain of cattle and in four cases it was due to a gain of ruminants. Only in two cases was the change of type due to a shift in land holding. For full information about household characteristics, refer to Appendix VII, Tables 2 and 3.

3.4.1.1 Primary farm activity

Most farmers considered themselves both crop cultivators and livestock holders (Table 12). Only one famer interviewed was only livestock holder. This farmer belonged to type 4 and possessed many small ruminants. The respondent saying the primary farm activity was ‘other’ was involved in small business. Some farmers in type 1 and 5 (without cattle) consider themselves solely cultivators (Table 12).

Table 12: Number of farmers considering themselves cultivator, livestock holder, both cultivator and livestock holder and other.

	Farm type				
Primary farm activity	1	2	3	4	5
Crop cultivation	3	0	0	0	5
Livestock holding	0	0	0	1	0
Agriculture and livestock	3	8	11	5	2
Other	0	0	0	1	0

3.4.1.2 Livestock holding

In almost all cases cattle is owned by the men in the household. Small ruminants are more often under shared ownership or women ownership (Appendix VIII, Table 4).

3.4.2 Constraints

Capital was a constraint for all respondents. It was on average also the constraint which got the highest score (Table 13). Livestock was the second most important constraint, getting for all types a median score of 4 (Table 13). However, for type 5 less than 80% of the respondents considered livestock as constraining (Figure 14). Technology and education were most often seen as a constraint by farmers in types 1 and 5, while respondents from type 2 considered technology and education as constraints the least often. The constraints of education and technology got a score of 4 for types 1, 5 and 3, while types 2 and 4 gave them a score of 3. Cropping land was for all types a medium to weak constraint and it was present for 60% to 80% of farmers in all types. Grazing land was less often a constraint and it had the lowest constraint scores for all types. For farm type 5a median constraint strength of 0 was found.

For grazing land, education and technology a significant difference in the proportion of respondents listing elements as "constraint" or "no constraint" was found (Figure 14). The outcomes of the statistical tests can be found in Appendix VIII, Table 5.

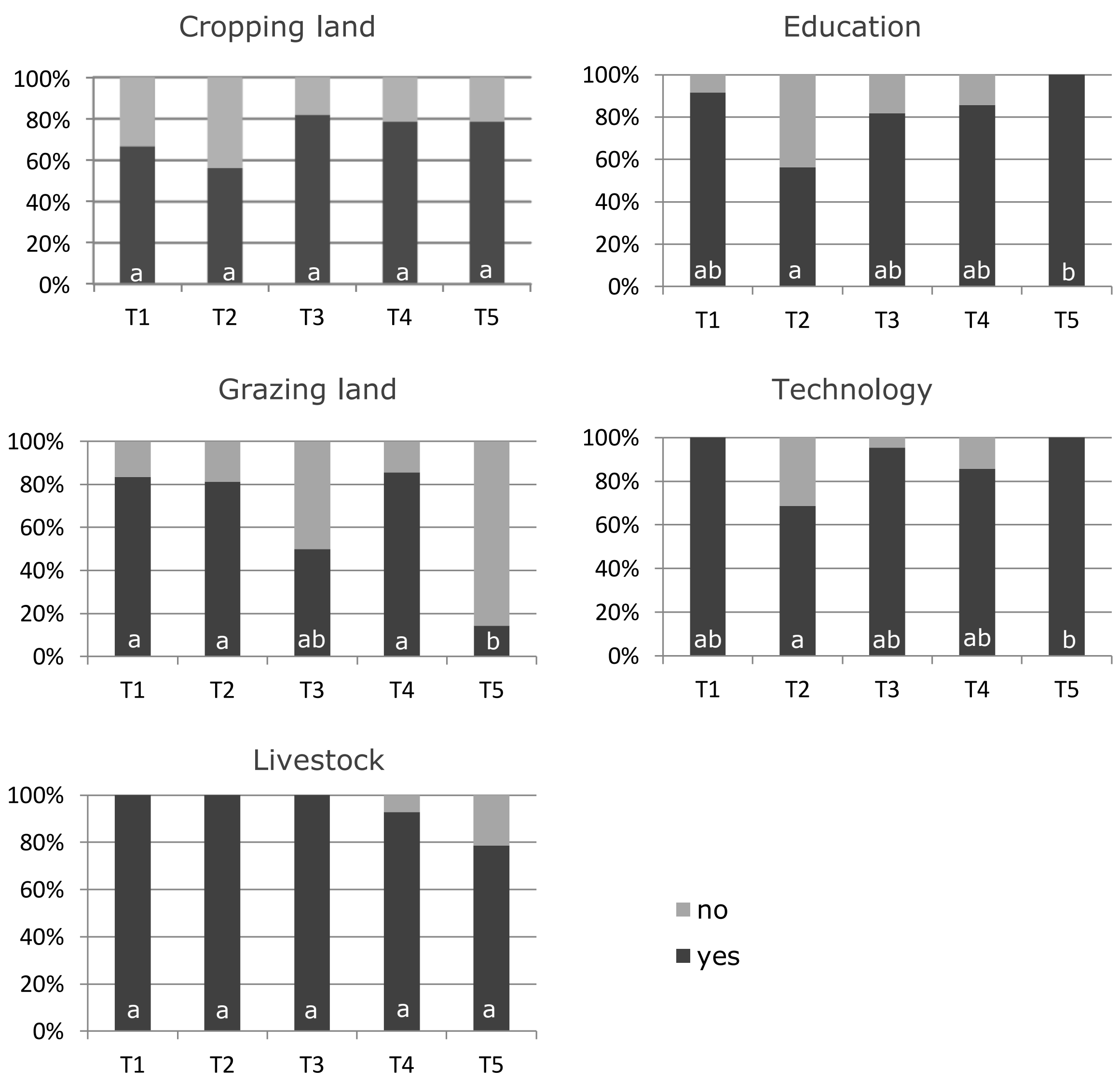

Figure 14: Proportions of 'yes' and 'no' answers given when asked if cropping land, grazing land, livestock, education and technology were constraints. Proportions are significantly different if no letter is in common.

Table 13: Average importance given to the constraints by farmers in the different farm types, when element is given as a constraint. Reddish and greenish colours indicate higher and lower percentages of respondents mentioning that the element is a constraint.

	Farm type				
Constraints	T1 (n=12)	T2 (n=16)	T3 (n=22)	T4 (n=14)	T5 (n=14)
Capital	4.3	4.3	4.5	3.4	4.6
Livestock	4.3	3.4	3.8	3.2	3.3
Technology	3.7	2.4	3.6	2.9	4
Education	3.8	2.1	3	2.6	3.8
Cropping land	2.9	1.9	2.8	3.1	2.9
Grazing land	0	0.9	0.7	0.9	0

No significant difference was found between men and women when comparing the proportions of respondents listing elements as constraints (Appendix VIII, Table 6).

3.4.3 Goals

For all farm types social cohesion was the most important goal (Table 20). This was the case because respondents worked on communal projects, such as the building of roads. Social cohesion was also important as it was a premise for living in a community. Next to this the village inhabitants lived closer to each other than they lived to family and mutual aid was important. Especially in case of problems it was important to know there was someone who could help.

Sustainable management of natural resources was the next most important goal, explained by the will to preserve the environment for the following generations and thus to ensure the survival of the family. To this end, many different management interventions were applied, including tree planting, zaï practice and the building of stone bunds to reduce erosion.

Food self-sufficiency was very important in all types except type 2 because it enabled feeding the family and decreased dependence on the market, remittances or other inhabitants of the community. However, it was also stated that food self-sufficiency was dependent on rainfall and was thus variable. For most farmers self-sufficiency was not achieved and food had to be bought for a varying number of months per year (from two to ten months). For type 2 self-sufficiency was a less important goal as 50% of the farmers produced enough food to survive throughout the year. This percentage was respectively of 0%, 4%, 7% and 0% for types 1, 3, 4 and 5. Once again type 2, which was considered the wealthiest type was significantly different from the other farm types for this goal (Appendix VIII, Table 7).

Maximising whole farm production and maximising yield were the next most important goals, except for type 5. Maximising whole farm production meant that not only yields were maximised, but also the crop residue production for livestock feed and manure production for amending the soil were maximised. This goal was relatively important because famers said more crop residues increased feed availability, increasing livestock productivity and manure production. Some farmers also sold crop residues for extra income. Sometimes it was however added that food production was the main aim and overall farm production should not reduce food production. This goal was less important for type 5 as respondents did not own livestock (64% of the respondents from this type did not put emphasis on maximising whole farm production).

Maximising yields was important. However, similarly as for maximising whole farm production, the score given by type 5 was significantly lower than the score given by other types (Appendix VIII, Table 7). This was due to the fact that 57% of the farmers said not to have enough means to be able to maximise yields. For types 1, 2, 3 and 4 the percentage of farmers who made the same statement was respectively of 8%, 13%, 9% and 0%. Maximising yields was important to produce more food and to be able to sell produce.

The goal labour minimization was not interpreted as total labour (hired + household labour). Only hired labour was taken into account by the respondents. For all farm types the average score for minimising labour was approximately equal (between 2.6 and 3.1). Farmers of type 1 explained that land area was relatively small and therefore there was no need for external labour (42%), or that they did not have enough capital to hire external labour (33%). In type 2 the majority of the respondents (75%) said labour was hired because of the big amount of work that needed to be done (timeliness of achieving activities). Type 2 farmers were the most resource endowed because they owned a lot of livestock and land. In type 3 only 45% of the respondents hired labour. In this type, 32% of the farmers stated they would like to hire labour but this was impossible due to capital constraints. In type 4 43% of the respondents said they hire labour, while 36% stated not to have enough capital to hire labour. Only 14% of the respondents in type 4 declared they did not need external labour force. For type 5 the scenario is different: 71% of the respondents told they needed more labour but they did not have enough capital to hire labour. The rest of the respondents of type 5 said family was big enough to meet the labour requirement.

Table 14: Average score given by the different farm types for the 11 goals.

	Type				
Average score for goals	T1	T2	T3	T4	T5
Ensuring social cohesion	4.9	4.1	4.6	4.4	4.4
Maximising sustainable management of natural resources	4.2	3.8	3.8	4.0	3.7
Maximising self-sufficiency	4.2	2.3	3.9	3.9	4.1
Maximising whole farm production	4.3	3.5	3.8	4.1	2.1
Maximising yield	4.2	3.3	3.3	3.9	2.4
Minimising labour input	2.7	2.9	3.1	3.1	2.6
Achieving activities in a timely manner	2.3	2.8	3.0	2.9	3.7
Maximising off-farm income	3.9	3.1	2.6	2.4	2.1
Ensuring land ownership	3.0	1.8	2.7	3.1	2.8
Maximising income	3.4	2.8	2.5	2.4	1.9
Maximising market orientation	3.2	2.7	1.6	2.1	1.6

Achieving activities in a timely manner received a medium score, except for types 3 and 5, who scored this objective higher. For type 5 this was because family is the main workforce. Type 5 had the smallest number of household members and was seen as the least endowed farmer type as no livestock was kept. For these respondents rural exodus was also an important factor limiting labour availability and thus the timely achievement of activities. Fifty percent of the interviewees of type 3 also said they depend on household labour. Thirty-six percent of the respondents of both type 3 and 5 said they had difficulties finding sufficient labour to perform the required tasks, while for the types 1, 2 and 4 this proportion was respectively 16%, 25% and 21%. This was due to the fact that type 1, 2 and 4 had enough labour available within the household and because the area to be cultivated was small enough to take care of.

Maximising off-farm income was most important for types 1 and 2 and least important for type 5. Type 1 was significantly different for this goal compared to the other types (Appendix VIII, Table

7). For the respondents having a vegetable garden, the selling of products from this vegetable garden was seen as generating off-farm income. In farm type 5 more than half of the farmers did not have another job, while as much as 36% of these respondents performed vegetable gardening. In types 4 and 1 the amount of farmers who did not earn income with off-farm origin was above 49%. In type 1 an often recurring reason for giving a high score was the absence of other sources of income. In types 2 and 3 less farmers expressed that there was a lack of off-farm opportunities for gaining money.

Land ownership got a score below 3 for all farm types except 1 and 4. In most farm types the percentage of land owners was around 55%, the other respondents rented land. This meant that more than half of the respondents were not afraid their land would be taken from them, as they were the legitimate owners. For types 1 and 4 the amount of land owners was lower, which might explain the importance of land ownership for those types. These two farm types were also the types with the smallest area of land.

Income maximisation was not the most important objective. However, in all types there were farmers with income generating activities. Type 1 farmers gave an average score of 3.4 to income maximization. In that type 33% of the farmers generated income either through the growing of crops for selling or through off-farm activities. In type 2 81% of the respondents declared crops were cultivated to generate income (such as sesame and groundnut). Thirty-six percent of farmers in type 3 had activities in the aim of increasing income (livestock raising, vegetable growing). In type 4 only one farm (7%) was busy with milk production in the dry season with the aim of increasing income. In type 5 36% of the farmers had activities to increase income: production of cowpea and groundnut, as well as vegetable production.

Market orientation was on average the least important goal for the respondents, except for type 1, for whom the average score was of 3.2 (this farm type was significantly different from the other farm types in this response). In this type 66% of the respondents said they sold products, when possible at the moment prices were highest. In type 2 80% of the farmers sold products. However, only 50% of the farmers sold products at the moment when the prices were best. In type 4, 5 and 3 respectively 40%, 14% and 12% of the respondents sold products, when possible. The farmers who did not sell their produce consumed it, as they were food insecure. Here again a difference was observed between type 2, the type considered most resource endowed and the other farm types.

Appendix VIII, Table 7 presents the Fisher exact test outcomes, signalling the presence (or not) of significant differences in the proportion of answers given by the different farm types.

For neither of the goals there was an association between the gender of the respondent and the scores given to constraints (Appendix VIII, Table 8).

3.4.4 Attitudes

3.4.4.1 Analysis of attitude

The most striking answers were those to the statements number 1, 3, 8, 11 and 13 where almost all respondents gave the same answer (Table 15). Of the 77 households only 4 households stated they were not proud of being farmer, because they felt they have no other choice than being farmer (statement 1). The feeling of proudness was sometimes said to depend on crop yield. Most farmers were proud to be farming as it enabled to produce their own food and support the family. This was also the reason why most farmers perceive farming as a fulfilling activity (statement 3). All the farmers thought there were problems in the current farming system and there was a need for new and improved technologies to improve the farming system (statements 8 and 11). Except for 3 % of the farmers all of them were also open towards new practices and technologies (statement 13). The justification for not being open towards new interventions is related to the absence of means to implement new interventions.

On the statement that it is a destiny to be farming (statement 2) the answers were mostly in agreement, because the respondents grew up in agriculture and farming was performed by their parents. For some participants it was also because they did not go to school. When farmers did not think it farming is a destiny, they said it was because there always is a choice.

Table 15: Percentage of farmers agreeing, disagreeing and giving a neutral answer to the statements.

Statement	Percentage of farmers giving the answer		
	Disagreement	Neutral	Agreement
1. I am proud to be a farmer	4	1	95
2. It is my destiny to be a farmer	13	4	83
3. Farming is fulfilling	4	9	87
4. Farming is a good way to meet my needs and those of my family	18	14	68
5. There is no better investment than an investment in farming	26	10	64
6. If I had a choice I would be a (full-time) farmer	43	8	49
7. I would prefer if my children would not end up farmers	22	25	53
8. There is/are no problems in the current farming system	100	0	0
9. The current way of farming functions well enough to cover my family's needs now and in the future	48	5	47
10. There is no hope for farmers like us to improve our standard of living	66	8	26
11. There is a need for new interventions and technologies to improve the current farming system	0	0	100
12. I seek information on good farming practices from extension officers / farm groups / other farms / external sources	18	8	74
13. I am open towards or practice new methods and interventions	3	1	96
14. I am prepared to give labour and capital to do new interventions and technologies	8	3	90
15. I want to avoid risk as much as possible	82	8	10

A little more than the majority of the farmers said there is no better investment than farming (statement 5). This had several different reasons: there are no opportunities except agriculture, respondents are proud to be farming, investments in agriculture enable maximising production and because agriculture is the activity the respondents know and master. When it was said that there are better investments than agriculture this was due to respondents saying they would invest in something else if there was a choice and stating agriculture does not meet the needs.

Half of the farmers would be farmer if they had the choice (statement 6). The other half would not be farmer, for several reasons: either they would prefer a job as civil servant, either they would prefer to raise livestock.

The answers concerning the hope for children to end up farming were variable (statement 7). Either the respondents said they are farming and therefore it is also good enough for their children. Some respondents also gave a neutral answer, mentioning that children should choose for themselves. Lastly some respondent preferred if their children did not end up farming, in the hope of building up a better life. For this reason some of the children were sent to school. The answers as to whether farming was a good way to fulfil all needs were also variable (statement 4). Half of the respondents answered this was the case, as their own food is produced and there is no dependency on other people. Other respondents stated yields are not high enough and farming is a tiring activity, which therefore does not fulfil all the needs.

The opinions are divided about the ability of the current farming system to cover current and future needs (statement 9). Positive answers are given thanks to the use of technologies (e.g. stone bunds) and due to the ownership of land. Negative answers are supported by stating that there is a need for new interventions and technologies, that climate change and the reduction in soil fertility will limit agricultural production in the future.

Mostly it was hoped to increase the quality of life through farming (statement 10). This was related to the fact that respondents relied on new technologies and information to improve yields and soil quality. The farmers who did not believe farming can increase the quality of life stated yields were too low and they did not have enough money to progress. The majority of the respondents stated they seek information about good agricultural practices (statement 12). The negative answers on information were given by women, who answered it is their husband who seeks information.

The biggest portion of the farmers was prepared to give labour and capital for the implementation of new technologies and techniques and they are open to taking (moderate) risks if the gains are high enough (statements 14 and 15).

3.4.4.2 Attitude cluster formation

Clusters of the respondents with the most similar answers given on the attitude statements were made. Some statements were not taken into account for the making of the cluster, for the following reasons:

- Statement 12 was omitted because the negative answers came from women, who said only their husband seeks for information. This meant that there was a search for information within the household.
- Statement 6 was not taken into account as livestock was seen as an activity different from farming.
- Statements 13, 14 and 15 were not included as some farmers did not answer the questions in the way the questions were intended.

The dendogram for the construction of clusters can be seen in Appendix VIII, Figure 1. The chosen cut-off point was located at a distance of 17.5, leading to the formation of 4 clusters (Table 16).

Farmers from all the clusters were proud to be farming, they thought it was their destiny to be farming, they felt farming was fulfilling and a good way to fulfil needs and that there was a need for new interventions to improve the current situation (Table 16). They also all stated there are problems in the current farming system. Differences between clusters are as follows:

- Cluster 4 had a neutral answer on the statement whether farming is a good investment. Respondents from cluster 1, 2 and 3 considered farming to be a good investment
- Cluster 2 was neutral as of the future of the children, whether they end-up farming or not, while clusters 1, 3 and 4 hoped their children do not end up farming.
- The opinions about farming being a good way to suffice needs were divided. Cluster 1 and 2 did think so, while cluster 3 and 4 were more hesitant.
- Respondents from clusters 1 and 4 were neutral about the statement that there is hope to improve the quality of life. Respondents from clusters 2 and 3 thought there is hope to improve the quality of life

A significant association between the clusters and the interviewers who conducted the interviews was found (Appendix VIII, Table 9). There was no significant difference between the interviewers 1 and 2 but both were significantly different from interviewer 3, meaning either the interviewers themselves influenced the answers through the way of conducting the interviews, or there was a location effect, as each interviewer conducted interviews in a different village.

Table 16: Average score given to the statement accompanied by standard deviation, for the four clusters (1=disagreement, 2=neutral, 3=agreement).

	Cluster			
Statement	1	2	3	4
1. Proud to be farmer	3.0 (±0.0)	2.9 (±0.4)	2.9 (±0.5)	2.9 (±0.5)
2. Destiny to be a farmer	2.7 (±0.7)	2.9 (±0.4)	2.7 (±0.7)	2.4 (±0.9)
3. Farming is fulfilling	3.0 (±0.0)	2.9 (±0.3)	2.9 (±0.5)	2.6 (±0.7)
4. Good way to fulfil needs	2.8 (±0.6)	2.5 (±0.8)	2.4 (±0.9)	2.4 (±0.8)
5. Good investment	2.9 (±0.3)	2.4 (±0.9)	2.4 (±0.9)	1.9 (±0.9)
7. I would prefer if my children would not end up farming	2.6 (±0.6)	1.9 (±0.9)	2.4 (±0.8)	2.5 (±0.8)
8. There are no problems in the current farming system	1.0 (±0.0)	1.0 (±0.0)	1.0 (±0.0)	1.0 (±0.0)
9. The current way of farming is good enough to suffice my needs	2.7 (±0.7)	2.4 (±0.9)	1.2 (±0.5)	1.6 (±0.9)
10. There is no hope for farmers like us to improve our quality of life	2.4 (±0.9)	1.4 (±0.9)	1.1 (±0.5)	1.6 (±0.9)
11.There is a need for new interventions and technologies to improve the current farming system	3.0 (±0.0)	3.0 (±0.0)	3.0 (±0.0)	3.0 (±0.0)

3.5 Expert opinion on constraint strengths

Only the interventions 'leaving crop residues on the field' had no constraints at all (Table 17). Cropping land was a constraint only for the intervention fallowing, for which cropping land is taken out of production. The only interventions for which livestock was constraining was when manure was applied to the fields. For the planting of native and exotic species, pasture area was necessary and therefore considered a constraint. Education, technology, capital and labour were constraining for the following interventions:

- Pasture planted with exotic species,
- Planting of drought tolerant crops,
- Planting of dual-purpose crops,
- Collection and storage of crop residues as animal feed,
- Application of manure on the fields,
- Physical treatment of crop residues,
- Chemical treatment of crop residues

Next to this, education, technology and labour were constraining for the planting of the pasture with native species. Labour was the major constraint for the collection of crop residues livestock feed.

Table 17: Expert opinion on the strength (0=weak, 1=medium and 2=strong) of constraints for the implementation of interventions.

Intervention	Constraining element						
	Cropping land	Pasture	Livestock	Education	Technology	Capital	Labour
Pasture planted with native species	0	2	0	1	1	0	1
Pasture planted with exotic species	0	2	0	2	2	2	1
Planting of improved dual-purpose cowpea and sorghum	0	0	0	1	1	1	1
Planting of drought-tolerant millet and sorghum	0	0	0	1	1	1	1
Leaving 10-20% of the land fallow for 5 years	2	0	0	0	0	0	0
Collection of herbaceous biomass for animal feed	0	0	0	0	0	0	1
Collection and storage crop residues for animal feed	0	0	0	1	1	1	2
Leaving of crop residues on the field	0	0	0	0	0	0	0
Application of manure	0	0	1	2	1	1	2
Physical treatment of crop residues for improved palatability	0	0	0	1	2	1	2
Chemical treatment of crop residues for improved palatability	0	0	0	2	2	1	1

3.6 Matching expert opinion to farm constraints

When matching expert opinion (Table 17) to farmer-reported constraints (Table 13), similarities and differences were seen between types (Tables 18 to 22).

The collection of herbaceous biomass for animal feed and leaving crop residues on the field did not pose a constraint for any farm type, as there was no constraint to the implementation of these interventions following the expert opinion (labour was not taken into account).

For the planting of pastures with native species, education and technology were constraints in all the farm types. All constraints were of medium strength, except for type 5 which was strongly constrained in technology. When exotic species were planted the same constraints played a role, with the addition of capital and all constraints, for all types, were strong. The same was true for the chemical treatment of crop residues, except for the medium constraint of capital in type 4. The results for the physical treatment of crop residue were similar to the results for the chemical treatment of crop residues, minus the reduced strength for the education constraint, which was medium for all types.

For the planting of dual-purpose crops, drought tolerant crops and for the collection and storage of crop residues as animal feed the same three constraints were present. For most types education and technology were medium constraints, while capital was strongly constraining. This was not the case for type 4 for which capital was only mildly constraining. For type 5 technology was also strongly constraining.

The only constraint for all types for the implementation of fallowing was cropping land. Depending on the strength of the constraint in the different types the final constraint was either medium or strong (medium for type 2, which has a lot of land and strong for all the other types, which own less land).

Table 18: Resulting constraint scores from the matching of the expert evaluation with the constraints of type 1, for the different interventions. Green boxes show there is no constraint, orange boxes show a medium constraint and red boxes show a strong constraint. The higher the score the more important the constraint.

Intervention	**Constraining element**					
	Cropping land	Pasture	Livestock	Education	Technology	Capital
Pasture planted with native species	0	0	0	0.38	0.38	0
Pasture planted with exotic species	0	0	0	0.75	0.75	1
Planting of improved dual-purpose cowpea and sorghum	0	0	0	0.38	0.38	0.5
Planting of drought-tolerant millet and sorghum	0	0	0	0.38	0.38	0.5
Leaving 10-20% of the land fallow for 5 years	0.5	0	0	0	0	0
Collection of herbaceous biomass for animal feed	0	0	0	0	0	0
Collection and storage crop residues for animal feed	0	0	0	0.38	0.38	0.5
Leaving of crop residues on the field	0	0	0	0	0	0
Spreading of manure on fields	0	0	0.5	0.75	0.38	0.5
Physical treatment of crop residues for improved palatability	0	0	0	0.38	0.75	0.5
Chemical treatment of crop residues for improved palatability	0	0	0	0.75	0.75	0.5

The application of manure on the field required many elements: livestock, education, technology and capital. The education constraint was always strong, as this was defined as a strong constraint for the intervention by the experts and all the farm types were in greater or lesser extent limited by education. Type 1 was the only type strongly constrained by livestock. For manure application type 5 was strongly constrained by technology while for the other types this was a medium constraint. All types were strongly constrained by capital, except for type 4, for which it was a medium constraint.

Table 19: Resulting constraint scores from the matching of the expert evaluation with the constraints of type 2, for the different interventions. Green boxes show there is no constraint, orange boxes show a medium constraint and red boxes show a strong constraint. The higher the score the more important the constraint.

Intervention	Constraining element					
	Cropping land	Pasture	Livestock	Education	Technology	Capital
Pasture planted with native species	0	0	0	0.5	0.25	0
Pasture planted with exotic species	0	0	0	0.5	0.5	1
Planting of improved dual-purpose cowpea and sorghum	0	0	0	0.25	0.25	0.5
Planting of drought-tolerant millet and sorghum	0	0	0	0.25	0.25	0.5
Leaving 10-20% of the land fallow for 5 years	0.25	0	0	0	0	0
Collection of herbaceous biomass for animal feed	0	0	0	0	0	0
Collection herbaceous biomass for selling	0	0	0	0	0	0
Collection and storage crop residues for animal feed	0	0	0	0.25	0.25	0.5
Spreading of manure on fields	0	0	0.38	0.5	0.25	0.5
Physical treatment of crop residues for improved palatability	0	0	0	0.25	0.5	0.5
Chemical treatment of crop residues for improved palatability	0	0	0	0.5	0.5	0.5

Table 20: Resulting constraint scores from the matching of the expert evaluation with the constraints of type 3, for the different interventions. Green boxes show there is no constraint, orange boxes show a medium constraint and red boxes show a strong constraint. The higher the score the more important the constraint.

Intervention	Constraining element					
	Cropping land	Pasture	Livestock	Education	Technology	Capital
Pasture planted with native species	0	0	0	0.38	0.38	0
Pasture planted with exotic species	0	0	0	0.75	0.75	1
Planting of improved dual-purpose cowpea and sorghum	0	0	0	0.38	0.38	0.5
Planting of drought-tolerant millet and sorghum	0	0	0	0.38	0.38	0.5
Leaving 10-20% of the land fallow for 5 years	0.5	0	0	0	0	0
Collection of herbaceous biomass for animal feed	0	0	0	0	0	0
Collection and storage crop residues for animal feed	0	0	0	0.38	0.38	0.5
Leaving of crop residues on the field	0	0	0	0	0	0
Spreading of manure on fields	0	0	0.38	0.75	0.38	0.5
Physical treatment of crop residues for improved palatability	0	0	0	0.38	0.75	0.5
Chemical treatment of crop residues for improved palatability	0	0	0	0.75	0.75	0.5

Table 21: Resulting constraint scores from the matching of the expert evaluation with the constraints of type 4, for the different interventions. Green boxes show there is no constraint, orange boxes show a medium constraint and red boxes show a strong constraint. The higher the score the more important the constraint.

Intervention	Constraining element					
	Cropping land	Pasture	Livestock	Education	Technology	Capital
Pasture planted with native species	0	0	0	0.25	0.25	0
Pasture planted with exotic species	0	0	0	0.5	0.5	0.75
Planting of improved dual-purpose cowpea and sorghum	0	0	0	0.25	0.25	0.38
Planting of drought-tolerant millet and sorghum	0	0	0	0.25	0.25	0.38
Leaving 10-20% of the land fallow for 5 years	0.75	0	0	0	0	0
Collection of herbaceous biomass for animal feed	0	0	0	0	0	0
Collection and storage crop residues for animal feed	0	0	0	0.25	0.25	0.38
Leaving of crop residues on the field	0	0	0	0	0	0
Spreading of manure on fields	0	0	0.38	0.5	0.25	0.38
Physical treatment of crop residues for improved palatability	0	0	0	0.25	0.5	0.38
Chemical treatment of crop residues for improved palatability	0	0	0	0.5	0.5	0.38

Table 22: Resulting constraint scores from the matching of the expert evaluation with the constraints of type 5, for the different interventions. Green boxes show there is no constraint, orange boxes show a medium constraint and red boxes show a strong constraint. The higher the score the more important the constraint.

Intervention	Constraining element					
	Cropping land	Pasture	Livestock	Education	Technology	Capital
Pasture planted with native species	0	0	0	0.38	0.5	0
Pasture planted with exotic species	0	0	0	0.75	1	1
Planting of improved dual-purpose cowpea and sorghum	0	0	0	0.38	0.5	0.5
Planting of drought-tolerant millet and sorghum	0	0	0	0.38	0.5	0.5
Leaving 10-20% of the land fallow for 5 years	0.5	0	0	0	0	0
Collection of herbaceous biomass for animal feed	0	0	0	0	0	0
Collection and storage crop residues for animal feed	0	0	0	0.38	0.5	0.5
Leaving of crop residues on the field	0	0	0	0	0	0
Spreading of manure on fields	0	0	0.38	0.75	0.5	0.5
Physical treatment of crop residues for improved palatability	0	0	0	0.38	1	0.5
Chemical treatment of crop residues for improved palatability	0	0	0	0.75	1	0.5

3.7 Decision tool

For the selection of the appropriate intervention per farm type, information of different parts of this thesis should be assembled. Take the following steps (Figure 15):

1. Determine the aim of the project
2. Determine the farm type for a particular household (Figure 5)
3. Use Tables 18 to 22 (depending on the farm type) to determine which interventions are possible without encountering any constraint, which interventions are possible when alleviating medium constraints and which interventions are possible when alleviating one or several strong constraints.
4. Assess the potential impacts of the intervention for the specific farm type, using Appendix VII, tables 1 and 2.
5. Determine which interventions are applicable, weighing the potential impact on various indicators, against the constraint limiting their adoption.
6. Check the intervention supports the goals of the farmer (Table 14). If this is not the cases repeat the steps 5 and 6

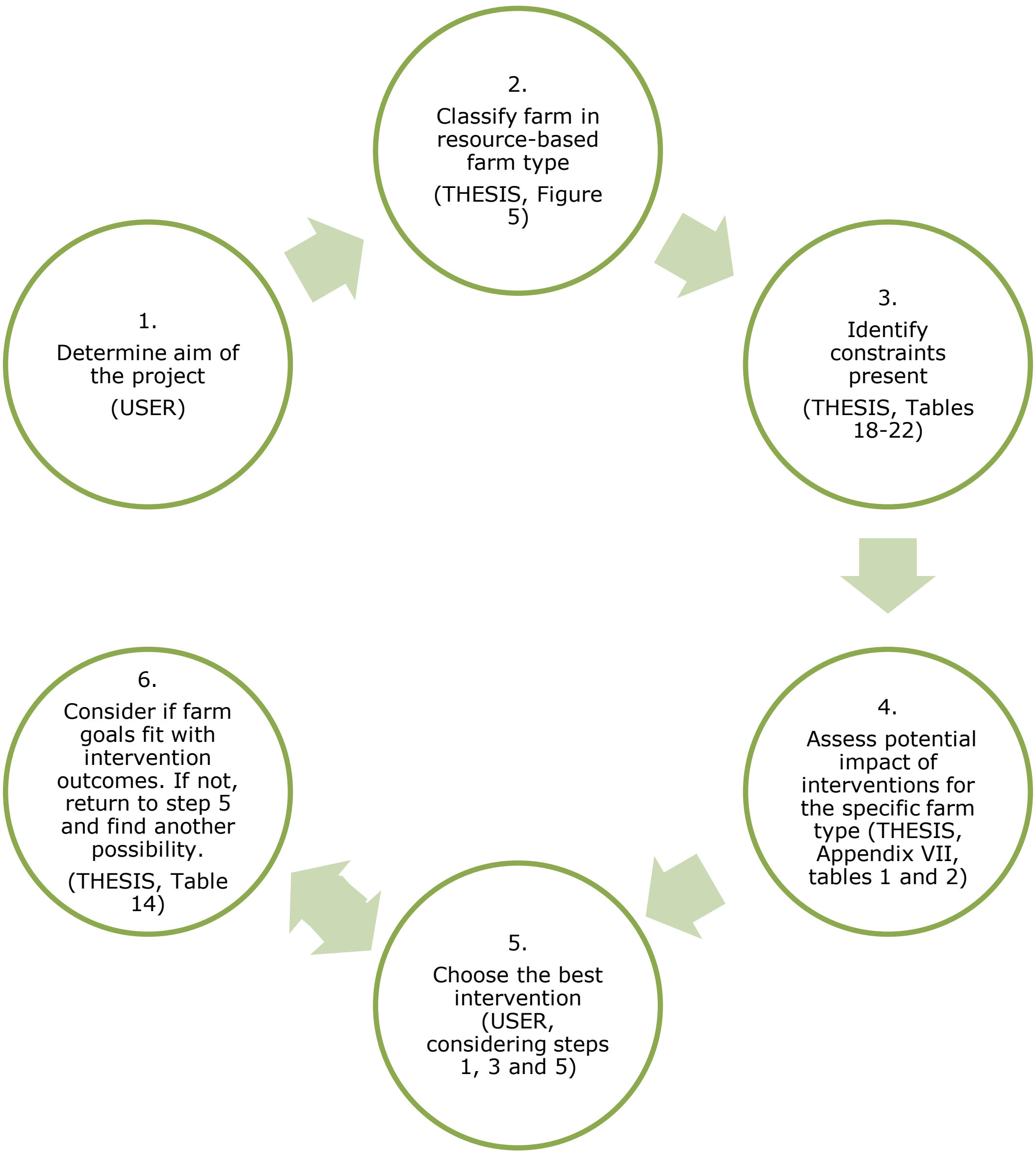

Figure 15: Flow chart of the steps in the decision process. User mean the step should be taken by the user, thesis means the information is available in the thesis.

3.8 Example

In the following paragraph an example is given on how the decision tool could be used. The steps are taken in the order given in Figure 15.

1. The project aim is to increase calorific production.
2. One household is considered, with 5ha but no cattle. Using Figure 5 it is determined that this household belongs to Type 1.
3. Refer to table 18 (as the household belongs to type 1) to see which interventions bring along which constraints.
4. Using Appendix VII and Table 1 it was found that interventions the most beneficial for the improvement of calorific production are applying manure followed by decreasing cowpea area (reducing the area of dual-purpose crop) and by increasing water conversion efficiency of crops (taking drought-tolerant crops into use).
5. Spreading manure is strongly constrained by livestock, education and capital and the medium constraint of technology is also present.

   Using drought-tolerant crops is slightly negative for livestock production. It is strongly constrained by capital and medium constrained by education and technology.

   Reducing cowpea area is negative for livestock production and it has the same constraints as the implementation of drought-tolerant crops.

   With this information the choice is made to go for using drought tolerant crops: there are fewer constraints than for the implementation of manure spreading and the impact on calorie production is greater than for the reduction of cowpea area, it also has less negative impact on livestock production.
6. This intervention is mostly in line with farmer goals: it will increase food self-sufficiency and maximise yield. Crop residue production is also increased.

4 Discussion

4.1 Setting of baseline scenario

4.1.1 Crop

For this exercise only one farm type grew maize. This has two main causes. Firstly maize is not a major crop in the Ouahigouya region (Funk et al., 2012). Secondly the cut-off points chosen for including a crop in a representative farm played a role: a crop was taken up in the simulation if more than 50% of farmers grew the crop. If a lower cut-off point would have been chosen maize would have been taken up in the simulation exercise more frequently. The area over which maize is grown was on average quite small (over all farms growing maize the average area was of 0.6ha) so that including maize would have only a small impact on the overall farm outcomes.

The area allocated to cereals on the farms is larger than the area allocated to legumes. This is among others due to the fact that women are largely responsible for the cultivation of legumes (Nhamo et al., 2003), traditionally women's crops. Women are most often only allowed to perform agriculture on land which is owned by the husband but not used in that particular season, as they have to get access to productive resources in accordance with their husband (Kevane & Gray, 1999). Next to this the calorie yield of legumes is also smaller for legumes as for cereals.

4.1.2 Livestock

When only a small number of cattle are owned, the herd is predominantly male, while the fraction of females increases with herd size. This is due to the fact that the first need is for ploughing and draft power. Once this need is satisfied farmers will invest in cows for milk production and the provision of calves. In Kenya a similar relation was found between the function of cattle and the structure of the herd: when cattle was important for providing draft power keeping male animals was more important, while for the production of milk the fraction of females in the herd was increased (Rege et al., 2001).

4.1.3 Fertilizer

Fertilizer and manure use was low due to the lack of capital at the start of the growing season (S. Coulibaly, personal communication). The limited use of manure is partly due to the labour needs for collection, transport, storage and application. Transport is limited as manure is bulky and transportation equipment is required. Manure use is also limited because quantity and quality are often low (Bayu et al., 2005), primarily due to feed limitation. Manure might also have different uses within the household, such as fuel (Bayu et al., 2005). From the interview it is however clear those farmers recognise the importance of manure in their farming system and they voice their will to use it. Thus far it is mainly restricted due to transport and handling costs.

4.1.4 Crop residues

For the simulation purposes it was assumed that 100% of the crop residues were eaten by livestock. This is however an overstatement as not all residues are edible (low feeding values of certain parts) (McDowell, 1988). It is therefore possible that a small amount of crop residues stay on the fields, impacting soil fertility. Crop residues also have many alternative functions (fuel, construction material, etc.), leading to a pressure on this biomass resource (Powell et al., 2004; Valbuena et al., 2015). The farmer's choice of crop residue use is dependent on his or her preference, total crop residue production, the availability of other biomass sources and on the demand for crop residues (Valbuena et al., 2015). This implies that in reality less than 100% of the produced crop residues are available for the livestock. In the simulation exercise this would lead to a reduction in livestock productivity (taking away 10% of crop residues is similar to the 10% fallow situation, which led to a reduction in livestock productivity).

4.2 Outcomes baseline scenario

Calorie production, SOC and livestock productivity decrease over time. SOC decreases due to the fact that there is no organic matter input into the soil (crops and residues are taken away, no manure is applied), thus there is more organic matter decomposition than input. This decrease in SOC is followed by a decrease in yields. This is in general the case in sub-Saharan Africa, where low soil fertility is a major factor in the declining per-capita food production (Bayu et al., 2004). The final value of SOC (year 12 of simulation) is still in the range of values found in Burkina Faso (Beal et al., 2015). Livestock productivity decreases due to the low quality of feed available.

4.2.1 Yields

At the start of the simulation exercise the yields are in the higher part of yields currently found in the area. It is possible that the simulation outcomes overestimate yields, as for example diseases and pests are not taken into account (Marinus et al., 2015). In the last simulation year the yields are in the lower range of the yields currently found in sub-Saharan Africa. A big jump in yields is observed between the first and second year. This was due to the fact that there was strong water shortage in years 2 and 3 (years of drought) (Nagothu, 2016).

4.2.2 Food self-sufficiency

It was expected some households would not be self-sufficient, as there is a great number of people undernourished in Burkina Faso (around 4 million in 2016, an amount that has increased since 1990) (FAO, 2015). It is assumed all the crops produced are eaten, while this is not always the case in reality, as part of the harvest may be sold (e.g. to cover expenses for health). This means that the amount of food eaten might be lower, decreasing the amount of calories available and reducing food self-sufficiency. At the same time households might buy external food, increasing calorie intake.

Livestock products were not included in the calculation of food self-sufficiency. Including these products would not have had a great effect, as livestock productivity was low. On average the consumption of livestock products in Burkina Faso is low and meat and milk are only rarely eaten (Lykke et al., 2002). Even in case of shocks, such as crop failure, livestock products are not consumed (Kazianga & Udry, 2006), rather livestock is sold to buy staple foods (Binswanger & McIntire, 1987; McDermott et al., 2010).

4.2.3 Livestock production

Livestock weight gain is related to quantity and quality of available feed (Powell et al., 1996). In sub-Saharan Africa feed shortage is one of the most important constraints limiting milk and meat production (Sanogo, 2011; Bayu et al., 2005) as traditionally the pastures comprise the main source of animal feed (Sanogo, 2011; Sanon et al., 2007; Bayu et al., 2005). Crop residues are also important, especially in the dry season when the nutritional value of rangelands decreases (Rattunde, 1998). Weight is thus gained during the wet season and lost during the dry season.

From the model outcomes it was found that livestock lose weight during all the seasons. As in all seasons more biomass is offered than is eaten, meaning that feed quality and not quantity was limiting. Livestock weight loss was lowers during the wet season. In this season only the basic amount of feed is fed (grass + roughage) which is then of the highest quality (Table 23). In the early dry season grass quality decreases, reducing the quality of the basic amount of feed given (Table 23). During the late dry season this decrease is even stronger. During these dry seasons also crop residues are fed. The quality of these residues is also below the quality of the basic amount of feed given during the wet season (Table 24). This means that the overall feed quality (basic feed + crop residues) is lower than feed given during the wet season. This explains the stronger decrease in livestock productivity in the dry seasons compared to the wet season.

Table 23: Quality during the different seasons of the mixture of grass and roughage given throughout the year.

Season	CP (g/kg DM)	ME (MJ/kg DM)
Wet season	92.20	8.14
Early dry season	78.60	7.50
Late dry season	54.58	6.62

Table 24: Average over 12 years of crop residue quality (crude protein and metabolisable energy).

Type	CP (g/kg DM)	ME (MJ/kg DM)
T1	92.89	7.83
T2	82.06	7.52
T3	85.32	7.58
T4	93.91	7.86
T5	76.02	7.34
T6	76.51	7.36

As in general livestock gain weight during the wet season in Burkina Faso, the quality of the feed given during this season should have been increased to get more realistic results. This could have been done through increasing the quality of the fodder or through increasing the ratio of grass fed compared to the ratio of roughage given.

4.3 Impact of interventions

Cattle weight and milk production can be greatly increased through the interventions but none of the interventions assessed had a big effect on SOC or crop yields. This is because of the sensitivity of livestock to feed changes. The soil is less sensitive to small changes because it is a more static component. Yields are also less sensitive for changes than livestock, mainly due to the fact that yield depends on soil quality (Marinus et al., 2015).

The trends of the results were similar for all farm types, due to the fact that the soil and rainfall conditions are the same. The magnitude of the impacts of the interventions is different between the farm types, depending on crops grown, herd size, the area of land and the ratio between the land area and the number of cattle head. A smaller area of land leads to more cows per land area and the fodder quality will depend less on the crop residues and more on the basic amount of feed given. More cows per land area also means that more manure is produced per area land and thus the impact of manure collection is bigger.

Of the list of interventions assessed there are no interventions which promote all objectives (food production, SOC and livestock productivity) at the same time. Sometimes the interventions promoted only one or two of the three goals (e.g. increase of forage quality) and sometimes a trade-off was found between the optimization of different objectives.

The increase of feed quality, the physical or chemical treatment of crop residues, the improvement of livestock forage (quality and quantity) and the implementation of dual-purpose sorghum through increased residue quality all only affect livestock production. This is due to the fact that in the baseline scenario manure application was set to 0. This means that there is no return of nutrients from the crop residues back to the fields in the form of manure. Allowing the collection and application of manure to the fields increased yields. For future research it would be interesting to see what the effect is on SOC and calorie production of the previously mentioned interventions when manure collection and application happens. Livestock production is increased for all these interventions as fodder quality is improved.

Manure application was positive not only for calorie production, it also increased SOC. However, it had no significant impact on livestock as fodder quality is only slightly impacted (the increase in the amount of crop residues produced on per hectare is of 180kg for sorghum and 200kg for cowpea, negligible quantities compared to the total amount of crop residues fed and the small amount of basic feed given).

A trade-off is found for the establishment of dual-purpose crops and the establishment of drought-tolerant crops. The implementation of dual-purpose cowpea reduced calorific yield as cowpea yield is lower than the other crops and calorific value was lower than groundnut, millet and maize. It however improved livestock productivity as cowpea residues are of a better quality than residues of sorghum and millet, and grass in the dry seasons. Increasing the ratio of cowpea residues in livestock feed therefore increase fodder quality, the limiting factor for livestock productivity. The uptake of drought tolerant sorghum and millet of the uptake of dual-purpose sorghum with an increased crop residue production both led to a greater availability of sorghum (and millet) crop residues. This residue is of lower quality of residue from cowpea or groundnut, therefore decreasing overall fodder quality in the dry seasons, and decreasing livestock productivity. These interventions however improved calorie production, as grain yields were increased. When implementing these interventions the farmer has to make a choice in improving livestock productivity or yield.

Fallow is the only intervention which was not advantageous for any objective. Calorie production decreased proportionally to the amount of land not taken into production. Fallowing also did not improve the SOC, due to the low qantity of residues applied and due to the high decomposition rate. Livestock productivity is also decreased, as less crop residues are available during the dry seasons, reducing forage quality in these seasons (refer to table 23 and 24 to compare the quality of the basic feed given and the quality of crop residues produced on farm).

4.4 Modelling considerations

4.4.1 Weather and soil data

The weather data used was for the years 1981-1992, which was the most complete data-set available. This is however already 24 years ago and the overall rainfall pattern may have slightly changed. For example in the years 1931-1960 and 1968-1990 there was a decline in rainfall (Nagothu, 2016). The data also encompasses the years 1983-1984 and 1991-1992, which were years of widespread droughts (Nagothu, 2016) and may therefore not be representative for average years. The effect of the drought in the years 1983-1984 can be seen in the yields of the baseline scenario (Figure 6).

The available soil data for the region was variable, with for example SOC reaching from 0.5% (A. Ayantunde, personal communication, soil in the proximity of Ouahigouya, in the villages Sabouna and Ziga) to 2% (Leenaars et al., 2014). In this thesis a SOC of 0.8% was chosen as starting situation. Higher SOC leads to higher yields, as yields are strongly related to soil quality. For example taking an SOC of 1% as a starting condition for the simulation exercise would have led to yields higher during the whole simulation period (Figure 17).

Modelling has many advantages in this research, as the use of the model has enabled the mixing of 'generalised science based knowledge' to 'local specific data' (van Paassen et al., 2011), to help in the choice of more locally-adapted interventions. Exploratory modelling is a good tool for assessing the effect of different interventions on different farm types. However, the model does not take into account socio-economic circumstances and traditions. Therefore the possibility for implementing the different interventions still has to be checked (labour shortage, input availability, etc.). It also has to be reviewed whether the interventions fit the knowledge of farmers and their values (van Paassen et al., 2011). The use of a model also has limitations, in the sense that the model cannot contain all the details of the farming system and that approximations are sometimes needed (e.g. fallow modelled through growing a crop not producing grain that is entirely left on the field). The starting conditions used for the model are also approximations, as they are not well known. The accuracy of the model is also reduced through several set rules, such as the obligatory selling of a bull after 6 years of work and the inability to buy another bull before that time.

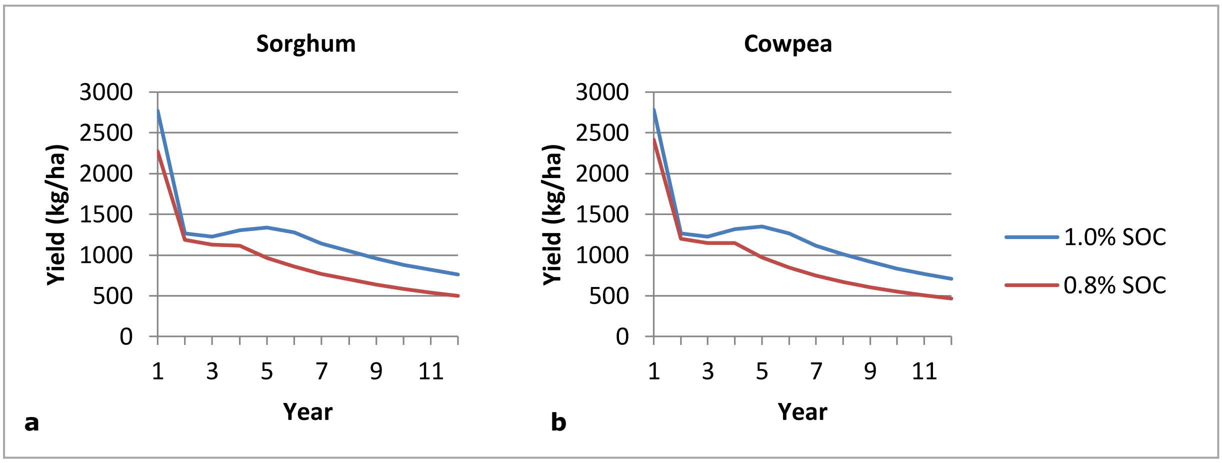

Figure 14: Yields of sorghum (a) and cowpea (b) when the initial SOC is set at 1.0% and 0.8%.

As the model was used to perform an exploratory study, it is interesting to consider how realistic the interventions are. It is possible for the forage quality of crop residues to be improved with 20%? Would a farmer convert 100% of the farm area to cowpea if this increases livestock productivity? Is it possible for farmers to collect and apply 100% of the produced manure to the fields? The answer to these questions would also impact the adoptability of the interventions for farmers. Another interesting question is how well the interventions were simulated. There is for example a difference between a real fallow and growing a (grain less) crop that which is left on the field.

4.4.2 Modelling limitations

The way the livestock module was configured was restrictive for the exploratory modelling, as it was impossible for the farms to buy extra bulls. In reality there is a chance that livestock would be bought, as it is a saving which can be sold in time of need (Herrero et al., 2003). For one farm type the number of cattle had to be reduced considerably (from 33 to 20 head) to enable the running of the model. This greatly influences the results, as livestock is one of the outcomes monitored. Increasing the number of cattle is important for the production of manure but also reduces the amount of crop residues available per animal. Next to this livestock have many other functions, such as insurance in case of crop failure (Herrero et al., 2003). These aspects are not (yet) captured by the model.

Sesame, one of the crops which accordingly to the set rules should have been taken into account in the simulation exercise could not be included because sesame cannot yet be simulated within FARMSIM. This crop could be developed to enable the inclusion in the model, to make the simulation more realistic.

It would have been interesting to test the interventions with the farmers or to simulate the interventions in the presence of farmers, to see what their opinions and ideas are. The knowledge of the field agents could also have been further exploited, as they have a more concrete knowledge about the (im)possibilities for farmers in the region. It was however not done due to time limitation and because it was beyond the scope of this thesis. This would be an interesting field of research for the future.

4.5 Interview

4.5.1 Basic farm characteristics

Trading and death of livestock led to households changing types. This shows that a typology which is static on paper is dynamic in real life. The change from one farm type to another occurs rapidly (e.g. disease causing death of livestock) and can have big impacts on the farm strategies and management. This might be an indication that livestock holding was not the best indicator for making a typology, although it is an important farm asset and a source of farm heterogeneity.

The result about how a farmer sees himself (e.g. livestock holder or crop cultivator) gives an insight in where the farmer puts the focus in the farming system and which are the most important key elements in the farming system. This may be important in determining which interventions interest the farmer.

Livestock are mostly owned by men. This should be taken into account when promoting interventions. If this tools is to be used for different regions, it should be checked whether livestock ownership is similar, to promote the best interventions (Oladele & Mankhei, 2008).

4.5.2 Constraints related to type

Resource endowment plays a role in the setting of many constraints. For this reason farm types should be taken into account in the formulation of interventions. Labour should also be considered as a potential constraint, although it was not part of this thesis. The livestock constraint was interpreted differently between the farmers, leading to the need to clarifying the notion of livestock constraint.

The capital constraint is the strongest constraint, for all farm types. As stated before this corresponds to the lack of capital to buy farming inputs at the start of the growing season and the low rate of fertilizer and pesticide use in Burkina Faso. It would be interesting to see whether the answer to the question if capital is constraining would be different if asked in another period, for example just after harvest.

The grazing land constraint is low as there is at this moment still enough space for cattle to graze. Similarly, cropping land can also still be expanded. However, population increase and urbanization will limit the options for expanding cropping and grazing land in the future (Asadu et al., 2008) and land will become a more pressing constraint. This should be taken into account in future studies.

The similarity in results for technology and education can be related to the fact that technology and education (in the form of on-farm management) are often brought through the same channels (the same project will educate and bring the resources for field trials, etc.). It is also possible that higher education stimulates farmers to try new technologies, as education is found to have a positive effect on the adoption of interventions (Strauss et al., 1991). At the same time higher resource endowment was found to reduce education and technology constraints. This might be due to the fact that resource endowment enables the purchase of required technological inputs (Vanlauwe et al., 2010).

4.5.3 Goals related to type

Resource endowment plays a role in the determination of most goals. The farm types are therefore important in choosing the right interventions.

When promoting an intervention the social traditions and culture should be considered as social cohesion is important. An example of this is the construction of a vegetable garden, an activity which is traditionally conducted by women. It would require a big change for males to grow a vegetable garden, even if the sale of vegetables could potentially be a good way to gain capital (S. Coulibaly, personal communication).

As sustainable management is important, interventions promoting this have a greater chance of being adopted. However, there are often constraints for the implementation of these interventions. For example many farmers state they want to use manure to improve soil fertility. However, due to the labour need for the collection and spreading of manure this is not often done (S. Coulibaly, personal communication). Even when a compost heap is used the quality and the quantity of the compost is often not enough to improve soil quality (Bayu et al., 2005).

The importance of maximising yields, whole farm production and land ownership was dependent on farm type. Resource endowment should therefore be taken into account when promoting and implementing interventions with those aims.

Minimising labour and achieving activities in a timely manner was of medium important for all types, emphasizing the need to take these goals into account when deciding of interventions. Maximising off-farm income is in general less important for all types, signalling that most effort goes into the farm. This is a positive signal for the chance of adoption of interventions, as it means there is a greater chance farmers will put effort in the farming system, instead of putting energy in maximising off-farm opportunities. One farm type is different as it puts more emphasis on off-farm income (type 1). This might be the case because this farm type is searching for alternative sources for income. This can either make the respondents less likely to take-up new interventions (as they are less dependent on agriculture for their income) or this could stimulate respondents from this type to take-up new interventions to be able to rely more on farming.

Maximising income and market orientation are the least important goals for less resource endowed farms. Interventions aiming to increase income and market orientation will probably less easily be adopted by these farms. This means that once again farm resource endowment will play a role in the setting of household goals, influencing interventions adoption.

4.5.4 Constraints and goals related to gender

For both constraints and goals no association was found between gender and the constraints and goals mentioned. This could mean that the effect of resource endowment (type) is stronger than the effect of gender. This result could also emanate from the way the interviews were conducted. For example is the interview is held at the same time for both household members or one of the household members is present while the other gives the answers the answers given could have been influenced.

It was expected that constraints would have been different between men and women, as for example the only land to which women have access is the land, owned by the husband, which is not cultivated (Kevane & Gray, 1999). To improve the view on the constraints present it is also possible to focus the constraint questions more on the respondents rather than on the farm.

4.5.5 Attitude

The results on attitude indicate the need for clearer statements, with a more straightforward goal as it was not possible to create typical farm attitude groups. It is positive that respondents are proud to be farming and that they are open towards new interventions as this might facilitate the spreading of new techniques. However, most farmers hope their children will not end up farming. Before promoting interventions, information is needed on why farmers do not want their children to end up farming, as this might shape the future of farming in the region.

Especially in this part of the interview, where personal questions were asked, it is possible that respondents tried to give the ‘appropriate’ answer. The field agent conducting the interview also has a great effect on results through the way the questions are asked and the answers are reported. This could have led to the association between field agent and attitude cluster. It is however also possible that farming attitude cluster was dependent on the village (e.g. differences in education, tradition and customs).

For future research the attitude statements should be made clearer, to reduce ambiguity and collect more reliable data (e.g. define what is meant with 'investment' when asking if farming is a good investment). It is also possible to develop the 'attitude' part of the thesis in another way. An example is the measuring of the attitude towards risk as the aversion to risk leads to diversification and risk can be either restricting or favouring new interventions (Bidogeza et al., 2009; Kebede et al., 1990). For example, Kebede et al. (1990) found that risk aversion is usually negative for the adoption of new interventions.

4.6 Considerations interviews

4.6.1 Overall considerations

The use of a Likert scale posed advantages and constraints. Farmers easily understood the answering in terms of "agreement" and "disagreement", which allowed the surveys to go relatively quickly. However, the answers were probably influenced by the way the questions were asked, as it is more obvious to answer in agreement. Farmers had more difficulties in discerning the gradient between "disagreement" and "strong disagreement". For this reason those answers were combined in the final data analysis. It is also possible that respondents avoid choosing the "extreme" answers, distorting the results. Using a Likert scale was a good way to obtain quantifiable data on qualitative subjects, directly from the farmer, also enabling statistical analysis. Many different ideas however exist on the right methods for the statistical analyses (Clason, 1994). In this thesis the average was calculated for constraint and goals, while this is not advised as the use of a Likert-type scale gives rise to 'greater than' relationships, with the amount of 'greater than' not being expressed. This makes the data ordinal and leads to the requirement of the calculation of medians and not averages (Ott & Longnecker, 2015; Boone & Boone, 2012).

When performing interviews many flaws about this way of collecting data were discovered. There were difficulties in translation (between English, French and the local language) and the understanding of the interview questions was different between the enumerators. The notation and interpretation of results was also different per enumerator, making the quality of the data dependent on the ability of the enumerator. These problems probably also occurred during the data collection for the CCAFS and WLE projects. Using interviews for data collection was however interesting as it was possible to capture verbal and non-verbal communication and it was also possible to go into depth into certain answers to get all the information required.

The sample size of the farmers was sufficient to get an idea of the situation, although it is unknown which fraction of the population has been interviewed in each village.

Both paradigms for intervention adoption are used in this thesis (economic and innovation diffusion, refer to paragraph 1.5). The importance of the innovation diffusion paradigm was often stressed during the interviews, when farmers provided an explanation when asked if and how they sought for information (when asked if education was a constraint). This ranged from: "I am always looking for information and new technologies" over "I only implement interventions when promoted by field agents" to "I only adopt an intervention when it has proven to be worthwhile for my neighbors". In the future it might be an interesting option to ask where respondents get their information from, as this might influence the adoption and spread of interventions.

4.6.2 Considerations constraints

In this thesis the labour availability constraint was not taken into account when conducting the interventions. This is an important gap as the shortage of labour can be an important factor in the (non)adoption of interventions: it can be determinant in the non-adoption of labour requiring interventions but it may also promote the adoption of labour-saving technologies (Bidogeza, 2009). Labour is also one of the three main farming assets, together with land and capital (van Vliet et al., 2015). Labour was also considered an important constraint by experts.

In this thesis the constraints are seen as 'fixed' and reducing interventions adoption. It is not considered how easily constraints can be alleviated. If the 'strong constraint' can be easily removed, the implementation of the intervention becomes easier.

4.6.3 Considerations goals

Farming goals are not fixed and can evolve over time. This could be taken into account in further studies. For example, several cases have been found where an increase in population pressure led to the increase in soil maintenance practices (Asadu et al., 2008). This could mean that in the future there could be more demand for implementing soil maintenance interventions. Next to this, the trend in farm development in sub-Saharan Africa is expected to be different from many in developed regions, where the number of farms decreased and the area expanded. It is expected that smallholders will remain dominant, with a larger number of farmers and a decrease in farm area (McDermott et al., 2010; van Vliet et al., 2015). Therefore interventions promoting intensification have a chance of becoming more important for farmers in sub-Saharan Africa in the future.

4.7 Decision tool

The final decision tool is a very broad tool, which can lead to many outcomes depending on the aim of the project and on the emphasis put by the user on farming constraints, intervention outcomes and farmer goals. This makes the decision tool easy for use. However the tool is now made specifically for the Yatenga region in Burkina Faso and adaptation might need to be made if the tool is to be used in any other region as constraints and goals might be completely different.

To make good use of the decision tool, the user should know with certainty to which type the farm belongs to. This might be tricky as farms (as seen in this thesis) can rapidly change from type.

The presence of constraints through the matching off farming constraints and expert opinions led to relatively similar results for all the types. Mostly the same constraints were present for the same interventions, even if the strength of the constraints was different. This is related to the method used: scores were categorised and the use of the key matrix to match interventions to types globalised scores and smoothed out differences.

In the decision tool only farming constraints and goals are taken into account. It is however known that the farmer's perception of the interventions, as well as traditions and habits may also play an important role in the adoption of interventions (Adesina & Baidu-Forson, 1995). To enhance the adoption rate of the interventions it is therefore interesting to study these aspects.

For the modelling part of this thesis only calorie production, livestock productivity and SOC outcomes were analysed. If the aim of the project is different the modelling exercise should be done anew. Social outcomes, such as social cohesion are not taken into account in the FARMSIM model. Other models also including social outcomes could be created.

5 Conclusion

In this thesis it was shown how modelling, household survey data and qualitative data on goals, constraints and attitudes can be combined to create a decision tool which may help in increasing adoption potential of promising interventions.

In the modelling baseline scenario yield, livestock productivity and SOC decreased over time. Yields declined due to the decline in soil fertility. SOC decreased because the input of organic matter into the soil did not off-set the output of organic matter into the soil. Food self-sufficiency decreased over the years due to the reduction in yields but was also dependent on farm typology, defining the ratio of land cultivated per household member. Feed quality was low and led to the reduction of livestock productivity, especially in the dry season, when grass quality was lowest.

When modelling the interventions, the impacts on food production, livestock productivity and SOC showed the same trends for all farm types. The magnitude of the impacts however differed depending on farm type, due to the ratio of farm area: livestock and the area of crops grown. Therefore the interventions potentially increasing SOC, livestock productivity of calorie production were the same for all types but the quantitative impact depended on farm type. As manure collection was set at 0, there was no return of nutrients to the field in the form of manure and there was no feedback mechanism between the improvement of livestock diet and crop yield or soil. The shortage in feed quality led to the livestock being sensitive to changes in feed quality, while farm calorific production and SOC were more static. Not one of the interventions improved all the objectives (livestock productivity, SOC and crop production). Either 1 or 2 objectives were improved or a trade-off was found between different objectives when implementing the interventions.

Farming constraints and goals were dependent on resource endowment and therefore the use of a resource-based typology is a good way to classify farmers to find the most suitable interventions to promote. Farming goals and constraints, as well as farm typology are not constant and need to be measured and reviewed frequently. The labour constraint should be taken into account in the future as labour is an important farm asset. For the good implementation of the decision tool the difficulty of alleviating the constraints should be analysed, as this impacts the selection of suitable interventions for the farms. From this thesis, no conclusions can be made based on farmer attitude and the willingness or not to implement interventions. A different way for quantifying farming attitude should be found.

Gender was not found to play a role in the defining of farming goals or constraints. This can be due to the fact that resource endowment is more important in setting goals and constraints. It could however also be due to the way in which the interviews were conducted. More research is needed to confirm these hypotheses.

The final decision tool is broad and leaves space for the user to fill in the goals of the project. When having been through all the steps and having chosen an intervention, cultural values, practices and tradition should be taken into account as they can play a role in intervention adoption. The decision tool is constructed for farms in the Yatenga region. It is possible the impacts of interventions and farming goals and constraints are different in other regions. These should then be measured again.

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7 Appendices

7.1 Appendix I: Nutritional values for food

Table 1: Nutritional values of food elements (source: USDA, 2016).

Product	kcal / 100 g
Sorghum grain	329
Millet raw	378
Cowpea, common, mature seeds, raw	336
Peanut, all type, raw	567
Corn grain yellow	365

7.2 Appendix II: Parametrising FARMSIM

Table 1: Monthly and yearly rainfall (mm) in Ouahigouya, for the years 1981 to 1995.

	Rainfall (mm)												
Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Yearly Total
1981	0	0	3	11	222	82	182	175	106	55	0	0	836
1982	0	4	3	3	43	68	67	129	33	15	0	0	365
1983	0	0	0	6	8	60	110	122	51	1	0	0	358
1984	0	0	0	1	33	25	133	82	98	19	2	0	393
1985	0	0	0	4	8	62	148	133	64	2	0	0	421
1986	0	0	0	1	40	101	128	172	141	8	0	0	591
1987	0	0	0	0	0	124	106	89	131	6	0	0	456
1988	0	0	0	43	0	9	207	294	154	1	0	0	708
1989	0	0	0	0	34	25	147	311	61	34	0	0	612
1990	0	0	0	3	20	24	154	97	76	29	0	16	419
1991	0	0	0	1	65	159	83	229	106	22	0	0	665
1992	0	0	0	0	28	75	184	255	135	6	30	0	713

Table 2: FARMSIM input parameters for Méré cattle.

Cattle category	Parameter	Unit	Value								
All cattle											
	Birth weight of calves	kg	22								
	Distance walked by a cow per day	km	6								
	Energy requirement to walk	J/m/kg	1.5								
	Maturity groups (early, medium, late)	-	3								
	Maximum fraction of concentrates in diet as part of total dry matter intake	-	0.4								
	Fraction of the produced milk given to the calf	-	0.6								
	Milk substitute supplied to the calves depending on age	kg/year	800	800	0						
	Age steps of the calf for milk allowance	year	0	0.1667	1.5						
	Crude protein content of milk fed to calves	g/kg DM	3.7								
	Dry matter content of milk fed to calves	g/kg DM	142								
	Metabolizable energy in milk fed to calves	MJ/kg DM	23.3								
	Age at which the calf stops receiving milk	year	1.4166								
	Minimum weight curve depending on age. If below this value the cow dies	kg	18	40	65	78	95	130	140	140	
	Age steps for a specific minimum weight	year	0	1.4	3.1	4.1	6.1	12	20	25	
	Live weight gain value	MJ/kg DM	19								
	Live weight loss while lactating	g/kg	138								
Bulls											
	The effect of age on mortality rate	-	0	0	0	0	0	0	0	1	1
	Age steps for mortality rate	year	0	1	2	3	4	5	12	20	25
	Potential growth curve, maximum weight depending on age	kg	30	159	280	345	388	400	400	400	
	Age steps for potential weight	years	0	2.1	4.1	6.7	9.1	12	20	25	
	Activity allowance for beef cattle	MJ/day	0.00696								
	Correction factor for fasting metabolism requirements	-	1.15								
	Correction factor for the emery value for weight gain	-	1								
	Correction factor for nutrition level		1								

	Sex-specific correlation factor for energy retention	-	1.15								
	Correction factor for net protein in weight gain, depending on maturity type	-	1								
	Compensatory growth rate depending on metabolisability of the feed	kg/year	182.5	182.5	365	547.5	730	730	730		
	Metabolisability of the feed steps for compensatory growth rate	MJ/MJ	0.2	0.3	0.4	0.5	0.6	0.7	0.8		
<u>Cows</u>											
	Effect of age on the calving rate of a dam	-	0.75	1	1	0.85	0	0			
	Age steps for calving rate	year	3.5	5	9	10	20	25			
	Maximum calving rate per year	/year	0.95								
	Fraction affecting the effect of age on lactation		0.8	0.8	1	1	0.6	0.3	0.3		
	Age steps for effect of age on lactation	year	3.5	4.5	5.5	8	15	20	25		
	Reduction factor for lactation based on he condition index	-	0	1	1						
	Condition index steps for the effect on lactation	-	0	0.3	1						
	Max annual body weight loss depending on lactation phase	kg/year	128	128	10	10					
	Lactation phase steps for max annual body weight loss	year	0	0.0625	0.625	1.5					
	Max length of lactation	year	18								
	Fat content of the milk depending on the lactation phase	g/kg	40.5	48	55.5	60	63				
	Lactation phase steps for fat content of the milk	year	0	0.25	0.5	0.833333	1.5				
	Modifier for feed intake of lactating cows depending on lactation phase	-	1.1	1.35	1.286	1.2	1				
	Potential lactation curve depending on lactation phase	kg/year	2200	2200	1250	0	0				
	Lactation phase steps for potential lactation curve	year	0	0.166667	0.75	1.5	2				
	The effect of age on mortality rate	-	0	0	0	0	0	0	0	1	1
	Age steps for mortality rate	year	0	1	2	3	4	5	12	20	25
	Length of gestation period	days	282								
	Feasible age set for reproductive age depending on weight	year	3.5	4.23	5	6.1	12	13	20	25	
	Weight steps for the reproductive age	kg	230	169	115	110	120	140	145	145	
	Potential growth curve, maximum weight depending on age	kg	30	139	214	255	280	300	300	300	

Age steps for potential weight	years	0	1.4	3.1	4.1	6.1	12	20	25
Activity allowance for beef cattle	MJ/day	0.00917							
Correction factor for fasting metabolism requirements	-	1							
Correction factor for the energy value for weight gain	-	1.3							
Correction factor for nutrition level	-	1							
Sex-specific correlation factor for energy retention	-	1.1							
Correction factor for net protein in weight gain, depending on maturity type	-	0.8							
Compensatory growth rate depending on metabolisability of the feed	kg/year	120	182.5	182.5	365	547.5	547.5	547.5	
Metabolisability of the feed steps for compensatory growth rate	MJ/MJ	0.2	0.3	0.4	0.5	0.6	0.7	0.8	
Efficiency for growth of concepta	-	0.133							

Table 3: Crop characteristics used as input in FARMSIM (source: Nijhoff 1987 a, b).

Crop characteristics	Unit	Maize	Cowpea	Millet	Sorghum	Groundnut
Number to identify the crop	-	1	2	3	4	5
Legume (0 = no, 1 = yes)	-	0	1	0	0	1
Harvest index	-	0.4	0.26	0.26	0.27	0.33
Shoot : root ratio	-	6	11	6	6	6
Light determined yield	kg/ha	24400	19200	19200	18500	19200
Water conversion efficiency	Kg/ha/mm	89	72	72	70	72
Minimum and maximum values for N, P and K in grains and stover						
Maximum grain N (%)	kg N/kg DM	0.032	0.047	0.0385	0.032	0.056
Minimum grain N (%)	kg N/kg DM	0.0095	0.029	0.008	0.01	0.035
Maximum stover N (%)	kg N/kg DM	0.01	0.027	0.01	0.012	0.022
Minimum stover N (%)	kg N/kg DM	0.004	0.0075	0.0032	0.0035	0.007
Maximum grain P (%)	kg P/kg DM	0.009	0.006	0.009	0.0065	0.008
Minimum grain P (%)	kg P/kg DM	0.0015	0.002	0.0012	0.0013	0.0027
Maximum stover P (%)	kg P/kg DM	0.0035	0.003	0.007	0.003	0.0052
Minimum stover P (%)	kg P/kg DM	0.0005	0.0008	0.0004	0.0005	0.0011
Maximum grain K (%)	kg K/kg DM	0.008	0.018	0.008	0.007	0.026
Minimum grain K (%)	kg K/kg DM	0.003	0.009	0.002	0.0025	0.012
Maximum stover K (%)	kg K/kg DM	0.024	0.037	0.036	0.028	0.024
Minimum stover K (%)	kg K/kg DM	0.01	0.0085	0.009	0.008	0.007
Dry matter content (fraction) of total biomass	-	1	1	1	1	1
Carbon content of stover	kg C/kg DM	0.42	0.45	0.42	0.45	0.45
Root C content	kg C/kg DM	0.32	0.32	0.32	0.32	0.32
Root N content	kg N/kg DM	0.005	0.005	0.005	0.005	0.005
Root P content	kg P/kg DM	0.001	0.001	0.001	0.001	0.001
Ration of nictrogen (N) from N2 fixation to the total above ground plant N (only for legumes)	-	0	0.6	0	0	0.6
Parameters for reduction factor relationship for water capture efficiency						
Parameter a	-	0.9889	0.9889	0.9889	0.9889	0.9889
Parameter b	-	-0.4706	-0.4706	-0.4706	-0.4706	-0.4706
Parameter r	-	0.9028	0.9028	0.9028	0.9028	0.9028

Table 4: Pasture quality over the seasons, data input for FARMSIM.

Parameter	Units	Rainy season (June, July, August, September and October)	Early dry season (November, December and January)	Late dry season (February, march, April and may)
Dry Matter (g/kg)		200	500	800
Metabolisable Energy	MJ/kg DM	10.3	8.7	6.5
Gross Energy	MJ/kg DM	22	18	16
Fermentable Metabolisable Energy	MJ/kg DM	12	12	12
Crude Protein	g/kg DM	134	100	40
Acid Detergent Insoluble N	g/kg DM	1.235	1.116	0.906
Dry Matter Digestibility	g/kg DM	0.65	0.48	0.41
A: proportion of water soluble N in the total N in feed	Kg N/kg N	0.4	0.56	0.56
B: proportion of potentially degradable (slowly degradable) N other than water soluble N in total N in feed	Kg N/kg N	0.6	0.38	0.38
C: Fractional rumen degradation rate per hour of the b fraction of the feed N with time	Kg N/kg N/h	0.2	0.04	0.04
Neutral Detergent Fibre	g/kg DM	670	670	670
P concentration	Kg P/kg DM	0.002	0.002	0.002
K concentration	Kg K/kg DM	0.016	0.016	0.016

7.3 Appendix III: Interviewing protocol

Protocol for Questionnaire 'Assessing biomass enhancing options for the Ouahigouya region, Burkina Faso'

7.3.1 Introduction

In this document we present the protocol for a farmer survey that aims to collect information about the farm production constraints and the goals and attitudes of farmers. This survey is conducted within the project 'Realising the full potential of mixed crop-livestock systems in rapidly changing Sahelian agro-ecological landscapes', WLE Volta and Niger Focal Region (WLE-Volta project). This project, led by the International Livestock Research Institute (ILRI), puts emphasis on the impact of biomass enhancing interventions on agricultural productivity, natural resource sustainability, food security and livelihoods.

Biomass serves many purposes in farming systems. It is important as a source of food, feed, fuel and fibre, but it also provides organic matter and a cover for the soil, improving soil quality. Improved soil quality can lead to improved food and feed availability. Burkina Faso is a country with yearly food deficits and therefore increasing biomass production could decrease the hunger period.

There are many ways for enhancing biomass production, such as the planting of dual-purpose improved varieties or composting. However, not all interventions are suitable for all farmers. To make a decision tool to help in choosing the right interventions it is important to have knowledge about the environment of the farming system and about what is of interest and concern for farmers. Consequently, when suggesting a new technology or intervention to a farmer, certain points have to be kept into mind.

Firstly, the intervention has to be beneficial for a farmer and to the farming system. To assess this, the impact of the intervention on the farming system has to be known. Secondly, it is of interest to know if it is possible for a farmer to implement the intervention. This will depend on the production constraints present in the farming system. The number of production constraints and the degree of effort to overcome these production constraints will define which interventions can be implemented. For example, if land is severely constraining, leaving land fallow is not a suited intervention as it takes land out of production. Thirdly, the farmer's goals and his or her attitude towards farming have to be taken into account, as this will influence the decision to implement the biomass enhancing intervention. Goals are the causes for which a farmer will strive and they define what is important to farmers. The farmers' attitude towards farming defines the farmer's way of looking at farming. The attitude towards farming characterizes the way farmers perceive interventions (e.g. is he/she willing to try new options, is he/she a risk taker, etc.). Together, goals and attitude influence the farmer's perception of the technique's advantages and therefore play a role in defining how inclined a farmer is to adopting the intervention.

7.3.2 Aim

The main aim of this interview is to collect information to understand what are <u>constraints</u> in a farming system, and what are different farmer <u>goals</u> and farmer <u>attitude</u> towards farming. This information will be used to see how these concepts play a role in the decision of adopting or not adopting a new intervention. From this information a decision support tool will be constructed, which couples types of farmers to the interventions that are most promising for their situation.

As farmers have different assets and possessions, the most easily adoptable interventions will be different for different farmers. Therefore farmers from different types (based on household size, land and livestock possession) will be interviewed, as well as male and female household members. The generated data will give information on the best suited interventions for different farm types from the perspective of both men and women within these types.

To get the data for the construction of the decision tool, interviews have to be conducted, with questions about farm constraints and farmer goals and farmer attitude. These interviews are spread over the three different villages. Farmers from all the different farm types are interviewed, and men and women are interviewed separately. Firstly the farmers to be interviewed are selected. In a second step the survey is held. A deeper explanation on how to select the farmers to interview can be found in Chapter 3, “Farmer selection”. More information about the way the interview should be conducted can be found in Chapter 4, “Interview”. At the end of the protocol a checklist is present, to make sure all the steps for farmer selection and setting up an interview are taken in the right order.

7.3.3 Farmer Selection

Four villages are selected for the WLE-Volta project: Ziga, Thiou, Ninigui and Pogoro-silmimossin. Select three of these villages to conduct the interview. In these three villages households corresponding to every farm type should be interviewed. Both a male and female member of the household should be interviewed within one household. The typology is based on household size, total land area, cereal land area, number of small ruminants and number of cattle. Six farm types have been made, which are explained below and can be found in Table 1.

Type 1 farmers have a small amount of land and animals. Type 2 farmers have the biggest number of household members and have a big land area, compared to the other farm types. Farm type 3 are average, farmers having some land and some animals. In type 4 there are quite some animals, but only a little land. Type 5 does not possess any livestock. According to farmers it is very important to possess livestock, therefore this type is seen as being the less endowed farm type. These are also the farmers which are hired and work on farms of the types 1, 2, 3, 4 and 6, as farm type 5 is constrained by capital. The type 6 has the largest number of animals, both cattle and small ruminants, and is seen as being the most endowed farm type. The average values for the number of household members, total land area, number of small ruminants and number of cattle can be seen in the following table.

Table 1: Average values for household size, cropping area and livestock possession for the six different farm types.

Type	1	2	3	4	5	6
Household members	8	13	8	9	6	15
Area	1.5	10.6	4.8	2.3	2.9	17.9
Cattle	2	5	1	5	0	33
Ruminants	3	20	9	15	0	36

As it is impossible to interview all farmers, a selection of farmer is made for the interviews. Based on the total number of farmers present in specific types, a varying number of farmers is selected per specific type. In Table 2 the minimum number of households to interview in each type per village can be found. The minimum amount of household interviews to be conducted for farm types 1, 2 and 3 is thrice per village. Farm type 4 is interviewed twice per village and farm types 5, 6 and 7 are interviewed once per village. During those household interviews both men and women have to be questioned. If possible the woman interviewed within the household should be the main wife, and the man interviewed should be the household head.

From information which was already collected within the WLE-Volta Project , it was possible to select farmers to interview. The compiled list can be found at the end of the protocol (“List of farmers to be interviewed”). Use this list to know which farmers to interview. The list also presents extra household head names, which can be interviewed in case an interview is cancelled.

Table 2: Number of households to be interviewed per village.

Farm Type	V1	V2	V3	V4	V5	V6	V7	Total
Number of farms in type across all villages	30	44	73	19	3	7	7	**183**
Number of households interviewed per village	3	3	3	2	1	1	1	**14**
Number of interviews conducted (men + women) per village	6	6	6	4	2	2	2	**28**
Total number of interviews conducted (men + women)	18	18	18	12	6	6	6	**84**

7.3.4 Interview

The interview is for the main part a structured interview, but in the final section it allows space for discussion. Within a household the interview is done twice; once with the male household head and once with the main wife. Number each interview.

The interview is sub-divided in three parts. Parts one and three have to be asked to both household members (man and wife separately). Part two of the interview has to be conducted only once within a household as the answers are expected to be similar for the two household members. Conducting the full interview (parts 1, 2 and 3) should take about 1h30. The second interview within the household (which only includes parts 1 and 3) should last about one hour.

When starting the interview, a short introduction should be given about the project and the aim of the survey should be explained, i.e. that information is collected about farming constraints, farmer goals and farmer attitude towards farming in order to match interventions to farm types.

When no answer is given to some of the questions, fill in N.A. If the answer is zero, fill in 0.

7.3.4.1 Part One

7.3.4.1.1 To fill in by the interviewer

Date	dd/mm/yyyy
Time of interview start	hh:mm
Time of interview end	hh:mm
Village	Code A
Farm type	Code B
Household ID	
Interview number	Number
Name of the interviewer	Name
A) Village number: 1 = Ziga, 2 = Thiou, 3 = Ninigui, 4 = Pogoro-silmimossin *B) Type number: 1, 2, 3, 4, 5, 6 or 7, as described in Figure 1.*	

7.3.4.1.2 Basic Information

Ask for the following information and fill in the table.

Name of household head	Name
Name of respondent	Name
Gender of respondent	Code A
Primary activity of the farm	Code B
Marital status	Code C
A) Gender: 1 = Male, 2 = Female *B) Primary activity of the farm: 1 = crop production, 2 = animal husbandry, 3 = crop production and animal husbandry, 4 = other (specify)* *C) Marital status: 1 = Married, 2 = Single, 3 = Divorced, 4 = Other (specify)*	

7.3.4.2 Part 2 Only for first interviewee

7.3.4.2.1 Household information

Please fill in the number of male and female household members above and below 15 years of age. Household members are the people present for more than half of the year on the family property.

Household members	Number
Male adult (above 16 years of age)	
Female adult (above 16 years of age)	
Boys (up to 16 years of age)	
Girls (up to 16 years of age)	

7.3.4.2.2 Land information

Total area of land	
Unit of land area	Code A
Area of land under cereal	
Unit of land area	Code A
A) Unit of land area: 1 = ha, 2 = m², 3 = other (specify)	

7.3.4.2.3 Livestock information

Does the household possess livestock? Yes or no. If no, mark 0 in the column total. If yes, indicate the number of animals for every species. Also indicate if the animals are owned by men, women or if they are owned jointly. Finally ask if there are any other animals that have not been asked about.

Species	Total number	Owner (1=men, 2=women, 3=jointly)
Cattle		
Small ruminants		

7.3.4.3 Part Three

7.3.4.3.1 Perceived Constraints

Production constraints are the restrictions which limit or reduce the agricultural production. It is important to assess the farming system constraints and their severity, as this information will help identify the interventions which can most readily be implemented. These have a greater chance of adoption. To understand how important certain constraints are for a farmer, fill in the following table.

Begin by clarify the meaning of the constraint to the farmer, as explained under the table *(E.g.: grazing land is constraining when there is not enough biomass available to keep the livestock alive throughout the year, and there is not enough biomass to be able to perform the wished amount of cut and carry).* Then ask if the farmer does or does not feel constrained. Note the answer in the table, under the column 'Constraint present'.

If the farmer identifies the item as a constraint, ask how the constraint plays a role, and when it is most important *(E.g. "Why is grazing land constraining? When is it most constraining?". Typical answers could be "There is more and more livestock on the pastures, there is not enough feed for all the animals. This problem is worst at the end of the dry season, when the least feed is vegetation is present").* This information should then be noted under the column 'Explanation'. After this, ask the farmer how important the constraint is to him/her. Note this in under the column 'Importance'.

Once the mentioned constraints have all been filled in, ask the farmer if there are other production constraints present in the farming system which have not been mentioned. For these constraints follow the same routine as for the other constraints. This information should be filled in under the row "Other".

The last step, once all the production constraints have been filled in, is to ask the farmer what he or she thinks the top three most important constraints are. For this it might be handy to repeat all the constraints mentioned before. This information should be filled in the rightmost column.

Production constraint	Constraint present (0 = no, 1 = yes)	Importance (code A)	Explanation
Area cropping land			
Area grazing land			
Number of livestock			
Capital			
Education			
Technology			
Other:			

A) 1 = very low, 2= low, 3 = average, 4 = strong, 5 = very strong
B) Top three constraints: 1 = most important constraint, 2 = second most important constraint, 3

= third most important constraint, 0 = constraint which is not in the top three

** Definition of the production constraints:*

- ***Cropping land** is the land used with the purpose of growing crops. It is constraining when there is not enough land to feed the household and produce crop residues for the livestock. Or if there is not enough land to generate products for the market, if desired.*
- ***Grazing land** is the area of common pastures. It is constraining if there is not enough area of grassland or if the biomass production is too low for the livestock to eat from and survive throughout the year. Or if biomass production is not sufficient to allow sufficient biomass for cut and carry purposes.*
- ***Education** is the knowledge and skill which is gained through classes and contact with other farmers, extension agents, etc.. Education is a constraint when the desired knowledge is not available or accessible, or when access to school, the existence of (farming)groups and external sources of information, the presence of extension agents, contact with fellow farmers is limited.*
- ***Technology** is seen as being improved agricultural practices, such as crop varieties, inputs, tools and machinery. Technology is constraining when availability and accessibility is limited.*
- ***Livestock** are the cattle, small ruminants and other animals present on the farm. Livestock is constraining when not enough manure is produced, not enough draught power is available, and the livestock cannot serve as savings for difficult times.*
- ***Capital** are the financial assets. Capital is constraining when there is not enough money to buy the necessary inputs for the farming system.*

7.3.4.3.2 Farmer Goals

Farmer goals are the purposes for farming, the aims which farmers want to reach by farming. To understand the goals of farmers, fill the following table.

Ask the question in bold, for every category. For supporting questions and to give help in giving an answer, ask the questions which are not in bold. The answer to the question in bold should be of the following range:

- not important,
- slightly important,
- important,
- very important
- or extremely important.

Write the answer in the column 'Rank'. An explanation can be given in the column 'Explanation'. When the table is filled, ask the farmer if he/she has a goal that has not been mentioned before. If this is the case write it down in the additional rows.

Category	Statement	Rank (code A)	Explanation
Self-Subsistence	- **How important is it for you to be self-subsistent?** -Do you provide all you own food? Do you depend on the market to feed your family? - Do you depend on others for subsistence (food, income, etc.)?		

Keeping land ownership	**-How important is it for you to make sure you stay the owner of the land?** -Is the land yours or do you rent it? Do you have security that you can keep farming on the land? - Would you be ready to make sacrifices to keep the land (money, time,...)		
Maximizing yields	**- How important is it for you to increase the crop yield or animal productivity as much as possible (kg/ha or kg/animal respectively)?** - Do you choose crops for their ability to give maximum yields? - Do you apply external inputs to maximize yields? - Do you feed animals for higher daily milk yield?		
Maximizing whole farm productivity	**- How important is it for you to increase the whole farm production, and not only yields?** - De you try to maximize not only the crop yield and animal production, but also the production of the by-products such as crop residues or manure?		
Maximizing income	**- How important is it to you to maximize income?** - Do you select crops that will give you the most cash? - Do you perform extra paid activities with the aim of increasing income?		
Maximize market orientation	**- How important is it to you to sell products on the market?** - Do you sell part of your harvest? - Do you sell your products at the moment the prices are best? - Are the species you grow selected in the aim of selling them, and does this influence your choice of crop to grow?		
Minimizing labour	**- How important is it to minimize labour?** - Is it worth paying for labour in order to save time? Is it worth paying for labour to reduce the workload?		
Achieving activities in a timely manner	**- How important is it to have enough labour when needed?** - Is there labour available when needed? - Is it worth paying for labour in order to save time and achieve activities in a timely manner?		

Maximize off-farm income	- **How important is the maximization of off-farm income to you?** - Do you have other paid activities next to farming? - Do other household members have other paid activities next to farming? - Is the off-farm income more important than the on-farm income?		
Sustainable management natural resources	**- How important is it to you to think about the sustainable management of natural resources?** - Do you think about the repercussion of farming actions on the environment (soil, water,...)? - Have you taken measures against declining yields or to keep soil fertility high? - Do you intend to keep the farm in a good state for the coming generations?		
Keeping social cohesion	**- How important is it for you to keep a positive relationship with the inhabitants of the community and how important a role do they play in your decision making?** - Do you have good contact with other inhabitants and farmers around you? - Do you manage certain resources together with other inhabitants (wells, manage your herds together,...)? - Do you keep in mind the opinion of the community when you start a new technology/intervention? - Do your actions depend on the wills of other people?		
Additional:			
A) *Rank: 1 =not important, 2 =slightly important, 3 =important, 4 = very important, 5 = extremely important.*			

7.3.4.3.3 *Attitudes*

The farmer's attitude towards farming is his view on farming. Fill in the table by taking the following steps.

For every statement in the table, ask if the farmer agrees or disagrees, and how strong the feeling is (strongly disagree, disagree, neutral, agree, strongly agree). Note the answer in the column 'Rank'. Then ask for an explanation of the answer given, which can be noted in the column 'Explanation'.

Number	Statement	Rank (code A)	Explanation
1	I am proud to be a farmer		
2	It is my destiny to be a farmer		
3	Farming is fulfilling		
4	Farming is a good way to meet my needs and those of my family		
5	There is no better investment than an investment in farming		
6	If I had a choice I would be a (full-time) farmer		
7	I would prefer if my children would not end up farmers		
8	There is/are no problems in the current farming system		
9	The current way of farming functions well enough to cover my family's needs now and in the future		
10	There is no hope for farmers like us to improve our standard of living		
11	There is a need for new interventions and technologies to improve the current farming system		
12	I seek information on good farming practices from extension officers / farm groups / other farms / external sources		
13	I am open towards or practice new methods and interventions		
14	I am prepared to give labour and capital to do new interventions and technologies		
15	I want to avoid risk as much as possible		
A)	*B) Rank: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree*		

7.3.5 Checklist for procedures.

7.3.5.1 Farmer selection

Set up a meeting with members who have knowledge about the farmers in the village you are going to visit. Together organise the visits to the different households.

7.3.5.2 Interview set-up

- When at the household, conduct the first interview (with the household head or with the main wife). This interview first interview within the household should include all three parts of the questionnaire. It should take about 1h30.
- Then conduct the second interview within the household (with the household head or with the main wife), this time only ask parts 1 and 3 of the questionnaire. This should take about 1h.

7.4 Appendix IV: Determination of expert opinion

7.4.1 Questionnaire

7.4.2 Assessment of biomass enhancing interventions in Burkina Faso

I would like to ask for your help with a component of my MSc thesis, for which I rely on expert knowledge. I would like you to fill out a short table, about the inputs needed for the implementation of different interventions. This will only take a couple minutes, and I would be very grateful if you would consider helping me out!

In my thesis I am assessing the adoptability of several interventions for different farm types based on resource endowment. This is done through the evaluation of farmers' constraints, goals and attitude.

For the different farm types, I already know which constraints limit agricultural production. The general idea is that the implementation of interventions should not further stress these constraints. The constraints considered are:

- Cropping land (quality and quantity)
- Pasture (quantity)
- Education
- Technology
- Capital
- Labour

For the next step in my project I would like to assess the amount of resources needed (the cost) for the implementation of different interventions. I will complement quantitative information from the literature, with the opinion of experts like you.

Imagine a basic farm situated in Burkina Faso, with both cropping land and some cattle. To implement a proposed intervention, is there a need for any extra cropping land, pasture, livestock, education, technology, capital or labour, compared to the basic situation where the intervention is not implemented?

The answer to this question, for several interventions, is what I am looking for. The table below shows the interventions in the first column. Therefore the above stated question is asked for every row of the table. Please give your answer on a scale from 0 to 2. A '0' means there is no need for extra resources, '1' means there is a little need for extra resources, while '2' means there is a big need for extra cropping land, pasture, etc. In this way every cell in the table can be filled in.

Here is an example: for the intervention of fallow, there is an extra need for land, as land will be taken out of production. Therefore in the cell 'cropping land'*'fallow' I would judge the answer as being a '2'. For the implementation of dual-purpose crop the normal crop is replaced by a dual-purpose variant, so I assume there is no need for extra cropping land, and my answer to this question is of '0'.

The answers given do not need to be supported, I am asking for your personal opinion on the situation. Please return the completed table to me by 11 July.

Thank you for your cooperation!

Intervention	Cropping land	Pasture	Livestock	Education	Technology	Capital	Labour
Pasture planted with native species							
Pasture planted with exotic species							
Planting of improved, dual-purpose cowpea and sorghum varieties							
Planting of drought tolerant sorghum							
Leaving 10-20% of the land fallow for 5 years.							
Collection herbaceous biomass for animal feed							
Collection herbaceous biomass for selling							
Collection and storage crop residues for animal feed							
Collection of crop residues for selling							
Leaving of crop residues on the field							
Spreading of manure on fields							
Use of crop residues as building material							
Physical treatment of crop residues for improved palatability							
Chemical treatment of crop residues for improved palatability							
Rotational grazing in the rangelands							

Answer:

- 0 = no extra need compared to a basic situation
- 1 = a little need compared to the basic situation
- 2 = a big need compared to the basic situation

7.5 Appendix V: Typology

Table 1: Fraction of farmers within types growing specific crops. Green boxes represent crops taken up in the simulation exercise, red boxes represent crops which cannot be taken up in the simulation exercise

	Crops							
Type	Millet	Sorghum	Maize	Rice	Fonio	Cowpea	Groundnut	Sesame
T1	**1**	**0.6**	0.20	0.20	0.1	**0.57**	**0.63**	0.37
T2	**1**	**0.89**	0.48	0.23	0.02	**0.73**	**0.75**	**0.55**
T3	**0.90**	**0.73**	**0.60**	0.20	0.00	**0.75**	**0.68**	0.18
T4	**1**	**0.63**	0.42	0.16	0.11	**0.74**	**0.58**	0.26
T5	**1**	0.40	0.10	0.30	0.10	**0.50**	**0.50**	0.20
T6	**0.86**	**0.86**	0.43	0.14	0.00	0.43	**1.00**	**0.57**

Table 2: Fraction of farmers within types using manure, urea and fertilizer

	Fraction of farmers using fertilizer	
Type	Compost and manure	Inorganic fertilizer
T1	0.24	0.24
T2	0.37	0.39
T3	0.22	0.41
T4	0.11	0.28
T5	0.00	0.00
T6	0.25	0.00

Table 3: Percentage of farmers feeding concentrates to the livestock during the different seasons. Boxes are green when more than 50% of the farmers feed concentrates to the livestock, and thus concentrates are taken up tin the simulation exercise.

	Percentage of farmers feeding the livestock with cakes		
Type	Rainy season Jun-Oct	Early Dry season Nov-Jan	Late dry season Feb-May
T1	3	07	10
T2	20	07	27
T3	19	07	27
T4	21	11	47
T5	00	00	00
T6	00	71	43

7.6 Appendix VII: Impact of interventions

Table 1: Change (%) in crop yield based calorie production, SOC, livestock milk and weight production when implementing the interventions compared to the baseline scenario, for types 1, 2 and 3. Green boxes represent positive changes, while red boxes represent negative changes. The abbreviation 'n.a.' stands for not applicable.

		Type											
		T1				T2				T3			
Intervention		Yield	SOC	Milk	Weight	Yield	SOC	Milk	Weight	Yield	SOC	Milk	Weight
1	Grass quantity +1kg	0	0	n.a.	14.4	0	0	21.2	11.2	0	0	n.a.	10.8
2	Grass quantity +2kg	0	0	n.a.	26.6	0	0	36.9	18.6	0	0	n.a.	18.4
3	Grass quality +10%	0	0	n.a.	20.6	0	0	35.2	17.2	0	0	n.a.	7
4	Grass quality +20%	0	0	n.a.	74.5	0	0	73.3	51.2	0	0	n.a.	15
6	0.5kg Legume addition	0	0	n.a.	4.2	0	0	14.1	5.1	0	0	n.a.	1.2
7	1kg legume addition	0	0	n.a.	7	0	0	26.3	13	0	0	n.a.	2.8
5	2kg legume additon	0	0	n.a.	13.3	0	0	46.8	34.9	0	0	n.a.	6.5
6	0% Cowpea are	3.3	0.2	n.a.	-21.7	1.5	0.1	-17.9	-7.5	2.5	0.4	n.a.	-17.5
7	25% cowpea area	-2.1	-0.1	n.a.	6	-2.6	-0.2	76.2	18	-2	-0.2	n.a.	7.2
8	50% cowpea area	-7.5	-0.4	n.a.	17.6	-6.6	-0.6	177.1	59.1	-6.5	-0.3	n.a.	6
9	75% cowpea area	-12.9	-0.8	n.a.	24.6	-10.6	-0.9	286	101.3	-11	-0.6	n.a.	21.3
10	100% cowpea area	-18.3	-1.1	n.a.	83.4	-14.7	-1.3	549.6	132.5	-15.5	-0.9	n.a.	44.4
11	10% quantity CR sorghum	-0.1	0	n.a.	-0.5	-0.2	0	-0.4	-1.1	-0.2	0	n.a.	-13.5
12	20% quantity CR sorghum	-1.2	0	n.a.	-0.5	-1.4	0	-1.2	-2.7	-1.7	0	n.a.	-13.6
13	10% quality sorghum CR	0	0	n.a.	4.5	0	0	16.8	9.4	0	0	n.a.	6.6
14	20% quality sorghum CR	-0.5	0	n.a.	7.6	-0.7	0	78.6	20.1	-0.8	0	n.a.	13.5
15	10% quantity CR sorghum	-0.1	0	n.a.	-0.5	-0.2	0	-0.4	-1.1	-0.2	0	n.a.	-13.5
16	20% quantity CR sorghum	-1.2	0	n.a.	-0.5	-1.4	0	-1.2	-2.7	-1.7	0	n.a.	-13.6
17	10% quality sorghum CR	0	0	n.a.	4.5	0	0	16.8	9.4	0	0	n.a.	6.6
18	20% quality sorghum CR	-0.5	0	n.a.	7.6	-0.7	0	78.6	20.1	-0.8	0	n.a.	13.5
19	10% sorghum fallow	-10.0	0.1	n.a.	-0.5	-10.0	0.0	-1.2	-1.7	-10.0	-0.9	n.a.	-1.7
20	20% sorghum fallow	-20.0	0.1	n.a.	-1.0	-20.0	0.1	-2.1	-6.3	-20.0	-0.9	n.a.	-1.9
21	10% cowpea fallow	-10.0	-0.1	n.a.	-0.5	-10.0	-0.2	-1.2	-1.7	-10.0	-1.1	n.a.	-1.7

22	20% cowpea fallow	-20.0	-0.2	n.a.	-1.0	-20.0	-0.4	-2.1	-6.3	-20.0	-1.2	n.a.	-1.9
23	0% CR on field	Base	Base	Base	Base	Base	Base	Base	Base	Base	Base	Base	Base
24	25% CR on field	0	0.3	n.a.	-0.9	0	0.2	-2.7	-1.7	0	0.2	n.a.	-0.1
25	50% CR on field	0	0.3	n.a.	-3	0.1	0.2	-6.7	-2.3	0.1	0.2	n.a.	-0.4
26	75% CR ton field	0.1	0.3	n.a.	-6.5	0.1	0.2	-14.1	-4.3	0.1	0.4	n.a.	-0.8
27	100% CR on field	0.1	0.3	n.a.	-12	0.1	0.2	-42.4	-13.1	0.1	0.4	n.a.	-11.5
28	Manure 0% open	Base	Base	Base	Base	Base	Base	Base	Base	Base	Base	Base	Base
29	Manure 25% open	1.4	0.3	n.a.	0	0.4	0.2	0	0	0.2	0.2	n.a.	0
30	Manure 50% open	2.7	0.3	n.a.	0	0.8	0.2	0	0	0.5	0.4	n.a.	0
31	Manure 75% open	4.1	1.6	n.a.	0	1.2	0.2	0	0	0.7	0.4	n.a.	0
32	Manure 100% open	5.5	2	n.a.	0	1.6	0.2	0	0	0.9	0.4	n.a.	0
33	Manure 0%plastic	Base	Base	Base	Base	Base	Base	Base	Base	Base	Base	Base	Base
34	Manure 25% plastic	1.5	0.3	n.a.	0	0.4	0.2	0	0	0.3	0.2	n.a.	0
35	Manure 50% plastic	3	0.3	n.a.	0	0.9	0.2	0	0	0.5	0.4	n.a.	0
36	Manure 75% plastic	4.5	1.6	n.a.	0	1.3	0.2	0	0	0.8	0.4	n.a.	0
37	Manure 100% plastic	6	2	n.a.	0	1.8	0.2	0	0	1	0.4	n.a.	0
38	Feed quality +10%	0	0	n.a.	44.6	0	0	252.3	93.6	0	0	n.a.	42
39	Feed quality +20%	0	0	n.a.	409.6	0	0	520.6	168.2	0	0	n.a.	642

Table 2: Change (%) in crop yield based calorie production, SOC, livestock milk and weight production when implementing the interventions compared to the baseline scenario, for types 4, 5 and 6. Green boxes represent positive changes, while red boxes represent negative changes. The abbreviation 'n.a.' stands for not applicable.

		Type											
		T4				T5				T6			
Intervention		Yield	SOC	Milk	Weight	Yield	SOC	Milk	Weight	Yield	SOC	Milk	Weight
31	Grass quantity +1kg	0	0	32.3	9	0	0	n.a.	n.a.	0	0	14.4	14.8
32	Grass quantity +2kg	0	0	58.8	13.9	0	0	n.a.	n.a.	0	0	30.8	22.8
33	Grass quality +10%	0	0	65.8	17	0	0	n.a.	n.a.	0	0	43.7	25.4
34	Grass quality +20%	0	0	144.2	54.5	0	0	n.a.	n.a.	0	0	110	61.6
35	0.5kg Legume addition	0	0	29.7	7.3	0	0	n.a.	n.a.	0	0	19	8.4
36	1kg legume addition	0	0	56.8	14.7	0	0	n.a.	n.a.	0	0	37.4	22.4
37	2kg legume additon	0	0	103.1	28.7	0	0	n.a.	n.a.	0	0	78.6	36.9
10	0% Cowpea are	4.2	0.3	-37.7	-9.5	4.2	0.4	n.a.	n.a.	0	0	-0.5	0
11	25% cowpea area	-0.4	0	7.7	3.1	-0.4	-0.4	n.a.	n.a.	-4.3	-0.4	101.9	29.9
12	50% cowpea area	-5.1	-0.4	62.2	14.2	-5.1	-0.7	n.a.	n.a.	-8.5	-0.7	214.6	68.7
13	75% cowpea area	-9.7	-0.7	107.3	26.6	-9.7	-1.1	n.a.	n.a.	-12.8	-1.1	330.5	93
14	100% cowpea area	-14.3	-1.1	168.9	58.1	-14.3	-1.4	n.a.	n.a.	-17	-1.4	375	125.4
15	10% quantity CR sorghum	-0.1	0	0	-0.1	0	0	n.a.	n.a.	-0.1	0	-1.3	-0.1
16	20% quantity CR sorghum	-1.3	0	-1.8	-0.2	0	0	n.a.	n.a.	-1.2	0	-0.7	-0.1
17	10% quality sorghum CR	0	0	16.4	3.9	0	0	n.a.	n.a.	0	0	19.2	8.1
18	20% quality sorghum CR	-0.6	0	33.6	8.6	0	0	n.a.	n.a.	-0.6	0	18.8	18.2
15	10% quantity CR sorghum	-0.1	0	0	-0.1	0	0	n.a.	n.a.	-0.1	0	-1.3	-0.1
16	20% quantity CR sorghum	-1.3	0	-1.8	-0.2	0	0	n.a.	n.a.	-1.2	0	-0.7	-0.1
17	10% quality sorghum CR	0	0	16.4	3.9	0	0	n.a.	n.a.	0	0	19.2	8.1
18	20% quality sorghum CR	-0.6	0	33.6	8.6	0	0	n.a.	n.a.	-0.6	0	18.8	18.2
6	10% sorghum fallow	-10.0	0.1	-2.7	-0.3	-9.9	0.0	n.a.	n.a.	-10.1	0.0	-8.8	-2.9
7	20% sorghum fallow	-20.0	0.1	-6.2	-0.6	-19.9	0.0	n.a.	n.a.	-20.1	0.0	-10.5	-3.8
8	10% cowpea fallow	-10.0	-0.1	-2.7	-0.3	-9.9	-0.1	n.a.	n.a.	-10.1	-0.1	-8.8	-2.9
9	20% cowpea fallow	-20.0	-0.2	-6.2	-0.6	-19.9	-0.3	n.a.	n.a.	-20.1	-0.3	-10.5	-3.8

1	0% CR on field	Base	Base	Base	Base	Base	Base	Base	Base	Base	Base	Base	Base
2	25% CR on field	0	0.2	-6.8	-1.1	0	0.2	n.a.	n.a.	0	0.2	-10	-1.9
3	50% CR on field	0	0.2	-13.7	-2.2	0	0.2	n.a.	n.a.	0.1	0.2	-13.3	-2.6
4	75% CR ton field	0.1	0.2	-35.1	-7.7	0.1	0.2	n.a.	n.a.	0.1	0.2	-24.9	-5.4
5	100% CR on field	0.1	0.2	-53.6	-12.6	0.1	0.2	n.a.	n.a.	0.1	0.2	-32.1	-8
19	Manure 0% open	Base	Base	Base	Base	Base	Base	Base	Base	Base	Base	Base	Base
20	Manure 25% open	1.9	0.2	0	0	n.a.	n.a.	n.a.	n.a.	0.7	0.2	0	0
21	Manure 50% open	3.8	0.2	0	0	n.a.	n.a.	n.a.	n.a.	1.5	0.2	0	0
22	Manure 75% open	5.7	1.6	0	0	n.a.	n.a.	n.a.	n.a.	2.2	0.2	0	0
23	Manure 100% open	7.5	1.6	0	0	n.a.	n.a.	n.a.	n.a.	2.9	0.2	0	0
24	Manure 0%plastic	Base	Base	Base	Base	Base	Base	Base	Base	Base	Base	Base	Base
25	Manure 25% plastic	2.1	0.2	0	0	n.a.	n.a.	n.a.	n.a.	0.8	0.2	0	0
26	Manure 50% plastic	4.1	0.2	0	0	n.a.	n.a.	n.a.	n.a.	1.6	0.2	0	0
27	Manure 75% plastic	6.2	1.6	0	0	n.a.	n.a.	n.a.	n.a.	2.4	0.2	0	0
28	Manure 100% plastic	8.2	1.6	0	0	n.a.	n.a.	n.a.	n.a.	3.2	0.2	0	0
29	Feed quality +10%	0	0	194.4	68	0	0	n.a.	n.a.	0	0	286.5	80.4
30	Feed quality +20%	0	0	508.5	124.4	0	0	n.a.	n.a.	0	0	571	149

7.7 Appendix VIII: Interviews

Table 1: Number of farmer within each type, based on WLE dataset and on the data collected through interviews

Number of households in type	Farm type based on WLE dataset	Farm Type based on interviews
T1	9	6
T2	9	8
T3	9	11
T4	6	7
T5	4	7
T6	2	0

Table 2: Average number of household members in the different types

Average number of household members	T1	T2	T3	T4	T5
Total	13	20	15	16	11
Male adults	3	5	3	3	2
Female adults	3	5	4	4	2
Boys	3	6	4	5	4
Girls	4	5	4	4	4

Table 3: Average household characteristics for the farm types. number of cattle and small ruminants in possession of the different farm types.

	Farm type				
Household characteristics	T1	T2	T3	T4	T5
Cattle	0	7	3	3	0
Small ruminants	3	20	4	12	0
Total land area	2.2	9.7	5.5	2.9	5.5
Cereal land area	1.8	6.9	4.3	2.5	4.6

Table 4: Livestock possession by men and women in the farm types

		Farm type			
Livestock category	**Owner**	T1	T2	T3	T4
Cattle	Male	100	75	90	86
	Female	0	13	0	0
	Both	0	13	10	14
Small ruminants	Male	67	25	50	29
	Female	17	13	10	0
	Both	17	63	40	71

Table 5: P-value outcomes of fisher test for the assessment of significant difference in the proportion of respondents classifying elements as a constraint, between different types. Green boxes represent a significant difference. The abbreviation 'n.a.' stands for not applicable, used when the proportions are in all cases the same.

	T1	T2	T3	T4	T5
Cropping land					
T1					
T2	0.705				
T3	0.410	0.147			
T4	0.665	0.260	1.000		
T5	0.665	0.260	1.000	1.000	
Grazing land					
T1					
T2	0.059				
T3	0.075	0.088			
T4	1.000	1.000	0.039		
T5	0.001	0.001	0.039	0.000	
Livestock					
T1					
T2	n.a.				
T3	n.a.	n.a.			
T4	1.000	0.467	0.389		
T5	0.225	0.090	0.051	0.596	
Technology					
T1					
T2	0.053				
T3	1.000	0.065			
T4	0.483	0.399	0.547		
T5	n.a.	0.045	0.611	0.481	
Education					
T1					
T2	0.088				
T3	0.635	0.147			
T4	1.000	0.118	1		
T5	0.462	0.007	0.141	0.481	

Table 6: Fisher test for significant association between gender and the proportion of 'yes' and 'no' answers. The test is not run for capital as 100% of the respondents say capital is constraining.

	Constraint					
Test variables	Cropping land	Grazing land	Livestock	Capital	Education	Technology
P-value	0.209	0.493	1.000	n.a.	0.075	1.000
Significant difference	No	No	No	n.a.	No	No

Table 7: P-value of fisher test for association between the farm types and the score given to the goals. Green boxes represent a significant difference.

Self- subsistence

	T1	T2	T3	T4	T5
T1					
T2	0.003				
T3	1.000	0.002			
T4	1.000	0.020	0.885		
T5	1.000	0.001	1.000	0.855	

Land ownership

	T1	T2	T3	T4	T5
T1					
T2	0.098				
T3	0.184	0.306			
T4	0.681	0.147	0.360		
T5	0.049	0.158	0.953	0.187	

Maximising yields

	1	2	3	4	5
1					
2	0.035				
3	0.133	0.880			
4	0.397	0.530	0.383		
5	0.003	0.081	0.221	0.007	

Maximising whole farm production

	1	2	3	4	5
1					
2	0.084				
3	0.159	0.937			
4	0.577	0.545	0.854		
5	0.001	0.008	0.000	0.001	

Maximising income

	1	2	3	4	5
1					
2	0.003				
3	0.051	0.031			
4	0.108	0.122	0.787		

5	0.010	0.000	0.172	0.077	

Maximising market orientation

	1	2	3	4	5
1					
2	0.280				
3	0.000	0.001			
4	0.101	0.342	0.016		
5	0.001	0.000	0.706	0.003	

Minimising labour

	1	2	3	4	5
1					
2	0.085				
3	0.099	0.110			
4	0.510	0.159	0.700		
5	0.077	0.443	0.635	0.345	

Achieving activities in a timely manner

	1	2	3	4	5
1					
2	0.549				
3	0.193	0.462			
4	0.408	0.738	0.614		
5	0.003	0.099	0.363	0.147	

Maximising off-farm income

	1	2	3	4	5
1					
2	0.013				
3	0.026	0.141			
4	0.004	0.080	0.573		
5	0.001	0.054	0.589	0.383	

Sustainable management natural resources

	1	2	3	4	5
1					
2	0.313				
3	0.497	1			
4	0.577	0.038	0.088		
5	0.234	0.840	0.917	0.026	

Maximising Social cohesion

	1	2	3	4	5
1					
2	0.133				
3	0.050	0.337			
4	0.132	0.130	0.009		
5	0.020	0.805	0.297	0.044	

Table 8: Fisher test for association between the gender of the respondents and the proportion of answers given for the scoring of different goals

Goal	P-value	Significant difference?
Self-subsistence	0.879	No
Land ownership	0.760	No
Yield	0.843	No
Whole farm production	0.603	No
Income	0.417	No
Market orientation	0.419	No
Labour	0.224	No
Timely manner	0.434	No
Off-farm income	0.208	No
Sustainable management natural resources	0.820	No
Social cohesion	0.135	No

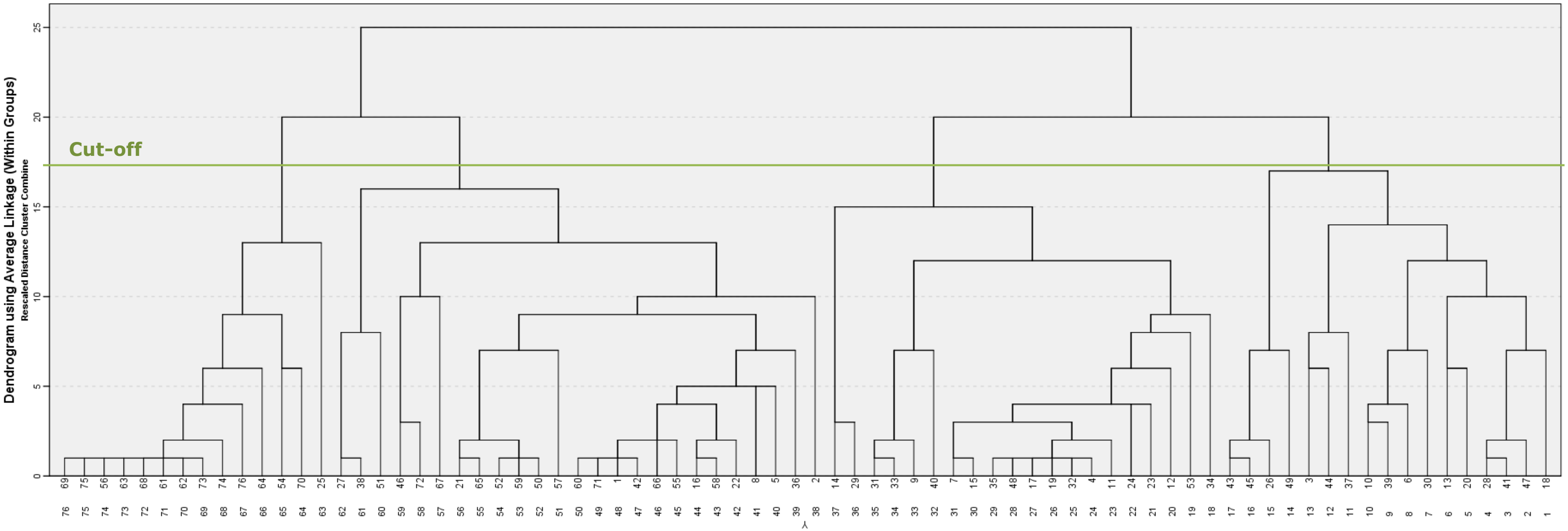

Figure 15: Dendogram with the classification of the different farm types based on the answering of the attitude statements

Table 9: Fisher test for association between interviewer and the clusters in which the farms are classified

Interviewers between whom difference is tested	P-value	Significant difference?
1 and 2	0.756	No
1 and 3	0.000	Yes
2 and 3	0.000	Yes