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Effect of Genetic Improvement of Sheep in Ethiopia: Development of a Dynamic Stochastic Simulation Herd Model

Doctoral Thesis

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Dedication

To our most respected and beloved mother W/ro Wezef Yebyo Berhe, for nursing and taking care of our daughter Kal (Kalkidan)

Table of Contents

Acknowledgements

እስመ ኣልቦ ነገር ዘኢሰኣኖ ለእግዚኣብሄር!!!

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List of Tables

List of Figures

List of Appendices

Abstract

A community-based sheep breeding program has been implemented in the highlands of Ethiopia to improve the body weight and reproductive performance of Menz sheep. This study adopts system dynamic methodology to develop a dynamic stochastic simulation herd model to evaluate the effect of genetic improvement and additional feed sources (forage production) on herd dynamics and profitability. The study also explores the opportunities of system dynamics approach in the context of designing breeding programs to predict annual genetic gain of traits. Historical data of monthly rainfall for a period of 10 years and 4 years of monthly temperature data were used. Sheep performance data were available from the herd-book of the community-based sheep breeding program. Additional input data were sourced from questionnaires, observation, literature and expert knowledge. The simulation model consists of three sub-models: vegetation growth and dynamics, herd structure and dynamics and economic analysis. The length of the time horizon was 240 months (20 years). The first 120 months served as a baseline scenario, where the fattening of culled breeding rams was practiced. For the second 120 months genetic selection of body weight was introduced considering two scenarios: culled ram and lamb fattening. For the prediction of genetic gain genetic selection for six month weight, pre-weaning survival and fertility rate was introduced from the initial stage of the simulation. Results from the model showed a gradual decrease in sheep population size while body weight of the animals improved. The model keeps heavier animals in smaller flocks to match the herd nutritional demand with the available resources. The simulation also demonstrates that breeding for heavier body weight was considerably more profitable than the baseline scenario; and lamb fattening was more profitable than culled ram fattening, which is the current practice. Smallholder farmers can gain more income by fattening young lambs due to a decrease of production (health, housing and labour) and feed costs compared to fattening of culled breeding ram. A reasonable annual genetic gain, rate of inbreeding and profit per ewe per year were predicted when community based breeding is performed. System dynamics modelling is a valuable tool to describe breeding programs by building a simple, flexible and usage driven simulation model. Results of the simulations were discussed on site with smallholder farmers and they are willing to reduce flock size in order to have healthy, fast growing animals. Further development and evaluation of the model is needed which shall lead to further refinement. This shall eventually aid in the further evaluation of genetic selection in the Menz sheep population, helping smallholder farmers to increase income.

Keywords: Modelling; Simulation; STELLA; Sheep; Genetic improvement; Ethiopia

Zusammenfassung

Im Hochland von Äthiopien wurden vor einigen Jahren dörfliche Zuchtprogramme zur Verbesserung von Körpergröße und Reproduktionsleistung von lokalen Menz Schafen implementiert. Die vorliegende Arbeit implementiert Methoden der dynamischen Systemanalyse in einem stochastischen Herdenmodell, um den Effekt der genetischen Veränderung und von Änderungen der Futtergrundlage auf Herdendynamik und Profitabilität der Schafherde zu untersuchen. Die Anwendung von dynamischen Modellen zur Analyse von Zuchtprogrammen und Vorhersage von daraus folgender genetischer Veränderung von Merkmalen wird ebenfalls untersucht. Historische Daten zu Temperatur und Niederschlägen werden verwendet. Leistungsdaten von Schafen stammen aus den Herdbüchern der dörflichen Zuchtprogramme. Zusätzliche Daten aus Fragebögen, Beobachtung, wissenschaftlicher Literatur und Befragung von Experten fließen ebenfalls in die Modellierung ein. Das Simulationsmodell besteht aus drei Teilmodellen: Vegetation und Dynamik des Pflanzenwachstums, Herdenstruktur und –dynamik sowie ökonomiosche Analyse. Der Zeithorizont beträht 240 Monate (20 Jahre). Die ersten 120 Monate dienen als Basis-Szenario. Zu Beginn der zweiten 120 Monate wurde eine laufende genetische Selektion für Körpergröße und Fruchtbarkeit implementiert und zwei Management-Szenarien zur Ausmast von älteren Schafböcken und von jungen männlichen Lämmern untersucht. Die Ergebnisse der Simulation zeigen eine graduelle Reduktion der Populationsgröße mit der Erhöhung des individuellen Körpergewichts, weil die Nachrungs-Ressourcen konstant bleiben. Die Simulation zeigt, dass das Szenario mit genetischer Selektion deutlich profitabler ist als das Basis-Szenario. Lämmermast ist deutlich profitabler als die aktuell praktizierte Ausmast von Böcken. Relaistische Werte für jährlichen Zuchtfortschritt, Inzuchtrate und Profit pro Mutterschaf und Jahr wurden im dörflichen Zuchtprogramm erzielt. Die Ergebnisse der Simulationen wurden mit den lokalen Bauern, welche die Zuchtprogramme implementieren besprochen und diskutiert und von diesen wurden Schlüsse zur weiteren Vorgangsweise gezogen. Es besteht der Wille, die Herden zu verkleinern, um gesunden schnell wachsende Tiere zu haben. Dynamische Systemanalyse ist ein wertvolles Werkzeug für die Analyse von Zuchtprogrammen, weil einfache, flexible und anwendungsorientierte Lösungen entwickelt werden können.

Schlagworte: Modellierung; Simulation; STELLA; Schaf; Züchtung; Äthiopien

Thesis structure

Chapter 1: Introduction

This chapter provides the background information on production system, breeding programs and dynamic systems modelling. It also presents the overall and specific objective of the thesis.

Chapter 2: Literature review

Menz sheep and its habitat, socio-economic importance and sheep production, and genetic improvement programs for low-input systems are described and reviewed. This section also covers dynamic system modelling and its application.

Chapter 3: Materials and Methods

This chapter focuses on the methodology used in this research, explains the research area, data collection, development of the simulation model: vegetation growth and dynamics, herd structure and dynamics, the economic analysis and evaluation of the simulation model.

Chapter 4: Results and Discussion

The results and discussions are presented in this chapter. It covers the simulation model output on herd dynamics and profitability, alternative management systems and prediction of annual genetic gain and economic response. In addition to this the chapter covers the contribution and further development of the simulation model.

Chapter 5: Conclusions and Recommendations

Chapter five presents the general conclusions and recommendations drawn from this research. It also deals with future potential research work.

Chapter 1- Introduction

The Ethiopian economy is heavily dependent on subsistence rain-fed agriculture sector which is unpredictable and with low outputs (Demeke et al., 2004). Human population growth, adverse climatic conditions and urbanization are the driving forces and will continue to significantly impact agriculture development and use (FAO, 2008). The livestock sector contributes 30% to 35% of the Ethiopian agriculture GDP (gross domestic product), 19% of the total GDP and more than 85% of farm cash income (Benin et al., 2002). The small ruminants account for 40% of cash income earned by farm households, 19% of the total value of subsistence food derived from all livestock production, and 25% of total domestic meat consumption (Hirpa and Abebe, 2008).

According to Asfaw and Jabbar (2008) 80% of the Ethiopian smallholder farmers own cattle while only about 31% to 38% and 21% to 33% of the smallholder farmers own sheep and goat respectively. Higher numbers of sheep are found in the highland areas of the country (CSA, 2011). The production systems in most highland areas are characterized by erratic and unevenly distributed rainfall, recurrent drought, and scarcity in livestock feeds and feed that is poor in quality (Bogale et al., 2008). The described detrimental effects are thought to become worse as climate changes and the human population in Ethiopia increases (Moreland and Smith, 2012). In those production environments the role of sheep in supporting the livelihood of smallholder farmers is increasing due to recurrent crop failure (Yeheyis et al., 2004; Tibbo, 2006). However, the sheep flocks are managed under traditional extensive systems with no or minimal inputs and improved technologies, which results in characteristically low productivity. They depend on natural pasture and fibrous crop residues for their survival, growth and reproduction. The available natural pasture lands are overloaded with livestock beyond optimum carrying capacity that has resulted in overgrazing and land degradation (Dejene, 2003). The combination of those factors is resulting in low agricultural productivity (Taddese, 2001).

The productivity of livestock is constrained by feed shortage, drought, lack of marketing strategies, disease prevalence and lack of appropriate culling and disposal strategies (Gizaw et al., 2010a; Tegegne et al., 2011; Gizaw et al., 2013a). The lack of feed supply has resulted in prolonged period to reach marketable weight and poor body condition at marketing age. Since both the quality and quantity of the natural pasture vary with season (Kitaba and Tamir, 2007; Bogale, et al., 2008), animals dependent on it are subjected to nutritional stress in the dry season when feed resources are senesced and in short supply (Abegaz et al., 1996; Dashtizadeh et al., 2008; Anya and Nsa, 2011). This has resulted in poor body condition and low reproductive performance of animals (Gatenby, 1986; Hirpa and Abebe, 2008). Smallholder cope with the feed shortage by provision of on-farm produced supplementary feeds, purchased feeds, irrigation of private grazing lands, and reduction of flock sizes (Gizaw et al., 2013a). It is reported that matching the herd size with the available resources (Dejene, 2003; Bogale et al., 2008) can be a way to tackle this challenge. It is also suggested the productivity of livestock can be improved by designing alternative feeding strategies and feed resources, such as improved pastureland management and development of forage crops (Abate et al., 2003; Gebremedhin et al., 2003; Tibbo et al., 2006; Bogale et al., 2008).

Ethiopia harbours a huge and diverse sheep population which is distributed across different ecological zones of the country (Gizaw, 2008) and the available within and between breed diversity of the sheep population is expected to result in higher selection response if functioning breeding programs are in place (Gizaw et al., 2007a). The centralized genetic improvement programs designed for subsistence low-input production systems did not result in sustainable genetic progress due to several reasons (Sölkner et al., 1998; Kosgey et al., 2006). As alternative community-based breeding program has been suggested to achieve sustainable genetic progress under those production systems (Sölkner et al., 1998; Kahi et al., 2005; Wurzinger et al., 2008), by involving the local community at every stage, from planning to operation of the breeding program. However, the poor nutritional conditions and the fluctuating economic and social conditions of the smallholder farmers are still hampering animals from expressing their genetic potential (Yapi-Gnaoré et al., 2001). Therefore, livestock genetic improvement programs have to incorporate improvements in the production environment and the traditional management practices of the communities (Gizaw et al., 2013a). Recently, a community-based sheep breeding program has been implemented in Menz highland areas of Ethiopia (Mirkena, 2010; Gizaw et al., 2013a) and it has continued to successfully operate performance recording and selection after the end of the research project initiating the program. This breeding program aims to improve body weight and reproductive performance of Menz sheep and farmers are selecting for fast-growing offspring of fertile dams as breeding rams (Mirkena et al., 2012). In such breeding programs maximising of genetic gain while restricting rate of inbreeding need to be considered (Gizaw et al., 2009; Gizaw et al., 2013b), since uncontrolled matting of animals is a common practice (Getachew et al., 2010).

Animal production systems (either at the level of the individual animal, the farm or the market) are dynamicaly complex due to presence of many elements and interactions between those elements (Thornton and Herrero, 2001; Herrero et al., 2009). System dynamics modelling approach is a powerful tool to understand the behaviour of such complex systems. It allows the understanding of the dynamic behaviour of a system in different scenarios, and helping managers to understand the relationships between decisions, actions and results (Guimaraes et al., 2009; Tedeschi et al., 2011). Modelling and simulation are techniques which enable to visualize various scenarios of a system with a range of precision as close to the real values as available data permits (Grant et al., 1997).

Through simulation, the behaviour of a modelled system can be studied step by step. Simulation models are composed of arithmetic and logical operations that together represent the structure (state) and behaviour (change of state) of the system of interest. They are especially useful when experiments on a real system are time consuming, expensive and site specific. System dynamics methodologies have been widely used in modelling of farm animal production systems to evaluate different management alternatives and support decision making of smallholders (Guimarães et al. 2009; Parsons et al. 2011; Tedeschi et al. 2011). However, consideration of periodic variation in livestock performance and population size due to seasonal feed supply is inadequate. Hence, seasonal feed supply is a key factor in the Menz highlands where the extensive management of livestock is directly linked to the environmental conditions, and its inclusion in simulation models can explain more the reality and give information to set up further livestock management policies.

The ongoing community-based sheep breeding program in Menz area targets improving body weight. As body weight of the sheep is a breeding goal, it is expected that the program affects the dynamics and the profitability of the herd. This was however, up to date, never evaluated. It is often suggested that production of improved forage can be used as a measure to decrease feed shortage and to improve the productivity of animals. Hence, system dynamics modelling is particularly useful in understanding the effect of genetic improvement on herd dynamics and evaluating additional feed sources (forage production). This study also explores the opportunities of the system dynamics approach in the context of designing breeding programs by developing a simple, flexible and usage driven dynamic simulation model that reflects the smallholders' circumstance as close as possible.

The overall objective of the study was to develop a dynamic stochastic simulation herd model employing a system dynamics methodology which demonstrates the existing sheep production and breeding practices in Menz highlands of Ethiopia. Sensitivity analyses were carried out by varying the key variables of the model to evaluate the robustness of the model results. The specific objectives were to develop a dynamic stochastic simulation herd model:

(a) To evaluate the effect of genetic improvement of body weight on herd dynamics and profitability.

(b) To evaluate the effect of forage production (alternative management systems) on herd dynamics and profitability.

(c) To predict genetic gain in a simulated breeding program for the Menz sheep population.

Chapter 2- Literature review

2.1- Small ruminant production in Ethiopia

2.1.1- Ethiopian sheep breeds and their habitat

Ethiopia is a home of most populous and diversified indigenous sheep breeds. There are about 14 traditionally recognized sheep populations in Ethiopia, furthermore, the sheep populations are classified into nine genetically distinct breeds and 6 breed groups (Gizaw, 2008). Table 1 shows the classification of the sheep population. They are found in different ecological zones of the country: sub-alpine, arid lowland, sub-humid lowland and wet highlands. Sheep production in Ethiopia is based on indigenous breeds, except Awassi-Menz cross-breds that contribute less than 1% of the population (Tibbo, 2006; Mengesha and Tsega, 2012).

Table 1: Summary of classification of Ethiopian sheep into breeds and breed groups.

Breed group	Breed	Population	Tail type/shape	Fiber type
Short-fat-tailed	Simien	Simien	Fatty and short	Fleece
	Short-fat-tailed	Sekota, Farta, Tikur, Wollo, Menz	Fatty and short	Fleece
Washera	Washera	Washera	Fatty and short	hair
Thin-tailed sheep	Gumz	Gumz	Thin and long	hair
Long-fat-tailed	Horro	Horro	Fatty and long	hair
	Arsi	Arsi-Bale, Adilo	Fatty and long	hair
Bonga	Bonga	Bonga	Fatty and long	hair
Fat-rumped sheep	Afar	Afar	Fat rump/fat tail	hair
	Black-Head-Somali	Black-Head-Somali	Fat rump/tiny tail	hair

Source: (Gizaw, 2008)

The indigenous sheep are year round breeders and mating is not controlled (Tibbo, 2006; Getachew, 2008). Menz sheep is one of the indigenous sheep populations in Ethiopia. It is small in body size with a short-fat-tail (Gizaw et al., 2007b). Menz highland areas are the main habitat for Menz sheep. This sheep breed is well adapted to the high altitude precipitous topography with scarcity of feed and limited production of crop due to extreme low temperatures (Lemma, 2002; Gizaw, 2009). Besides, it is well known for its meat flavor and smallholder farmers are keeping this breed as an important component of their livelihood activities (Yeheyis et al., 2004; Gizaw, 2008).

In Ethiopia, most sheep are kept in a traditional, low input and subsistence-oriented production system. The production system where Menz sheep is kept characterized as subalpine sheep–cereal system (Gizaw et al., 2008a), and in the extreme altitudes above 3000 masl climatic conditions (recurrent droughts and cold temperature) are limiting crop production to sheep production (Tibbo, 2006). In such a production system, sheep is the main source of cash, manure, meat, skin and coarse wool (Mengistu, 2000; Gizaw, 2008) in addition to the socio-cultural role. Natural pasture is the main source of feed during all seasons and sheep are supplemented with crop residue during the critical dry season. However, feed shortage is the main challenge since productive pasturelands are gradually turning into crop fields and communal pasturelands are shrinking (Bogale et al., 2008; Tegegne et al., 2011). Introduction of improved forage production is lacking (Gebretsadik et al., 2012). As a result feed shortage in supply and quality is considered to be a challenge to increase livestock productivity in highland areas of the country (Yeheyis et al., 2004; Tibbo, 2006; Mengesha and Tsega, 2012).

2.1.2- Socio-economic importance of small ruminants

Regardless of the harsh environmental conditions, small ruminants are important in feeding the rapidly expanding population of the developing world (Tibbo et al., 2006). In addition to their adaptation to the harsh environment, they require low initial capital and maintenance costs, are able to use marginal land and crop residues, produce milk and meat in readily usable quantities, and are easily cared by most family members. Small ruminants play an important role for sustainable rural livelihoods and the utilization of marginal ecological areas (Köhler-Rollefson, 2001; Thornton and Herrero, 2001). Small ruminants provide meat and milk to the smallholders and are considered as insurance mainly against cop failure, as saving, socio-cultural and ceremonial purpose (Kosgey et al., 2004; Tibbo, 2006; Habtemariam et al., 2012).

Hence, small ruminants are important to the livelihood of smallholder farmers and to the economy of the country. About 31%-38% and 21%-33% of the Ethiopian smallholder farmers own sheep and goat (Asfaw and Jabbar, 2008), The livestock sector contributes 30% to 35% of the Ethiopian agriculture GDP, 19% of the total GDP and more than 85% of farm cash income (Benin et al., 2002). Small ruminants account for about 40% of the cash income earned by farm households, 19% of the total value of subsistence food derived from all livestock production, and 25% of total domestic meat consumption (Hirpa and Abebe, 2008).

Sheep contributes close to 30% of the total ruminant livestock meat output and 14% of the total domestic meat production, with live animal and chilled meat export surpluses (Workneh et al., 2004). The sheep enterprise in the Ethiopian highland where crop and livestock production are integrated, is the most important form of investment and cash income and provides social security in bad crop years. Despite the economic importance of small ruminants to the farming household and overall economic development of a country, efforts to improve the productivity and production systems of small ruminants are lacking (MFED, 2010).

2.1.3- Constraints to improve productivity of small ruminants

In Ethiopia, the small ruminant production system is directly linked to environmental conditions and the productivity is constrained by complex and interlinked environmental, technical, institutional and socioeconomic factors (Gizaw et al., 2010a). More specifically genotype, feeding, animal health, institutional, environmental and infrastructural constraints are the factors that contribute to low productivity (Taddese, 2001; Tibbo, 2006; Bogale et al., 2008; Mengesha and Tsega, 2012). Lack of appropriate culling and disposal strategy is affecting the productivity of small ruminants (Tibbo, 2006; Gizaw et al., 2013a) since the superior young animals are sold to earn better price. The combination of those all factors results in low off-take rate and carcass weight (Gizaw et al., 2010a). Sale of live animals is taken as a last option and animals are generally sold when they are old, culled, or barren, which reflects the poor quality of animals supplied to markets (Ayele et al., 2006; Kassa et al., 2011).

Feed shortage is one of the limiting factors for increasing production and productivity of small ruminant in most of the agro-ecological zones in Ethiopia (Gebremedhin et al., 2007; Bogale et al., 2008; Mekoya, 2008). The ruminants in the smallholder sector depend on natural pasture and fibrous crop residues for their survival, growth and reproduction. The available natural pasturelands are overloaded with livestock beyond optimum carrying capacity resulting in overgrazing (Dejene, 2003) and land degradation, leading to low agricultural productivity (Taddese, 2001). Since quality and quantity of the natural pasture vary with season (Kitaba and Tamir, 2007; Bogale et al, 2008), animals dependent on it are subject to nutritional stress in the dry season when feed resources are senesced and in short supply. Studies (Abegaz et al., 1996; Dashtizadeh et al., 2008; Anya et al., 2011) showed that when animals are subjected to a period of nutritional stress they often exhibit high growth rate during subsequent re-alimentation and this phenomenon is known as compensatory growth. Gatenby (1986) discussed that animals exposed to periodic nutritional stress often compensate within the same time frame as their counterparts and often achieve greater growth rates. Thus, compensatory growth is faster than the average growth rate after periods of slow growth or weight loss when nutritious feed is plentiful. However, animals may respond differently to periodic nutritional stress due to genetic factors, the age at which restriction is imposed, the severity and duration of restriction, the quality of re-alimentation diet and duration of the re-feeding (Benschop, 2000; Lawrence and Fowler, 2002).

Compensatory growth has important implications in highlands of Ethiopia where livestock production largely depends on natural pasture grazing with seasonal variation in quality and quantity. This implies that live weight of animals is related to grazing conditions (Tolla et al., 2002). Mostly the alteration of short rainy season and a long dry season generates periodic nutritional stress for livestock and results in periodic variation in body condition of animals. Thus, during dry season animal ceases to grow and loses weight as it utilizes its body tissues to maintain essential bodily functions (Ermias et al., 2002; Negussie et al., 2003). Subsequently, when the feed supply is better, the animal regains weight more rapidly than would be predicted from its pre-stress growth-rate. Periodic nutritional stress has also a large effect on reproductive performance of ewes. In tropics and sub-tropics the reproductive performance of ewes is lower due to scarcity of feed and low quality of available feed which resulted in longer service period and lambing interval (Gatenby, 1986).

Price fluctuation is one of livestock marketing problems facing the smallholders (Kassa et al, 2011). Prices depend on supply and demand, which is heavily influenced by the season of the year and the occurrence of religious and cultural festivals or occurrence of drought and weather shocks. Ayele et al., (2006) reported seasons in which farmers faced severe cash shortages exhibited the lowest adjusted prices for animals they sold, indicating that although livestock may provide a fall-back position for cash in times of crisis, terms of trade may be worst when farmers need cash the most. Lack of market information, low price due to poor body condition during the dry periods are some of the constraints faced by smallholder (Gebremedhin et al., 2007; Gizaw et al., 2010a). Smallholders typically rely on itinerant traders or weekly markets to sell their stock and may often have poor bargaining power, leading to low price (McDermott et al., 2010), thus improving small ruminant marketing system is essential (Seleka, 2001; Ayele et al., 2006; Gizaw et al., 2010a; Kassa et al., 2011).

The poor nutritional conditions of most smallholder farms and the fluctuating economic and social conditions of the smallholder farmers interfere with the ability of the animals to express their genetic potential (Yapi-Gnaoré et al., 2001). More particularly in the highland areas of Ethiopia recurrent drought with frequent failure of crops are affecting the livelihood of smallholders; and the effects could become more severe as the climate changes and human population increases (Nardone et al., 2010; Moreland and Smith, 2012). In this case small ruminants play an important role in supporting the livelihood of smallholder farmers.

Therefore, interventions that improve the productivity of small ruminants are important in creating wealth and improving the standard of living of resource-poor farmers (Hirpa and Abebe, 2008).

2.2- Genetic improvement programs for low-input systems

2.2.1- Adaptive merits of indigenous breed

Indigenous sheep genetic resources have evolved largely through natural selection and developed specific adaptations to the existing harsh environment, which make them suitable for use in the traditional, low-input production system (IBC, 2004; Gizaw et al., 2008a). They produce and reproduce under climatic stresses, poor quality feed, seasonal feed and water shortage, endemic disease and parasite challenge (Gizaw et al., 2008b; Mirkena et al., 2010). The productive and adaptive characteristic of the sheep types is described in Table 2.

Table 2: Productive and adaptive characteristics of sheep breeds of Ethiopia

Sheep type	Characteristics	Sheep type	Characteristics
Menz	Adapted to cold, survive and produce in marginal areas; tasty meat; best wool producers	Arsi-Bale	Adapted to cold, to produce in good environment
Farta	Adapted to feed shortage; produce wool	Horro	Adapted to produce in good environment; good mutton producers
Sekota	Adapted to feed shortage	Bonga	Adapted to produce in good environment; good mutton producers
Semien	Adapted to cold, high altitude, feed shortage; produce wool	Gumz	Adapted to heat; unique genetic make-up
Tikur	Adapted to feed shortage; produce wool	Afar	Adapted to heat, feed and water shortage, long trekking; good meat yield; fatty meat
Wollo	Adapted to feed shortage; produce wool	Washera	Adapted to produce in good environment; good meat producer
Adilo	Adapted to produce in good environment; good mutton producers	Black-Head-Somali	Adapted to heat, feed and water shortage, long trekking; good meat yield; fatty meat

Sourced from Gizaw (2009)

2.2.2- Genetic improvement programs

In order to tackle the sheep production constraints, the Ethiopian national sheep production aimed to improve production per head of sheep instead of keeping very large number of mediocre animals (Tibbo et al., 2006), that contributes to land degradation and feed scarcity. Genetic improvement programs are targeting to improve the productivity of livestock per animal. In Ethiopia, it is expected that permanent selective breeding can lead to higher selection response due to the large and genetically diverse indigenous sheep breeds (Gizaw et al., 2007b; Tibbo, 2006). Productivity of an animal is determined by the genetic merit of the animal and by the production environment its kept in (Gizaw et al., 2009). In Ethiopia, in spite of the well adapted and large population of sheep, the current level of on farm productivity in the smallholder production system is low. Their productivity is limited due to various factors involving biological and environmental aspects as well as socio-economic factors such as feed scarcity, disease, lack of infrastructure, lack of marketing information and absence of planned breeding programs and breeding policy (Tibbo, 2006; Bogale et al., 2008; Gizaw et al., 2010a; Mirkena, 2010).

Designing and implementing effective breeding programs under smallholder livestock farming systems is a challenge in the developing countries. There has been a dilemma in genetic improvement programs how to effectively organize breeding schemes by involving smallholder farmers at village level and how to record such flocks and monitor progress due to the unfavorable environmental conditions (Kosgey et al., 2006). As a result the breeding strategies in the subsistence low-input production systems are characterized by lack of genetic progress in productivity due to diverse selection criteria, communal uncontrolled breeding practices, and negative selection practices through sale of best performing young animals (Getachew et al., 2010; Mirkena, 2010; Gizaw et al., 2013a). The centralized sheep breeding programs did not result in major genetic improvement of the sheep population, especially in the subsistence low-input production environments. Studies (Gizaw et al., 2007b; Tibbo, 2006) showed adequate within and between breed genetic variation in indigenous sheep breeds, which indicate that high response to selective breeding is possible. Institutions involved in research so far failed to yield a positive impact on the traditional sheep husbandry practices due to several reasons. The most frequently cited reasons are poor involvement of the livestock owners in decision making and implementing of breeding programs, lack of infrastructure, lack of well-defined breeding objectives and lack of recoding (Sölkner et al., 1998; Kosgey et al., 2006). Designing viable breeding programs for low-input subsistence production systems require characterization of the production systems and indigenous breeding strategies of communities (Getachew, 2008), and breeding objectives have to be identified in a participatory and comprehensive approach (Mirkena, 2010).

Therefore, as alternatives to the centralized breeding programs, community-based breeding programs have been suggested to achieve sustainable genetic progress in the low-input subsistence production systems (Sölkner et al., 1998; Wurzinger et al., 2008; Gizaw et al., 2009; Mirkena et al., 2012; Gizaw et al., 2013a). In addition to this, community-based genetic improvement programs contribute to efficient utilization and conservation of animal genetic resources (Köhler-Rollefson, 2001; Rege, 2001; Yapi-Gnaoré et al., 2001). In the community-based breeding programs, relatively small groups of smallholder farmers are the primary target groups (Gizaw et al., 2013a) and they are involved in planning and implementation process of the breeding program.

Design of genetic improvement programs is focused on a range of decisions in a logical order: planning and optimization. In optimized breeding strategies, maximising of genetic gain while restricting rate of inbreeding needs to be considered (Gizaw et al., 2009; Gizaw et al., 2013b). Selective breeding schemes are described in a mathematical way either in a deterministic or stochastic modelling approaches (Rutten et al., 2002; Dekkers et al., 2004; Willam et al, 2008; Pedersen et al., 2009). Unlike the stochastic, deterministic methods do not mimic breeding programs on individual animal level, but use deterministic equations to predict gain and inbreeding of a population. Stochastic simulation can be used to check the accuracy and validity of the deterministic equations (Dekkers et al., 2004). Hence, stochastic simulation may be helpful to validate and improve deterministic models, which lead to increase the understanding of the mechanisms that determine genetic improvement and rates of inbreeding in populations. There is no mathematical approach available for modelling the best design breeding programs because the complete range of issues (genetics and organizational structures) in animal breeding. Yet, modelling and evaluating alternative breeding plans are a pre-request to choose the best breeding strategy to be recommended for implementation.

A piece of software that follows pure deterministic simulation process, ZPLAN (Willam et al, 2008), does multi-trait modelling including return and costs over a given time horizon. Only one round of selection with overlapping generation is used. Lack of accounting for reduced genetic variance due to selection and inbreeding is considered an insufficiency of this approach. Inbreeding is a system of mating of more closely related individuals (Falconer and Mackay, 1996) and known to be associated with inbreeding depression on production and fitness traits in livestock. Genetic diversity can be lost from small, closed, selected populations at a rapid rate. The loss of diversity due to inbreeding depression and resulting increase in homozygosity may result in decreased production and/or fitness of inbred animals (Simm, 2000). Furthermore, inbreeding depression in farm animals can lead to a decrease in selection response and in potential genetic gains in economic traits. The software SelAction supports the design of animal breeding programs using a deterministic simulation under discrete or overlapping generations, so that it can be used as an interactive optimization tool (Rutten et al., 2002). While it does account for reduction of genetic variance due to selection, but it does not consider breeding costs and therefore provides (monetary) genetic gains as an output and not profit of the breeding operation. Alternative breeding plans have been documented targeting for the community-based breeding schemes in Ethiopia (Gizaw et al., 2009; Gizaw et al., 2010b; Mirkena et al., 2012). The results showed positive selection response for production and functional traits.

2.2.3- Intensification of small ruminant production systems

The income growth and population dynamics, urbanization and changing patterns of consumption have led to a dramatic increase in the consumption of animal products in the developing world (Seré et al., 2008). The increased demand for animal products is the driving force for changes in livestock production systems (Tarawali et al., 2011). In harsh production environments where crops will not flourish, livestock keeping is often the main or only livelihood option available (FAO, 2010). Although in the Ethiopian highlands the role of sheep in supporting the livelihood of smallholder farmer has increased due to recurrent crop failure, they are still managed under the traditional extensive systems with no or minimal inputs and improved technologies (Yeheyis et al., 2004), which results in characteristically low productivity. The potential of sheep in those areas as an important source of cash income is not utilized adequately due to the shortage of feed, which results in a prolonged period to reach marketable weight and poor body condition at marketing age (Ayele et al, 2006; Kassa et al., 2011).The country is not able to achieve the expected amount of benefit from sheep production due to various reasons. Among the reasons, the major are low potential of the breed, disease and inadequate animal feed in quality and quantity.

In general the inadequate supply of feeds, lack of improved grazing land management and little development of forage crops for feeding to animals, has resulted in keeping large numbers of livestock on limited grazing area leading to overgrazing and poor productivity of livestock (Taddese 2001; Tibbo et al. 2006). With climate change and population growth overgrazing intensified, vegetation cover reduced and runoff and removal of fertile topsoil due to erosion accelerated and infiltration rate reduced, as a result the landscape changed into bare lands where forages availability and quality cannot support the existing livestock resources (Nardone et al., 2010; Tegegne et al., 2011). For most of the year livestock are kept on degraded communal grazing lands with no practice of improved grazing management. In addition, feeding of crop residues, which are inherently poor in crude protein, vitamins and mineral content (Bogale et al., 2008), is the most important livestock feed resource during the dry season. In either case the available feed resource is inadequate both in quality and quantity of nutrient supply. On the other hand, farmers are not aware of improved livestock feeding systems and production of forage crops is rarely practised. Shortage of animal feed has still remained as one of the limiting factors for market oriented livestock development in the country. Market oriented livestock production helps to promote the expansion of fodder development technologies (Tegegne et al., 2011). Forage development also contributes to increase in groundcover and soil fertility (Kassie, 2011).

In view of the increasingly important roles of sheep for the livelihood of smallholders, drawing lessons and synthesizing opportunities on feed sourcing and feeding strategies are relevant sets of research questions for sustainable intensification (Mekoya et al., 2007; Mekoya, 2008). According to Bebe et al. (2002) intensification of livestock production system defined as the increase in the use of external inputs and services to increase the output quantity per unit of input. On the other hand, intensification in livestock production systems is application of more advanced management to increase the production per animal and per labour unit (Udo et al., 2011). Improvements of the production environment include management systems, feed resources, health and preventions (Gizaw, 2009). The performance of the animals can be improved by designing alternative feed resources like forage in order to supplement breeding females and young stock at critical seasons of the year. With improved forage development, livestock production and fattening emerged as key business oriented commodities with significant changes in the income of smallholder farmers (Tegegne et al., 2011). Alternative production systems targeting on development of small-scale market-oriented intensive production systems are also suggested to improve productivity of small ruminants (Gizaw et al., 2010a). The economic benefit of sheep production could be enhanced by introduction of finishing technology, selling animals after attaining optimum desired market weight which will have positive effect on improving the standard of living of poor farmers and increase export earnings. With regard to feeding, attention should also be paid to the shortest feeding regimen before the holidays in which most sales are occurring particularly through strategic feeding and fattening (Getahun, 2008).

Intensification of livestock production is site specific and requires more investment by smallholder farmers in extra input and services (Benin et al., 2002), which are the main limitations for market-oriented production systems. The efficient delivery of the extra inputs and services by market agents and provision of an improved infrastructure are also pre-requisite for intensification of production systems (Bebe et al., 2002; Gebremedhin et al., 2003). Increase in intensification of livestock production can have influence on the herd dynamics, see (Bebe et al., 2003), where Kenyan farmers practicing semi-zero and zero-grazing systems were unable to maintain sufficient heifers to replace the cows leaving the herd.

Therefore, comprehensive and coherent programmes for development of small ruminant production seem to be the most appropriate way to confront the population growth and adverse climatic conditions (MFED, 2010). Intensified feed and livestock production may be one way to raise production per land and livestock unit in a sustainable fashion. However, attempts to improve performance under the prevailing conditions must take into consideration their specific purpose in the production system and their performance potential under varying management levels (Rege, 2001; Getahun, 2008; FAO, 2010). , since indigenous sheep genetic resources have developed specific adaptations to survive, produce and reproduce under climatic stresses, poor quality feed, seasonal feed and water shortage, endemic disease and parasite challenge (Mirkena et al., 2010) which make them suitable for use in the subsistence-oriented traditional and low-input production system (IBC, 2004). It is important to consider all those features while setting up alternative management policies.

2.3- Complex systems modelling

A system is a set of interacting or interdependent elements, where any change in any element affects the set as a whole (Garcia, 2006). Systems are dynamic and they change over time. A system consists of two essential components, elements (visible or measurable objects or flows) and relationships (connections postulated to exist between elements) (Nicholson, 2007). Therefore, in order to study a system, it is requisite to know the elements that make it up, and relationships between them. Grant et al. (1997) defined system analysis, as application of scientific method to problems involving complex systems. It is a body of theory and techniques for studying, describing, and making predictions about complex systems use of advanced mathematical and statistical procedures and by use of computers.

2.3.1- System dynamics approach

System dynamics (SD) is a methodology and mathematical modelling technique for learning , understanding, and discussing complex issues and problems (Garcia, 2006). It is a concept that considers dynamic interaction between the elements of the studied system and can help to understand their behaviour over time with the use of feedback loops, stocks and flows, to build models, identify how information feedback governs the behaviour of the system and develop strategy for better management of the studied system (Ford, 1999; Deaton and Winebrake, 2000). System dynamics modelling approach allows to study behaviour of a dynamic system over time which is termed as evolution (Nicholson, 2007), unlike the static models were a point prediction for the value of a variable of interest at a specific future time is done.

Stocks are accumulations within the system and flows are the movement of components throughout the system. Feedback loops represent a chain of causality and they are responses created by the system that will change the current pattern (Ford, 1999). There are two types of feedback loops that reveal the structure of a system: positive and negative (Ford, 1999; Garcia, 2006). Positive feedback loops represent self-reinforcing processes and most of the time they destabilize systems. They are responsible for the growth or decline of systems. Whereas negative feedback loops describe goal-seeking processes that generate actions aimed at keeping a system at a desired state. Mostly, negative feedback processes stabilize systems. There are two modes of modelling changes over time: continuous time and discrete time event (Özgün and Barlas, 2009; Ossimitz and Mrotzek, 2008). Discrete event simulation is suitable for problems in which variables change in discrete times and by discrete steps. On the other hand, continuous simulation is suitable for systems in which the variables can change continuously.

Model is a substitute for a real system and can be developed using data from observation or experimentation (Garcia, 2006). If appropriate variables to describe the system are chosen and appropriately represent the rules governing change, then one is able to trace the state of the system through time, in which case the behaviour of the system can be simulated (Deaton and Winebrake, 2000). According to Deaton and Winebrake (2000) there are five common behaviour patterns in dynamics systems that can be observed over time. (1) Linear growth or decay pattern behaviour occurs when the reservoir of interest increases or decreases at a constant rate over time. This pattern of behaviour can be applied in resource management with constant inflows and outflows. (2) Exponential growth or decay is a pattern of behaviour that can be exhibited when the reservoir increases at a rate that is proportional to its current size. This kind of behaviour can be seen in population dynamics. (3) When a system initially exhibits an exponential growth which flattens out as the reservoir approaches a maximum sustainable value and if the initial value is above the maximum sustainable value then it will exhibit exponential decay approaching a steady-state value equal to the maximum sustainable value. This dynamic behaviour of a system is known as logistic growth and it can be applied in population growth under limited resources (Ford, 1999). (4) Overshoot and collapse pattern of behaviour is characterized by initial growth followed by peak and then collapse. It is applied in population growth with nonrenewable resources and in epidemiology. (5) Oscillation, where a strong counteracting feedback loop forces the system to oscillate around at equilibrium set of conditions. This pattern of behaviour can be observed in systems with consumers and renewable resources.

A model can be deterministic or stochastic (Grant et al., 1997). Deterministic models do not contain random variables and the prediction is under a specific set of conditions are always exactly the same. Unlike the deterministic, stochastic model predict under a specified set of conditions and predictions are not always the same, because random variables within the model potentially can take on different values each time the model is solved. Simulation is a process of using a model, or trace through step by step, the behaviour of the system being studied (Grant et al., 2000; Mulindwa et al., 2011). Simulation models are composed of arithmetic and logical operations that together represent the structure (state) and behaviour (change of state) of the system of interest.

Mathematical models are description of systems using mathematical concepts and symbols. Mathematical models usually divided into two categories according to their time dimension: static model and dynamic model (Nicholson, 2007). The difference between static and dynamic models of a system is that, dynamic model refers to runtime model of the system, whereas static model is the model of the system not during runtime. Dynamic models keep changing with reference to time whereas static models are at equilibrium of in a steady state. A typical modelling starts with a discussion of the dynamic problem to be studied and key variables in the system and their interconnections have to be defined (Grant et al., 2000). The stock and flow diagram has to be constructed, followed by building of the causal loop diagram. Most of the mathematical models have common features that lead to a certain types of behaviour which can be predicted and easily modeled (Deaton and Winebrake, 2000).

2.3.2- Evaluation of complex models

The justification for mathematical model building and modification of existing models in systems research is that experiments on a real system can be very site specific, time consuming and expensive. But it has to be noted that modelling cannot exist without data from observation and experimentation, which is necessary to develop and validate a model. Model validation is a test of the ability of the model to accurately assess the intended application (Sorensen, 1990). A model can be evaluated as a comparison to the observed data and technical evaluation can be used to find out whether the model components were behaving in a manner that is expected in real situation (Grant et al., 1997). Besides, sensitivity analysis can be used also to determine the degree of responses, or sensitivity, of model behaviour to changes in models components (Sterman, 2000). The sensitivity analysis can be numerical (when a change in assumptions changes the numerical value of the results), behavioural (when a change in assumptions changes the pattern of behaviour generated by the model), and policy related (when a change in assumptions changes the impacts of a proposed policy).

Ford (1999) discussed that a dynamic simulation model can be evaluated in terms of verification, face validity, historical behaviour, extreme behaviour and detailed model check. Model verification deals on consistency of the model results with the observed or published results (Mulindwa et al., 2011). Face validity focuses on the question whether the model structure and parameters are making sense to solve the objective of interest. Historical behaviour is informative when the developed simulation model is largely dependent on endogenous variables than the exogenous inputs. Extreme behaviour test is to challenge the model to major changes in the model parameters and check if the model response is acceptable. It is also mentioned that the confidence of a model can be checked by comparing the model results to an alternative model approach (Faust et al., 2003). Unit consistency of model questions has been also applied for model evaluation (Parsons, et al., 2011). It is also recommended simulation models should include at least three predictive indicators: numerical prediction which assesses the general behavioural trend (e.g. growth, decay, oscillations), qualitative and quantitative differences that arise due to change in management decisions (Nicholson, 2007).

2.3.3- Application of system dynamics

In the 1950s, system dynamics was used in Industrial dynamics assisted by the initial advances of computerized systems. From 1960s on system dynamics approach started to be used in social contexts and extended to several different areas such as in modelling of environmental systems and business managements (Forrester, 1968; Forrester, 1969; Forrester, 1971; Ford, 1999; Deaton and Winebrake, 2000). System dynamics modelling has been also more extended to perform ecological modelling and economic analysis of management decisions (Costanza and Gottlieb, 1998; Costanza and Voinov, 2001; Costanza et al., 1998) employing the STELLA modelling package. It has been also extensively used in production system modelling, studying herd dynamics and herd structure, aging chain and evaluation of profitability of management interventions (Kassa et al., 2002; Guimaraes et al., 2009; Parsons et al., 2011; Tedeschi et al., 2011). System dynamics approach has be also applied in modelling value chain analysis and market access for developing countries (Rich et al., 2009; Rich et al., 2011) focusing on small ruminant.

The use of models in livestock research is not without hazards, as a model can only be a simplification of a real-life system. A good model must include the key system elements and their relationships (Deaton and Winebrake, 2000). System dynamics modelling approach have been used in studying herd dynamics and production systems. It is clearly not possible to develop improved production systems without first studying the existing traditional system provides a baseline standard with which to compare the proposed alternative management system (Thornton and Herrero, 2001). Besides, an understanding of the resource requirements and constraints of the existing system provides guidance as to which of the possible alternative technologies are appropriate and worth pursuing, and which are not. In small ruminant production the major components of economic interest include nutrition or feed/pasture supplementation, reproduction and production efficiency (e.g. birth rates, mortality, age at first birth and growth rates), decision management variables relating to selling or purchasing and risk management, and market structure, credit and other policies. System dynamics has been also applied in demographic management of wild life population (Faust et al., 2003). In general system dynamics can applied whenever problems can be expressed as variable behaviours through time. Simulation attempts to imitate real life conditions using simple mathematical models. This is usually achieved by developing a model of variable interrelationships (usually in the form of modules) and running them in a sequence of steps over time (Deaton and Winebrake, 2000). These models generate data where actual time series data are not available or would have been too expensive (in money and time) to generate through experiments or through the long term observation of technologies or management strategies. A simulation model can be useful in identifying resource or production constraints within a system by changing the levels of resource use or availability in the model and through sensitivity analysis.

Chapter 3- Materials and Methods

3.1- Study area and Menz sheep breed

The study was conducted in the Menz area which is located in North Shewa administrative zone of Amhara regional state. It is about 280 km from the capital city Addis Ababa in the central northern part of Ethiopia. The reference sites were Molale and Mehal-Meda which are located in Menz Mama Midir and Menz Gera Midir districts, respectively (Figure 1). The Menz area is characterized as a low-input sheep-barley production system with a bi-modal rainfall pattern, where the main rainy season is from June to September and an erratic unreliable short rainy season is expected in February and March (Getachew et al., 2010). The mean maximum and minimum temperatures are 17.6 and 6.8°C respectively, and frost is common from October to November.

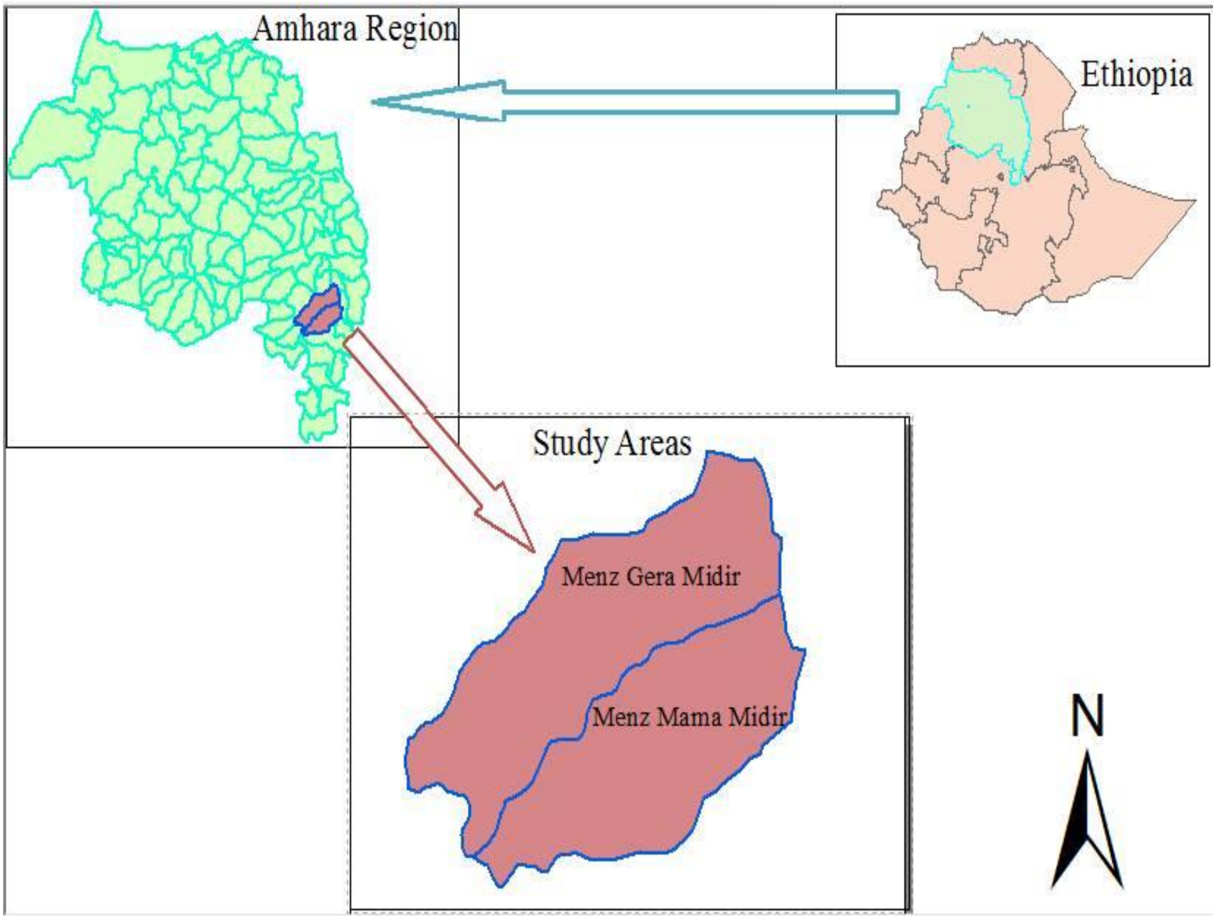

Figure 1: Approximate locations of the reference sites: Menz Gera Midir (Mehal-Meda) and Menz Mama Midir (Molale).

Menz area is the main breeding tract of Menz sheep breed. Menz sheep is a small breed with a short-fat-tail (Gizaw et al., 2007a) and coarse wool used for weaving traditional blankets and carpets (Figure 2 and 3). The breed is adapted to high altitude ranges from 2600-3200 masl with scarcity of feed and limited production of crop due to extreme low temperatures. This breed is mainly kept for meat production. Animals graze the whole year round on communal pastureland (Figure 4) and are supplemented with crop residue during the dry season. In general, the inadequate supply of feeds, lack of improved grazing land management and little development of forage crops for feeding to animals, has resulted in keeping large number of livestock on limited grazing area leading to poor productivity of livestock.

Figure 2: Menz sheep breeding ram.

Figure 3: Menz sheep breeding ewe.

Figure 4: A communal pastureland in Mehal-Meda site in November.

3.2- Site selection and data collection

Recently, the International Center for Agricultural Research in the Dry Areas (ICARDA), International Livestock Research Institute (ILRI) and the Austrian University of Natural Resources and Life Sciences (BOKU) in collaboration with the National and Regional Agricultural Research Systems in Ethiopia have initiated community-based sheep breeding programs in several regions of Ethiopia (Mirkena, 2010; Gizaw et al., 2013a). Menz sheep was one of the indigenous sheep breeds considered. The initiated community-based sheep breeding program has continued to successfully operate the breeding program of performance recording and selection after the project end. Therefore, input data for the development of the model were collected from the two reference sites of an ongoing community-based breeding program for Menz sheep. The two reference sites were Molale (site 1) and Mehal-Meda (site 2), each consisting of 60 households. The sites were verified for their potential for sheep production, presence of ongoing community-based sheep breeding program, presence of communal pastureland, and accessibility. The study used historical data of monthly rainfall for a period of 10 years and 4 years' worth of monthly temperature data. Figure 5 shows the mean monthly rainfall and standard deviations. The data revealed an annual rainfall of 965.6 mm and 906.6 mm respectively, for sites 1 and 2.

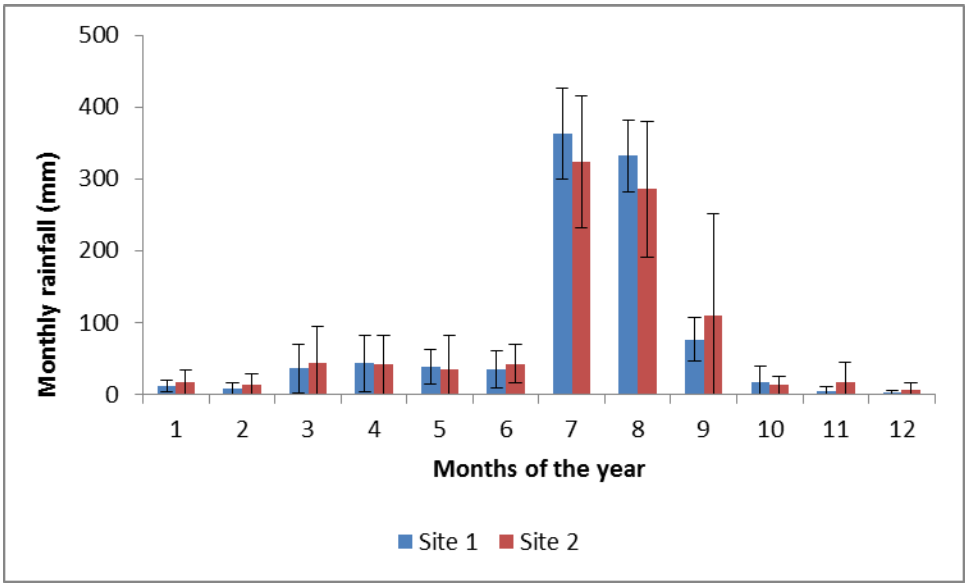

Figure 5: Mean monthly rainfall and standard deviations for sites 1 and 2.

Reliable information about sheep performance data for each reference site was available from the herd-book of the community-based sheep breeding program, thus the reference site were treated as two different sheep breeding units for simulation purposes. A semi-structured questionnaire was developed for 60 farmers in each reference site to gain information on sheep production system, herd structure, reproductive performance (age at first lambing, open period, lactation length), culling and mortality rates, revenues and production costs.

The semi-structured questionnaire was also used to generate smallholders' perception on the trend of crop production, feed availability and seasonality, ways to cope up with feed shortage and lose of crop and the possible management interventions to enhance productivity of Menz sheep. Thus, forage production was identified as a possible alternative management system to enhance productivity of sheep.

Workshops were held on the 17th and 18th of June 2013 for the members of the community-based sheep breeding program in both reference sites. The developed model was presented for smallholder farmers and feedbacks on the model were obtained. In addition to this, discussion was also held with smallholders on the opportunities and challenges of forage production.

Few smallholder farmers who had experience with forage production and experts from Debre-Berhan research center suggested that Vetch (*Vicia dasycarpa*) as one improved forage crop produced in the Menz area and offered to livestock as hay. Data on the yield and nutrient content of the improved forage were collected from the agriculture offices of the districts' and Debre-Berhan Agricultural Research Centre. Additional data were sourced from literature, observations, expert knowledge and measurements (physical mapping of the two reference sites). The herd-book, rainfall and temperature, questionnaire data were processed into percentage, average and frequencies using Microsoft Excel Spread sheet. Then prepared data were fitted in to the model for the development of the complete dynamic stochastic simulation herd model.

3.3- Model development

3.3.1- Modelling software used

The simulation model was developed using the main components of a system dynamics simulation (stocks, flows and feedback loops) in Structured Thinking Experiential Learning Laboratory Animation (STELLA 9.0.2., 2007) software. The software has been developed by combining current advances in object-oriented programming with Forrester notation (Forrester 1968; 1969; 1971). STELLA is based on the underlying logic of system thinking and allows for modelling various systems to generate simulate data that would account for the interconnections between the components. STELLA has three distinct layers: the interface layer, the map or model layer, and the equations layer. The model layer is where the modeler can use specific tools to build the model. The specific tools include stocks, flows, converters, and decision process diamonds.

The system dynamics language symbols for stocks, flows and converters are presented in Figure 6. Stocks are the accumulators and indicate the total amount that they are accumulating in the time. They collect whatever flows into them, net of whatever flows out of them. Flows are used to describe activities or changes causing modification of the stock (Ford, 1999). The main job of flows is to fill and drain accumulations. Flow can be positive (inflow) or negative (outflow), which result in increase or decrease of the stock content. Feedback loops represent a chain of causality. They are responses created by the system that will change the current pattern (Deaton and Winebrake, 2000).

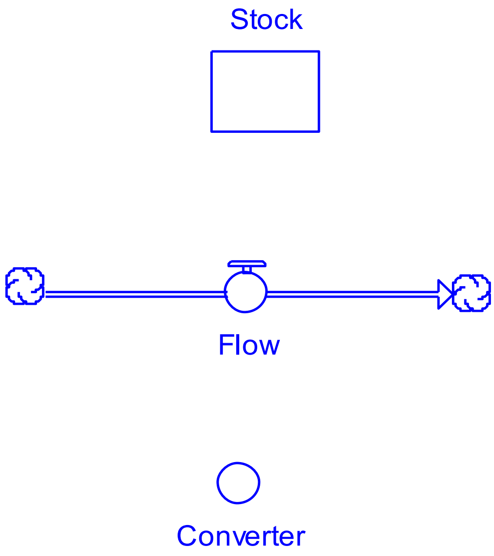

Figure 6: Model building blocks in system dynamics.

The converters modify the activities within the system and play several different roles within a system. They hold values for constants, define external inputs to the model, calculate algebraic relationships, and serve as the repository for graphical functions. Their most important role is to indicate the rates at which the flows operate and therefore the rate at which the stock content changes. The other specialized stock variable in STELLA is a conveyer. A conveyer accumulates individuals in a similar way as stock, but can retain its individuals for a specified amount of time. When material gets on the conveyor, it rides for a period of time, and then gets off. Figure 7 shows system dynamics model of a sheep population built using stock, flow and converter.

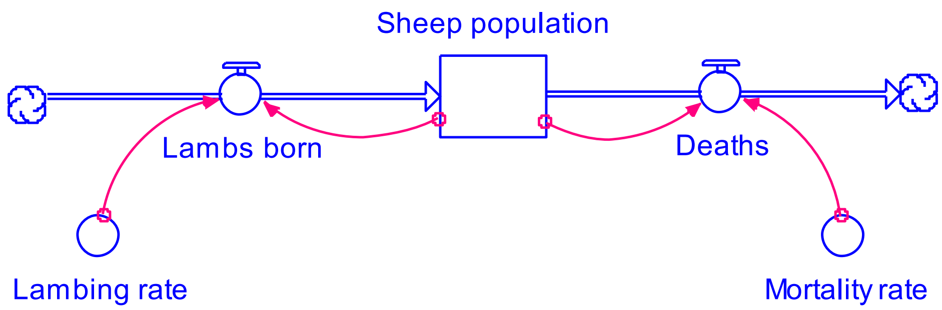

Figure 7: Simple system dynamics model of sheep population.

STELLA uses an iconographic interface to facilitate construction of dynamic system models (Costanza et al., 1998). The software includes a procedural programming language that is used to view and analyze the equations that are created though manipulation of icons. Once a structural diagram is completed, STELLA writes the equations for all levels internally in the form of first-order difference equations. It also provides a list of variables necessary to formulate all rate and auxiliary variables mathematically. It provides a wide array of special built-in functions that grouped into ten categories: test input, mathematical, trigonometric, logical, statistical, financial, discrete, cycle-time, array, and special purpose. In addition to this, STELLA provides optional integration methods (Euler's, the 2nd and 4th order Runge-Kutta), and high resolution output of both time-series and scatter plots.

3.3.2- Description of the simulation model

A dynamic, stochastic simulation herd model was built adopting the system dynamics methodology to study the effect of genetic improvement of body weight on herd dynamics and profitability. The simulation model was also further developed to evaluate the effect of forage production (alternative management systems) on herd dynamics and profitability and to predict genetic gain in a simulated Menz sheep population. The simulation time unit was “month” and time dependent variables were estimated on a daily basis and extrapolated to obtain the corresponding monthly values. A simulation algorithm of Euler integration method and simulation time step of 0.25 was used in this study; this means that for each month of simulation the program run four times for the integration process. This was done to reduce potential integration error as discussed by Ford (1999). The model simulates annually from January of each year onwards. The length of the time horizon was 240 months (20 years).

In the simulation model, minimum and maximum values for the key variables were used (conception rate, open period, live weight and mortalities) to allow for stochasticity. The periodic variations in sheep performance and population size were captured by the model. Upon execution, random values in the model were generated based on the interval defined by minimum and maximum values. The results of the model are presented in this study by means of 100 simulations.

The model considers three interactive sub-models: vegetation growth and dynamics, herd structure and dynamics, and economic analysis. Smallholder’s decisions on feeding, breeding and management practices influence sheep production. Therefore, the model tries to describe feeding practices in the vegetation growth and dynamics sub-model. The breeding and herd management practices are described by the herd structure and dynamics sub-model. Costs and prices were expressed in Euro (€) and the input and output of the production system are described by the economic analysis sub-model.

3.3.2.1- Vegetation growth and dynamics

In this study the feed sources used were communal pasture and crop residue. As the current practice, it was assumed that animals graze the whole year round in a communal pasture land and supplemented with crop residue in the dry season. The main dry season was from December to February and the months before the start of the main rainy season (May and June) were also treated with feed shortage. Based on the data obtained from Debre-Berhan research center and agricultural offices of the district's the barley yield per ha was 7.6 quintal (0.76 metric tons) and 7.6 quintal of barley crop residue was estimated using a conversion factor of 1. The average cropland holding per smallholder farmer is 1 hectare (ha). Since there is lack of information how much residue is allocated to sheep when compared to other livestock groups, it was assumed that 20 to 40% of the total residue produced from the 60 ha cropland was provided to sheep in dry season for the simulation purpose. It was assumed that smallholders produce barley once a year and the annual yield was distributed to monthly basis for the simulation purposes.

The vegetation (pasture) component is dynamic and depends on the monthly distribution of rainfall, which affects vegetation availability and quality, indirectly animal performance. The vegetation growth and dynamics sub-model was developed based on a model by D a -Solis, ta al. (2003) and which was later modified for North Texas by (Dube, 2005). Since frost is common (October to November) in the Menz highland areas, vegetation loss due to frost was considered according to D a -Solis at al. (2003). The simulation model is weather-based; rainfall and temperature were considered the main driving variables for vegetation availability which can therefore affect the sheep performance. The model simulates the dynamics of green and dry vegetation classes, grazing selection and animal production using equations provided by D a -Solis at al. (2003). The concept of rain use efficiency (RUE) proposed by Le Houreou (1984) was used to connect vegetation growth and rainfall. RUE is the amount of vegetation produced per unit of rainfall (kg DM/mm/ha). In order to simulate the seasonal variation in vegetation production, monthly rainfall was generated randomly from a relative cumulative frequency distribution as explained by Grant et al. (1997).

To estimate vegetation composition, standing biomass was divided into green pool (GP) and dry pool (DP). The vegetation stock increases through growth which is conditioned by climate (rainfall) and which decreases through consumption by sheep and death of vegetation. Thus, the GP increases as result of vegetation growth and decreases through senescence, grazing and frost. Vegetation growth is simulated on a monthly basis using a multiplicative function of vegetation condition (pastureland condition), RUE and monthly rainfall (mm). The green vegetation which undergoes senescence and frost flows into the DP. The DP in turn is affected by grazing and decomposition. The decomposition rate was formulated according to

D a -Solis et al. (2003) considering monthly rainfall and average monthly temperature. Furthermore, for the model to take into account the grazing selection in the model, proportion of GP in the diet was obtained as the product of sheep preference for green vegetation and its harvestability as discussed by Blackburn and Kothmann (1991). Similar procedures have been applied by D a -Solis et al. (2003) and Mulindwa et al. (2011). A green vegetation preference is calculated considering dry matter digestibility and crude protein contents of GP and DP respectively. The crude protein and digestibility values were adopted from Kitaba and Tamir (2007). Therefore, monthly crude protein and digestibility were used in the model to determine the proportion of the dry and green vegetation in the diet. It was assumed that the value for digestibility and crude protein of vegetation reported in Kitaba and Tamir (2007) for 120 days of harvesting stage represent the digestibility and crude protein for the dry pool vegetation; hence constant single values for digestibility (41.10%) and crude protein (4.20) of dry pasture were used in the model.

3.3.2.2- Herd structure and dynamics

The herd structure and dynamics sub-model represents the herd as a group of individuals and simulates the dynamics of different age groups (from birth to herd exit). It allows the tracking of both sexes through their respective life classes (e.g. young, mature, and breeding). It furthermore predicts the number of replacements (young ewes and rams), breeding ewes, breeding rams and culled and dead sheep given the seasonal dry matter supply. The model determines the changes taking place in each animal's status during the month of the simulation, using endogenous biological processes regulated by exogenous management policies. Thus, biological production parameters as length of gestation and lactation period, conception rate, open period and live weight of different sheep groups were considered and their values are listed in Table 3. Reproductive performance parameters were taken from the questionnaire and literature (Berhan and Van Arendonk, 2006; Mukasa-Mugerwa et al., 2000).

Table 3: List of main variables considered in modelling of the baseline scenario.

Parameters and variables	Unit, expression form	Values	
		Site 1	Site 2
Herd size (initial value)	Sheep/month	126	209
Gestation length	Months	5	5
Lactation length	Months	3	3
Open period (stochastic)	Months	2-4	2-4
Young ewe conception rate (stochastic)	%	60-80	60-80
Lamb mortality (stochastic)	%	5-10	5-15
Ewe mortality (stochastic)	%	1-5	1-5
Replacement mortality (stochastic)	%	1-5	1-5
Breeding ram mortality (stochastic)	%	1-3	1-3
Grazing area	ha	17	28
Birth weight	kg	2.2	2.2
Lamb 6 month weight	kg	13.1	13.4
Yearling weight	kg	15.6	18.8
Mature ewe weight	kg	21	22
Ram weight	Kg	23	24

Mortality rates were obtained from the herd-book and questionnaires. Considering the physiological status of the breeding ewes, simulation was performed in monthly intervals, assuming 5 months of pregnancy followed by 3 months of lactation. The herd is divided into the following groups depending on age and physiological status of the animals: young (0-6 month), young ewes (6-12 month), young rams (6-12 month), breeding ewes (>12 months), breeding rams (>12 months), ram fattening (36 to 42 months) and young fattening (6 to 12 months). Furthermore, breeding ewes were grouped according to their physiological status into pregnant, lambing and dry ewes.

In order to capture the age specificity and physiological status of the different animal cohorts, stocks and conveyers were used to represent them. They can increase or decrease depending on the inflow and outflow rates. A conveyer is a specialized stock variable in STELLA. Stock variables accumulate the individuals that flow into them; a conveyer accumulates individuals in a similar way to stock but can retain its individuals for a specified amount of time. Initial values for each of the stocks were fixed prior to simulation, and the initial herd size was set at 155 and 209 animals for site 1 and 2 respectively. The difference in initial values for herd size of site 1 and 2 is due to the difference in the size of available communal pastureland. The initial herd size used in this study is small compared to reality.

However, this was done to balance with the available dry matter supply and demand in January, at the start of the simulation.

After each lambing, ewes change categories from first parity to second parity, third parity, fourth parity and fifth parity following the physiological status: pregnant or non-pregnant. Figure 8 shows the aging chain process of the herd and the aging process of ewes beyond Lambing 2 has been deleted for ease of readability. In the complete model, the pathways from Lambing 1 to Lambing 2 were repeated for 4 more parities. After the fifth lambing, ewes stayed in the herd until the end of the lactation period and were then culled, as it is expected that they would have decreased production efficiency (Abdel-Moneim et al., 2009; Oishi et al., 2008).

As there is a very low twinning rate in Menz sheep (Mukasa-Mugerwa et al., 1995; Getachew et al., 2010), lambing ewes were all treated as single bearers and the sex ratio of lambs were considered to be 1:1 (male:female). Lambing occurred throughout the year (Getachew et al., 2010) and born lambs moved to the young ewe and young ram group after an age of 6 months. The average service period for a breeding ram was assumed to be 24 months. Since fattening of culled breeding rams is the most common practice in the study area (Getachew et al., 2010), breeding rams after 24 months of mating service were fattened for 6 months and then sold for meat.

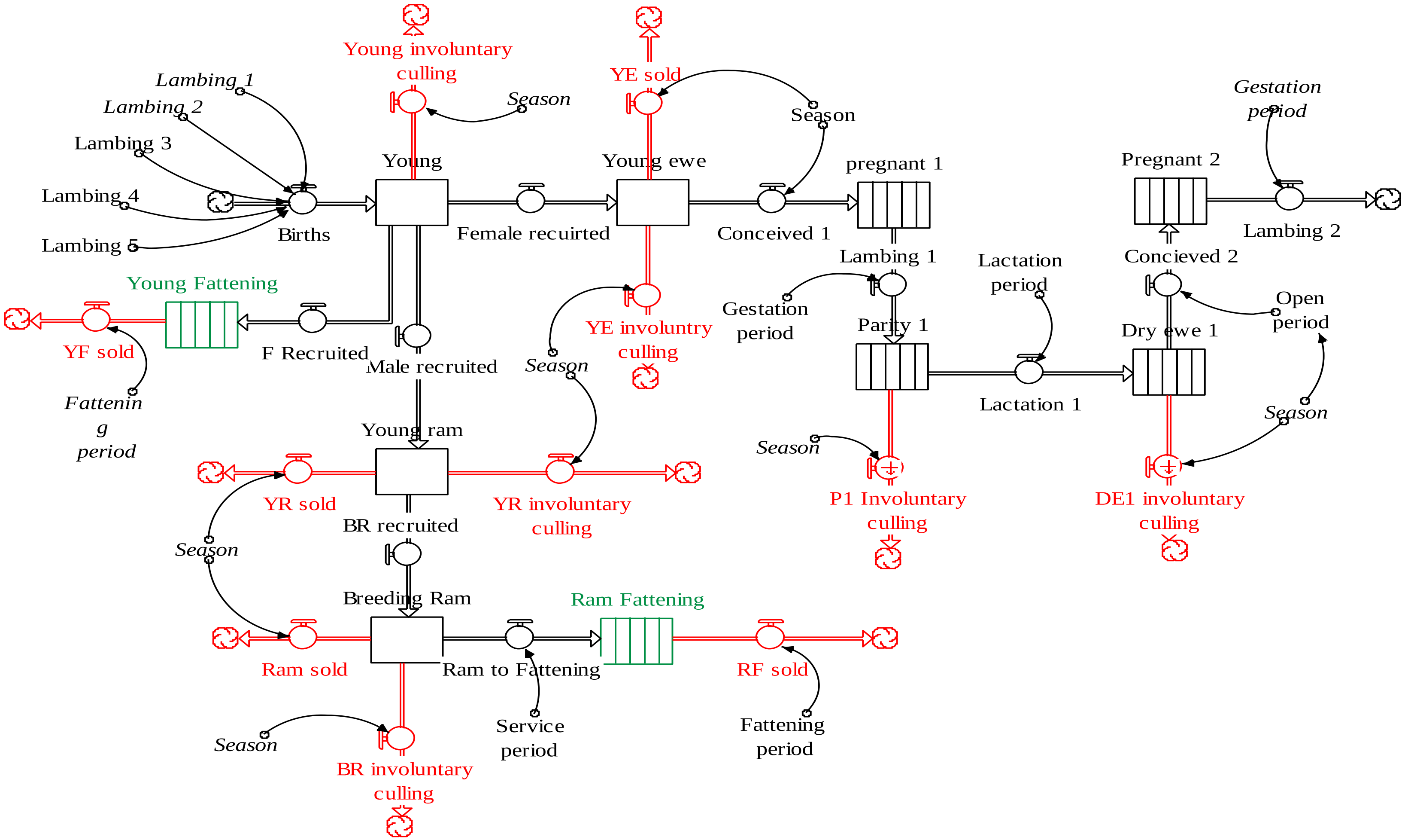

Figure 8: Diagram showing the aging-chain process of the herd. Young fattened (YF), young ewe (YE), young ram (YR), breeding ram (BR), ram fattened (RF), Parities (P1), Dry ewes (DE1).

The sheep population dynamics is influenced by the management decisions and biological parameters. The sheep herd increases through lambings and the herd decreases according to the involuntary culling and disposal rates which are regulated by the seasonal dry matter supply. The herd size is determined by the seasonal dry matter supply. The system is optimized based on dry matter demand and supply in all months of the year, which lead to establishment of herd at equilibrium. Yet, energy deficiencies are observed in the dry season. Since farmers do not keep more male animals in the herd, young ewes were sold by the model wherever the dry matter demand of the herd exceeded the dry matter supplied by the pasture and crop residue. Thus, the stock-flow structure allows the specification of a desired sheep population considering the available resources. The structure that generates this behaviour is controlled by the goal-seeking archetype of the dynamic systems model. The dynamics of the herd are mainly regulated by its mortality rate and reproduction rate as well as expulsion (culling or selling) to balance the sheep population with the seasonal dry matter supply.

3.3.2.2.1- Feed intake and nutrient requirement of the herd

The feed intake was defined as dry matter intake (DMI) (Kosgey et al., 2003). Potential voluntary intake of dry matter was calculated according to Gatenby (1986) from estimates of the mean intake of metabolizable energy by the various age and physiological categories, and live weights of animals grazing on natural pasture in the tropics. Therefore, actual DMI is calculated as a proportion of potential DMI depending on the dry matter yield as explained by Charmley et al. (2008) and adopted by Mulindwa et al. (2011). The available dry matter, depending on feed quality limits the ability of the animal to reach its potential DMI.

There is no adequate information regarding energy requirement of tropical sheep. Therefore, equations presented by Gatenby (1986) for outdoor kept animals were adopted for the calculation of daily energy requirements of maintenance and production (lactation, reproduction and growth). These equations are based on the information from Ministry of Agriculture, Fisheries and Food (MAFF) (1975) for sheep under favorable conditions and are related to body weight (LW in kg). The given recommendations include a 5% safety margin (Gatenby, 1986). As it has been done in Kosgey et al. (2003) for tropical meat sheep, a further 15% was also included for maintenance requirements because of the physical activity of grazing that increases the energy expenditure as recommended by Charray et al. (1992).

Growth rate was assumed to be equal for both sexes until 6 months of age. In the Ethiopian highlands, the alteration of a short rainy and a long dry season generates nutritional stress for animals. Thus, during dry season animal ceases to grow and loses weight as it utilizes its body tissues to maintain essential bodily functions. Subsequently, when the feed supply is better, the animal regains weight more rapidly than would be predicted from its pre-stress growth-rate. Gatenby (1986) reported that animals exposed to periodic nutritional stress often compensate within the same time frame as their counterparts and subsequently achieve greater growth rates. Thus, compensatory growth rate is higher than the average growth rate when nutritious feed is plentiful. Periodic nutritional stress has also a large effect on reproductive performance of ewes. In the tropics and sub-tropics the reproductive performance of ewes is lower due to scarcity of feed and low quality of available feed which resulted in longer service period and lambing interval (Gatenby, 1986). Therefore, the model was designed to stochastically take into account the seasonal variation in body weight and reproductive performance of ewes.

It was assumed that animals lose 5-10% of their body weight in the dry season due to scarcity of feed (both in quality and quantity). This was done by applying a special function RANDOM (0.9, 0.95). In turn, animals were assumed to gain up to 5% of the average body weight in the rainy season (vegetative season) assuming through compensatory growth. This was accounted for in a similar way using RANDOM (1,1.05) where 1 is the average body weight of an animal in a respective age without consideration of nutritional stress. Periodic nutritional stress was not considered for fattening animals (culled rams and young lambs) since fattening animals were supplemented in their nutrition, for purpose of fat deposition.

In the tropics and sub-tropics, the reproductive performance of ewes is low compared to the non-tropics, due to scarcity of feed (both in quality and quantity) which results in a longer service period and lambing interval (Gatenby, 1986). To simulate the effect of season on the reproductive performance of ewes; the open period (period between lambing and conceiving) was prolonged to four months and the conception rate of the young ewes was decreased to 60% in the dry season. Furthermore, periodic nutritional stress also contributes to variations in the livestock population size. The model therefore simulates stochastically the effect of season on animal disposal and mortality. In the dry season, farmers were modeled to sell more sheep due to feed scarcity, whereas mortality rates were set at a higher value in this season.

3.3.2.3- Economic analysis

The monthly gross profit of the herd was derived as the difference between the total returns and total costs of the system. Hence, a benefit cost ratio (BCR) was calculated as the division of total returns and total costs of the system. Table 4 provides the returns and expenses used in this study. The total returns (TR) were calculated by adding returns from sale of young ewes and rams, breeding rams, culled ewes, fattened sheep and wool (from replacements, breeding ewe, breeding ram). The total cost is the sum of variable costs: feed, labour, animal health and animal housing. The values are obtained from a questionnaire and from Gebre et al. (2012). In this model economical loss due to death of animals was treated as a cost.

Table 4: Revenues and expenses for sites 1 and 2.

Parameters (unit)	Values	
	Site 1	Site 2
Revenues		
Fattened sheep (€/kg)	1.05	1.1
Young ewe (€/kg)	0.6	0.5
Young ram (€/kg)	0.67	0.6
Breeding ram (€/kg)	0.5	0.7
Culled ewes (€/kg)	0.6	0.6
Wool (€/kg)	0.25	0.25
Expenses		
Labour (€ per sheep/month)	0.21	0.21
[a]Health cost (€ per lamb, fattened, replacements/month)	0.13	0.13
Health cost (€ per ram, ewe/month)	0.1	0.1
Housing costs (€ per sheep/month)	0.09	0.09

[a]Values taken from (Gebre et al., 2012)

Profit per herd size per year was also calculated as a difference between discounted returns and costs. The returns and costs were discounted according to FAO (2010) using a formula:

$$y = \frac{x}{(1+d)^t}$$

It is used to discount a profit of x monetary units next year to a current value of y. d is the discounting factor and in this study a value of 0.07 (7%) was used based on discussion with experts.

Feed consumption is one of the most important components in animal production systems, accounting for 49-57% of the total production costs (Kosgey et al., 2003). Since it was difficult to calculate the cost of natural pasture obtained from the communal grazing land, it was assumed that cost for natural pasture covers 50% of the total production costs. For supplement feeds current rates were applied. Seasonal variation in prices of animals was not included in the model (Kosgey et al., 2003); though there is considerable seasonal variation in sheep live weight prices throughout the year (Kassa et al., 2011).

3.3.3- Initialization of the simulation model

3.3.3.1- Herd dynamics of Menz sheep population

The first 120 months (10 years) served as the baseline scenario where farmers practiced the fattening of culled breeding rams after two years of mating service, without consideration for their genetic merit of body weight. Then genetic selection for body weight based on mass selection: the average performance (body weight) of an animal in a specific age was introduced for the last 120 months (10 years). In reality, smallholders are currently selecting animals for both body weight and reproduction trait (Mirkena et al., 2012), However, in this study, only genetic selection on yearling weight was used for the simulation purposes. A predicted annual genetic gain of 0.669 kg for yearling weight was adopted from Mirkena et al. (2012) and used on a monthly basis for all sheep groups in the simulation model.

The model furthermore assumes a steady rate of genetic progress with overlapping generations. The latter is reached only after a few generations of the breeding program. With the introduction of genetic selection, two scenarios were simulated. The first scenario (scenario I) considers the fattening of culled breeding rams after two years of mating service with an initial weight of 23 kg and 24 kg for site 1 and 2, respectively. The second scenario (Scenario II) considers the fattening of 6 months old lambs (young fattening) with an initial weight of 13.1 kg and 13.4 kg for site 1 and 2, respectively. It was assumed that 50% of the six month male lambs used in the scenario II, where young fattening was simulated. The other 50% of the six month male lambs go to the young ram stage which are used to replace culled breeding rams and sold as male replacements. In both scenarios the fattening period lasted 6 months.

Unlike the baseline scenario, where only involuntary culling of animals was considered, the model takes into account voluntary culling (2% per month) of breeding animals when genetic selection was introduced. With genetic selection, lamb mortality rate was reduced by half and lamb health management costs were doubled to avoid a confounded effect on the breeding program. Furthermore, numerical sensitivity analysis was carried out to evaluate the robustness of the model results considering live weight price, feed cost and length of open period as key variables of the model that affect the system response. This was done by changing the price of live weight (+/- 20%), feed cost (+/- 15%) and by increasing and decreasing (+2 months/-1 month) the length of open period for breeding ewes. All costs and prices are expressed in Euros (€), where €1≈ Birr. 23.54 (Ethiopian birr) at the time (September 2012).

3.3.3.2- Evaluation of alternative management systems

To evaluate the alternative management systems, the model was further developed to be able to simulate improved forage production. Also here, the first 120 months (10 years) served as the baseline scenario where culled ram fattening is practiced, without consideration of genetic merit of body weight in this system. Then genetic selection for body weight was introduced for the last 120 months (10 years) and two scenarios were evaluated: culled ram fattening (scenario I) and young lamb fatting (scenario II). Vetch (*Vicia dasycarpa*) was selected as the suitable improved forage for the study area. The vetch growth was developed based on D a -Solis et al. (2003), following similar procedure like the vegetation growth and dynamics sub-model. Since frost is common (October to November) in the Menz highland areas, the simulation model accounts for vetch loss due to frost.

It was assumed that vetch was harvested when it reach 15% of flowering stage which is about 3 months and it was assumed produced once a year which is in the long rainy season. The annual average yield (kg DM/ha) is 4.6 tons, thus this value was distributed on a monthly basis for the simulation purpose. It was assumed that vetch provided for animals in the form of hay. Therefore, vetch decrease through senescence was not considered, since it was harvested at flowering stage. The vetch stock increases through growth conditioned by climate forcing (rainfall) and decreases through harvest and loss due to frost. It was assumed that smallholders produce forage (vetch) in addition to the communal pastureland and crop residue. Therefore, based on the forage production two alternative management systems were introduced and evaluated in the simulation model.

Alternative management system I (AMS I): it was assumed that 25% (15 ha) of the cropland is devoted to forage production and the rest 75% (45 ha) is used for crop production.

Alternative management system II (AMS II): sheep production has important role in the livelihood of smallholder farmers in the study area (Yeheyis et al., 2004; Tibbo, 2006; Getachew, 2008; Gizaw, 2008) as a consequence of the extreme temperatures that limit crop production. Thus, it was assumed that 50% of the crop land (30 ha) is used for forage production and the other 50% (30 ha) for crop production. This alternative management system represents the sheep production system.

It was assumed that all sheep groups are supplemented with vetch hay throughout the year. Vetch supplementation was increased in the dry season when the feed supply from pasture land is in short. Therefore, the simulation model accounts for the increase in average daily gain and live weight of all sheep groups (young, male and female replacements, breeding ewes, breeding rams and fattening animals) due to increase in feed supply, both in quantity and quality. Therefore, as the weight of animals increased due to growth and genetic selection the model simultaneously accounts for increase in dry matter intake. The vetch supplementation was done according to Yeheyis et al. (2004) for fattening animals, where 500g/day was supplemented for the fattening period, which is 6 months. Other sheep groups were supplemented according to their live weight and physiological status (pregnant and lactating). It has to be noted that when part of the crop land is allocated for growing forage, the model accounts for decrease in crop residue supply. Therefore, the model takes into account this situation and adjusts the herd size at a given time. Open period was shortened by one month due to the improvement in animal nutrition. As the simulation model was set to goal seeking archetype, whenever the herd demand exceeded the dry matter supply still the model sells the young ewes to establish the herd at equilibrium.

The economic analysis sub-model of the simulation model was expanded to account additional costs due to forage production. In addition to this, the simulation model accounts for opportunity cost of crop (barley) production, since the profit from the land which is used to forage production is lacking. The input values for the economic analysis were sourced from the research center, agricultural offices of the districts´ and smallholder farmers. The vetch price was valued in terms of fertilizer, forage seed and labour cost to grow forage. Based on the data collected from Debre-Berhan research center, 100 kg of Diammonium phosphate (DAP) was applied per ha of land and the price per kg of DAP was 0.63€. The required vetch seed per ha was 30kg and the price per kg of vetch seed was 0.42€.

Barley production in terms of grain and residue yield was simulated. Based on the information from the agricultural offices of the districts', the barley grain and residue yield per ha of land was 7.6 quintal, using a conversion factor of 1. Total barley grain and residue yield was calculated as a product of yield per ha and total crop land, which is 60 ha. The barley return is obtained from sale of grain and residue and the prices used were 0.4€/kg and 0.2€/kg respectively. Barley production costs were barley seed and labour costs. The labour costs include land preparation cost, weeding cost, harvesting cost and marketing transport cost. The returns and costs were calculated per ha basis; and total returns and costs were obtained by multiplying with the total cropland (60 ha). Barley opportunity cost was calculated as the difference of gross profit before and after introduction of the alternative management systems. For example In AMS I, of the total 60 ha crop land, 45 ha (75%) was used for crop production and 15 ha (25%) for forage production. Thus, barley opportunity cost was calculated as the gross profit lost from the 15 ha of land which is used for forage production. The same procedure was applied for AMS II.

Moreover, numerical sensitivity analysis was carried out to evaluate the fitness of the model results. Live weight price, labour cost and proportion of young lamb fattening were identified as key variables of the model that affect the system response. This was done by increasing and decreasing the value of the key variables by 20%. All costs and prices are expressed in Euros (€), where €1≈ Birr. 24.01 (Ethiopian birr) at the time (November 2013).

3.3.3.3- Prediction of genetic gain in Menz sheep population

Since the two reference sites share similar sheep breeding structure, production systems and marketing conditions, for this objective only Molale site (site 1) was considered. The dynamic simulation model was improved to be able to describe the community-based sheep breeding program as close as possible to reality. Population parameters were added and a comprehensive dynamic stochastic simulation herd model was developed for the purpose of predicting annual genetic gain for the breeding goal traits. In order to capture the age specificity and physiological status of the different animal groups, conveyers (stages) were used to represent them. The model initializes with starting values for breeding ewe and breeding ram conveyers. The conveyer retains these initial individuals for a specific period of time defined by the user (e.g. gestation period, lactation length or open period) and simultaneously accumulates individuals transitioning in from the previous stage. While in the stage, individuals are susceptible to culling and death via a stage-specific culling and mortality rate. In addition to this, the simulation model discarded young female lambs whenever the herd dry matter demand exceeds the dry matter supplied by the system.

The initial herd size was set to 500 breeding ewes and 25 breeding rams and the feed supply from pasture land was increased to be able to handle the defined herd size by the simulation model. The initial value for the other sheep groups (lambs, male and female replacements) were set to zero. Therefore, in the first three years of the simulation there was a steep decrease in herd size. This is because of the reason that the simulation model accounts for the population reproductive parameters (gestation period, open period and maturation period), culling measurements and mortalities starting from starting month of the simulation. Therefore, there were not enough lambs to replace the culled and dead animals in the first three years of the simulation due to the higher outflow rates. The simulation model was given three years to stabilize the herd size and to realize genetic gain from the selected animals; afterwards genetic selection was monitored for the next 20 years.

The simulation model predicts the number of male and female animals in each stage (lambs, male and female candidates, breeding rams and breeding ewes). It also calculates the monthly number of disposals (culled) and deaths for each stage, and the number of individuals transitioning between stages. Breeding rams were used in the herd for the period of 2 years (24 months); afterwards they were transferred to the fattening stage. Ewes have their first lamb at age of 1.5 years (18 months) and stayed in the herd for a maximum of 5 years (60 months) to produce replacements. Rams and ewes were culled or died at a steady rate during their lifetime. The state of overlapping generations was reached after a few generations of the breeding program. In the simulation model, minimum and maximum values for the key variables were used (proportion of selected animals, conception rate, open period and animal disposal rates) to allow for stochasticity. Upon execution, random values in the model were generated based on the interval defined by minimum and maximum values.

Selection was among male and female animals based on own and maternal performance. The proportion of selected animals (%) was simulated using the RANDOM function, to generate a series of uniformly distributed random numbers between minimum and maximum values. Based on the information from the ram selection event in the study areas and discussion with experts, the selection proportion (%) for rams in the baseline scenario was set to be RANDOM (20, 30). This means the simulation model randomly picks a value between 20% and 30% every time unit for simulation purposes. Two scenarios were evaluated by changing the selection proportion to higher and lower levels by 10% each. More strict selection was applied in Scenario I, when the selection proportion was decreased to RANDOM (10, 20). In the case of scenario II selection proportion was increased to RANDOM (30, 40). Correspondingly, proportions of selected (%) female animals were set to RANDOM (70, 80), RANDOM (60, 70) and RANDOM (80, 90), respectively for the baseline scenario, scenario I and scenario II.

In the study area farmers sell young male animals that can fetch good price during seasonal festivals. Thus, selection of male animals was done three times in a year to retain the best animals in the herd before marketing. Therefore, male selection was carried out before Ester holiday, Ethiopian New Year and Christmas festival, respectively in March, August and November. Female animals were selected in all year round. Selection intensities were obtained directly from the proportions of selected animals. The selection proportion and respective selection intensity table was built into the simulation model as a graphical function. The p-matrix was built into the model following ZPLAN (Willam et al., 2008), to estimate the proportion of animals in different age classes and gene contributions from each age class. Following Nitter et al. (1994), generation interval for the selection group was also calculated from gene proportion and corresponding age classes.

The breeding goal traits are six month weight, pre-weaning survival rate and fertility rate. Selection for six month weight was included in this simulation to retain the best young lambs in the herd to use as breeding rams and breeding ewes. In this study, pre-weaning survival and fertility rate are defined as lambs survived to weaning as a proportion of lambs born and ewes lambed per ewes exposed to ram, respectively. Heritability and economic values for the traits selected are presented in Table 5. On-farm heritability estimates were not available for the traits considered in this simulation; therefore, average heritability was calculated from Abegaz and Negussie (2002), Safari and Fogarty (2003) and Abegaz et al. (2005). The Menz sheep is reared under similar production and marketing system to Washera sheep, and then economic values estimated by Gizaw et al. (2010b) for Washera sheep was taken for the simulation purposes. Economic value for fertility rate was lacking, and the same economic value used for pre-weaning survival rate is used for simulation purposes. Data for six month weight and pre-weaning survival rate were taken from the herd-book. Pre-weaning survival and fertility rate are binary traits, thus for pre-weaning lamb survival rate ewes lambed in the same month were taken and given a value of 1 (lamb weaned) and 0 (lamb died), thus means of pre-weaning survival rate are calculated. Taking the number of lambings from the herd-book fertility rate (%) data was generated using the RANDOM (70, 90) function. The mean value simulated for fertility rate was 80%, which is close to the value reported by (Berhan and Van Arendonk, 2006) for Menz sheep breed.

Table 5: Heritabilities (h^2), undiscounted economic values, phenotypic (σ_P) and additive genetic (σ_A) standard deviations for the traits in the breeding goal considered for the simulation purposes.

Traits	Unit	Heritability (h^2)	Economic weight (€/σ_A)	σ_P	σ_A
Six month weight (SMwt)	Kg	0.20	0.70	2.40	1.18
Pre-weaning lamb survival rate (PSW)	%	0.09	0.61	11.49	3.63
Fertility rate (Fr)	%	0.04	0.61	5.68	1.27

Source: Gizaw et al. (2010b), [a]Lambs survived to weaning as a proportion of lambs born , [b]Ewes lambed per ewes exposed to ram, kg (kilograms), % (percentage).

Data for each trait were sorted from the largest to the smallest and then imported into the model. Population standard deviations were calculated from the population data (including male and female animals). Additive genetic standard deviation was calculated as:

$$\sqrt{\sigma p^2 * h^2}$$

Where σp^2 is phenotypic variance and h^2 is heritability. Since selection was based on own performance for the live weight traits, thus accuracy of selection is obtained as $\sqrt{h^2}$. In the case of pre-weaning survival and fertility rate selection was based on dam performance, therefore, accuracy of selection is calculated as $0.5 * \sqrt{h^2}$ (Simm, 2000). Annual genetic gain is calculated according to Rendel and Robeston (1950) sited in Nitter et al. (1994).

$$\frac{i_m r_m + i_f r_f}{L_m + L_f} * \sigma_A$$

Where i is the selection intensity, r is the accuracy of selection; L is the generation interval and σ_A is the additive genetic standard deviation. The subscripts refer to selection for male and females animals. In this study random mating of selected animals is assumed, afterward, rate of inbreeding per year (∆F) is approximated using a formula:

$$\frac{1}{8mL^2} + \frac{1}{8fL^2}$$

where m and f are refer to the number of male and female animals entering the population every year, respectively (Simm, 2000). L is the generation interval in years. N_e was estimated according to Falconer and Mackay (1996) using the formula:

$$\frac{4MF}{M+F}$$

Where M and F are refer to the number of breeding ewes and rams in the population

The economic analysis sub-model was further developed and a total economic response (profit per ewe per year) is calculated as the difference between returns and costs. The return and costs are undiscounted. Following to Nitter et al. (1994), only costs that are additional to the normal husbandry practices of smallholder farmers were taken into account. These were costs of genetic evaluation, animal identification (tag and tagging cost), six month weight measuring, pre-weaning survival and fertility rate recording (Table 6). The costs were taken from Gizaw et al. (2010b) and from the ongoing community-based sheep breeding scheme in the study area. Total returns were obtained as product of annual genetic gains and economic value for each selection criterion. The returns do not include the whole return obtained from farm output, but the extra return obtained as a result of genetic gain. All costs and prices are expressed in Euros (€), where €1≈ Birr. 24.01 (Ethiopian birr) at the time (November 2013).

Table 6: Costs (€) per ewe per year.

Cost elements	Costs (€)
[a]Genetic evaluation	0.076
[b]Animal identification	0.253
[b]Measuring six month weight	0.0035
[b]Recording pre-weaning survival	0.0035
[b]Recording fertility rate	0.0035

[a]Sourced from Gizaw et al. (2010b).

[b]Costs were derived from the ongoing community-based sheep breeding program.

3.4- Model evaluation

Since a model is based on empirical equations consisting of many experimental results and assumptions, it is very important to evaluate the confidence and relative usefulness of the model for a particular objective (Grant et al., 1997). However, the community-based sheep breeding program in Menz area is in the initial stage and we could not get enough data to evaluate the model against field results. Thus, technical evaluation of the model was done to find out whether the model components were behaving in a manner that is expected in the real system based on published information and expert opinions. Extensive logic testing during the building phases was conducted and the model results were compared to independent calculations to determine whether the model was matching expectations, and to help clarify the relationships between variables. Besides, sensitivity analysis was done to determine the robustness of the model outputs, or sensitivity, of model behaviour to changes in models components. In this study numerical sensitivity analysis was carried out by varying the level of key variables of the model to evaluate the robustness of the model against change in degree of model variables.

Chapter 4- Results and Discussion

4.1- Herd dynamics of Menz sheep population

4.1.1- Model behaviour

The comprehensive simulation model in this study simulated the herd size at equilibrium from month 1 to month 240 by balancing dry matter supply and demand. In the Ethiopian highlands, the main livestock feed sources are crop residues which supply almost 61% of the dry matter followed by communal pastureland (21%), stubble grazing (13%), private pastureland (3%) and fallow land grazing (2%) (Bogale et al., 2008). The dry matter sources used in this study were communal pastureland (throughout the year) and crop residue supplementation (20-40%) in the dry season. In this study the main dry season was from December to February and the months before the main rainy season (May and June) was also treated with feed shortage. The simulated herd size in this study is small compared to reality since additional feed from private pastureland, fallows land grazing and from stubble grazing were not calculated.

The figures presented here are for the baseline and scenario I. In scenario II there was small increase in herd size when compared to scenario I, but the herd trend stays similar to scenario I. The model showed a gradual decrease in sheep population size after introducing the genetic selection scenario (Figure 9). This is due to the consideration of voluntary culling and the increase of body weight of the animals due to genetic selection for body weight. When the weight of animals increases, dry matter intake also increases, and then the model adjusts to a smaller population size and heavier animals in order to balance the dry matter demand with the dry matter supply. Reduction of herd size along with breeding for heavier animals can be challenging in the field, since smallholder farmers keep sheep not only for meat production but also for social security reasons. The dry matter supply and demand gap can be closed by culling low-producing animals and allocating alternative resources to young and highly productive group of animals without reducing the herd size. Traditional management practices have to improve and additional feed sources such as the production of improved forage needs to be introduced by resourceful smallholders if there is a wish to keep a productive and large herd.

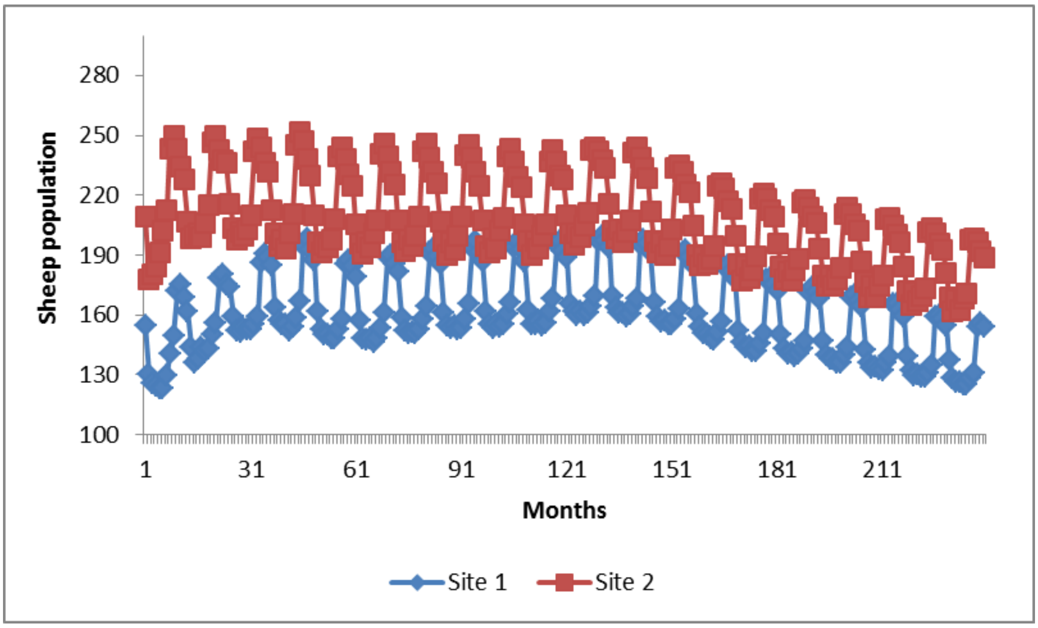

Figure 9: Simulated herd in equilibrium before and after genetic improvement of body weight for sites 1 and 2.

Figure 10 and 11 show the distribution of sheep population in the baseline and scenario I in the months of the year with respective standard deviations for site 1 and 2 respectively. As expected, a large population size in the baseline scenario and a decrease in population size after genetic selection for body weight were observed. The population was also larger in the vegetative season due to higher green and dry standing vegetation supply when compared to the dry season. The decrease in population size in the dry season is caused by the shortage of dry matter supply, which resulted in a higher mortality and disposal rate of animals. Lambing occurs throughout the year, thus, there was higher loss of lambs which are born in the dry season due to the shortage of feed and poor body condition of lambing ewes. This resulted in a lower number of replacements which affected the number of lambs born and decreased the total population size.

The distribution of breeding ewe population in the baseline and scenario I in the months of the year for site 1 and 2 are presented in Figure 12 and 13 respectively. In contrast to the total sheep population, an increase of the breeding ewe population was not observed in the early vegetative season. This could be because of the longer time (considering the reproductive period) required to restore the population from the dry season. Young ewes were discarded from the system whenever the herd's dry matter demand exceeded the supply. This resulted in subsequent shortage of female replacements. However, in practice, farmers have a larger number of breeding ewes in the vegetation season than in the dry season (Getachew et al., 2010). This is partly due to the purchase of young ewes or breeding ewes in early vegetative season which was not considered in this study. A deterministic age-transition matrix model which explicitly accounts for within-year demographic variability of an extensively managed sheep population in North Senegal has been developed and discussed by Lesnoff (1999). Here, the vegetative season was characterized by higher mortality and outflow rates, leading to an overall decrease in herd size. The opposite was however observed by this study.

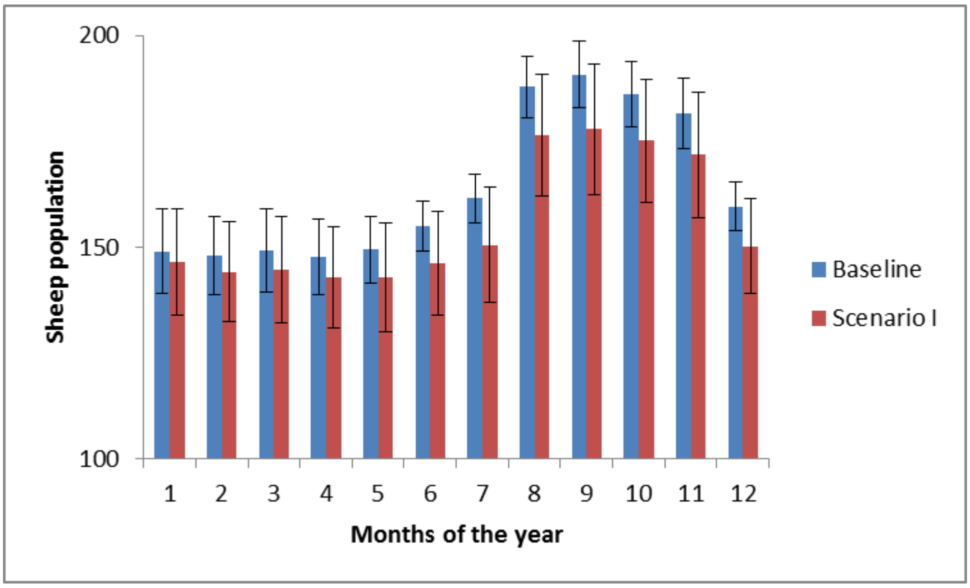

Figure 10: Simulated sheep population size with standard deviation in the baseline and scenario I for site 1.

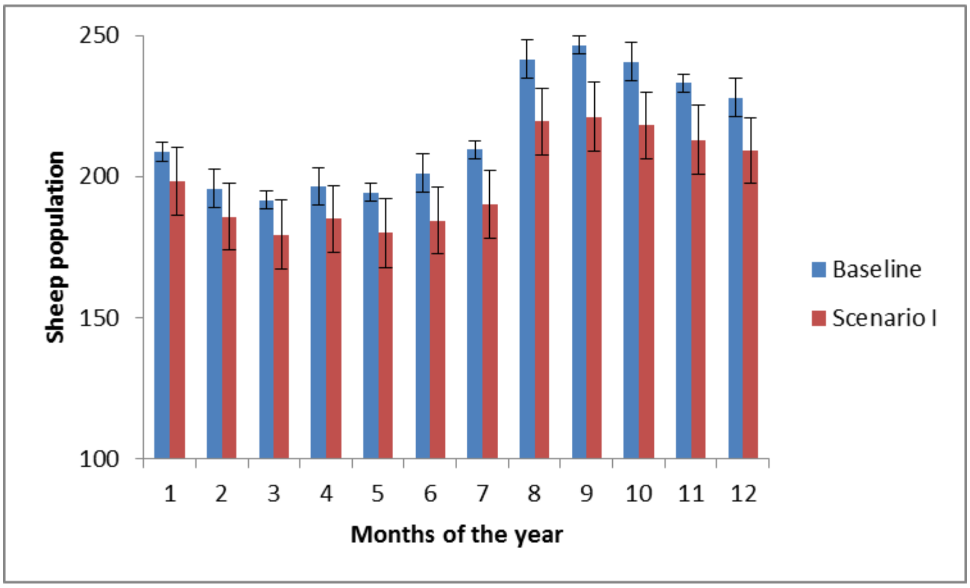

Figure 11: Simulated sheep population size with standard deviation in the baseline and scenario I for site 2.

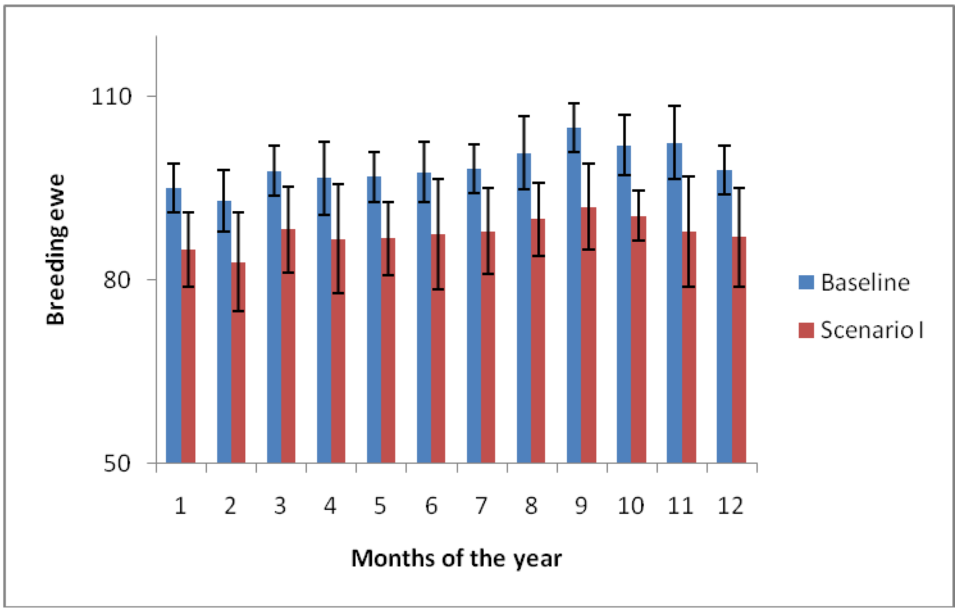

Figure 12: Simulated breeding ewe population size in the baseline and scenario I for site 1.

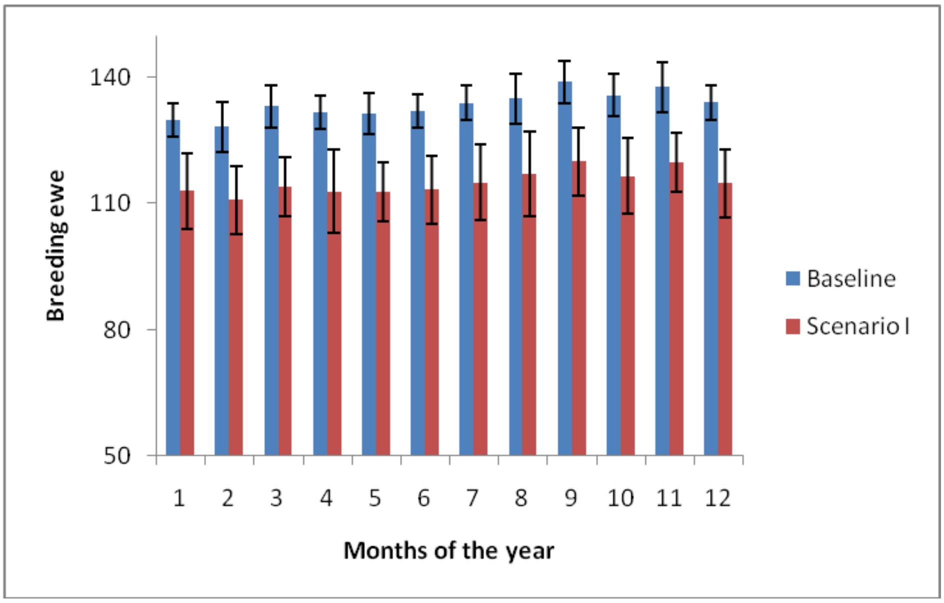

Figure 13: Simulated breeding ewe population size in the baseline and scenario I for site 2.

The average proportion of breeding ewes was simulated to be around 50% of the total sheep population, for both sites. This was in agreement with Getachew et al. (2010), in which the proportion of breeding ewes equalled 46.8% of the total flock for the study area. Mukasa-Mugerwa et al. (2000) discussed that the ewes which were mated in the dry season and subsequently lambed in the vegetative season showed a higher reproductive performance than those ewes that were mated in the vegetative season and lambed in the dry season (weaning rate of 0.76 versus 0.53 respectively). This could be in agreement with the assumption of higher lamb mortality in the dry season.

Live weight of animals was simulated and the first 120 months show the behavioural pattern of the baseline scenario and the last 120 months shows the scenario I (genetic improvement scenario). Figure 14 showed the simulated birth weight in the baseline and genetic improvement scenario. Figure 15 also showed that the simulated six month lamb weight in site 1 and 2. It can be seen that lambs were heavier in the vegetative season due to good pasture production leading to good body condition. A similar pattern of behaviour was observed for young rams, young ewes, breeding rams and breeding ewes relative to their initial weight, and are presented in Figure 16 - 19. Animals reached at minimum the average live weight during the vegetative season but subsequently lose weight during the dry season. Weight fluctuation showed the same pattern of behaviour in all animal categories except for fattening, and this was caused because the model was allowed to account effect of seasonal feed supply in live weight of animals, thus animals were tended to lose weight in the dry season and gain in the vegetative season. Animals were heavier in the vegetative season due to good pasture production which leads to good body condition. Thus, animals achieved the average live weight or more during the favorable season but lost weight during the unfavorable season.

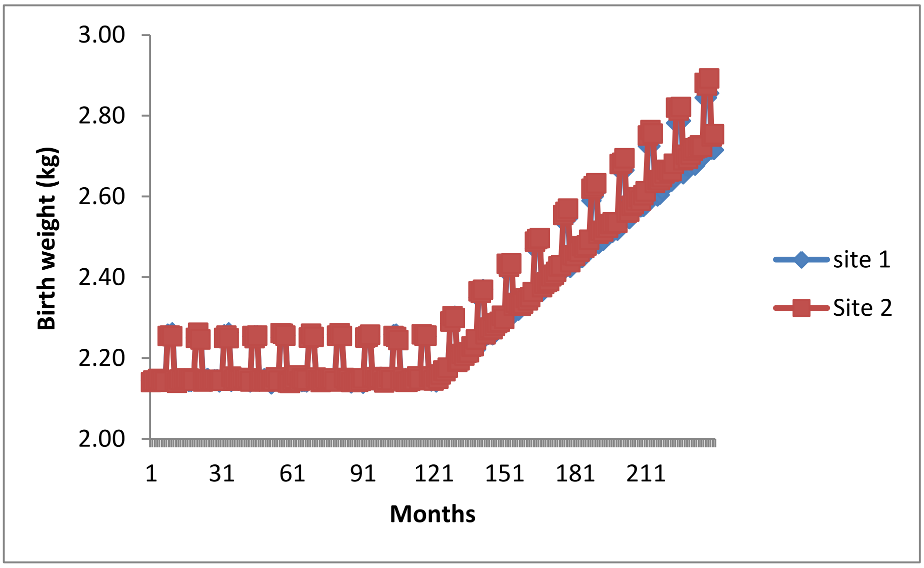

Figure 14: Simulated birth weight of lambs in the baseline and genetic improvement scenario for sites 1 and 2.

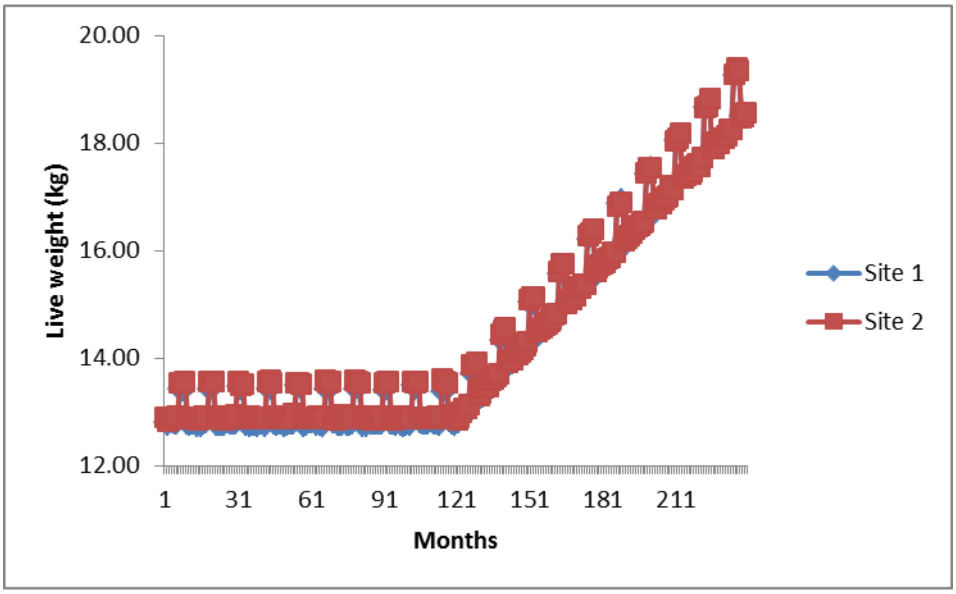

Figure 15: Simulated six month lamb live weight in the baseline and genetic improvement scenario for sites 1 and 2.

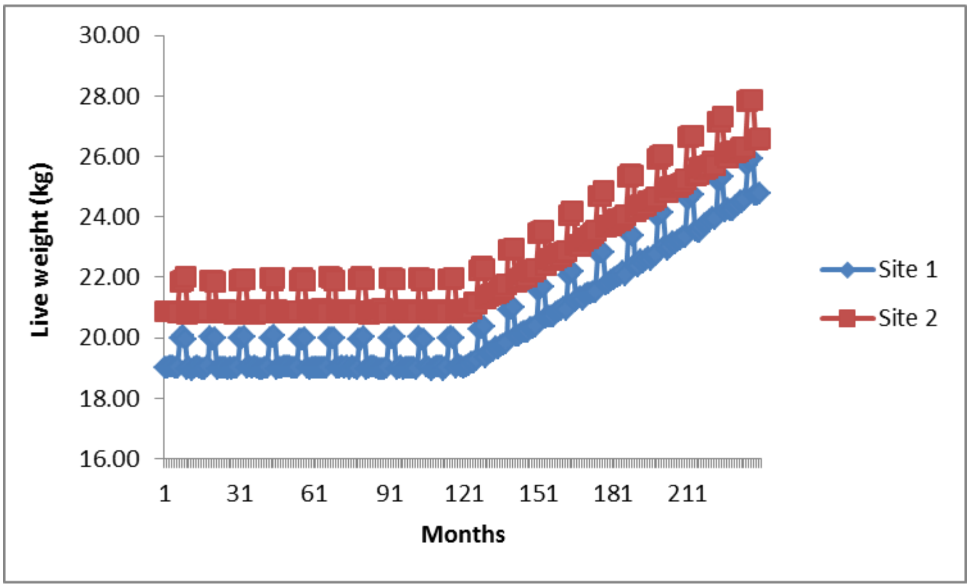

Figure 16: Simulated young ram live weight in the baseline and genetic improvement scenario for sites 1 and 2.

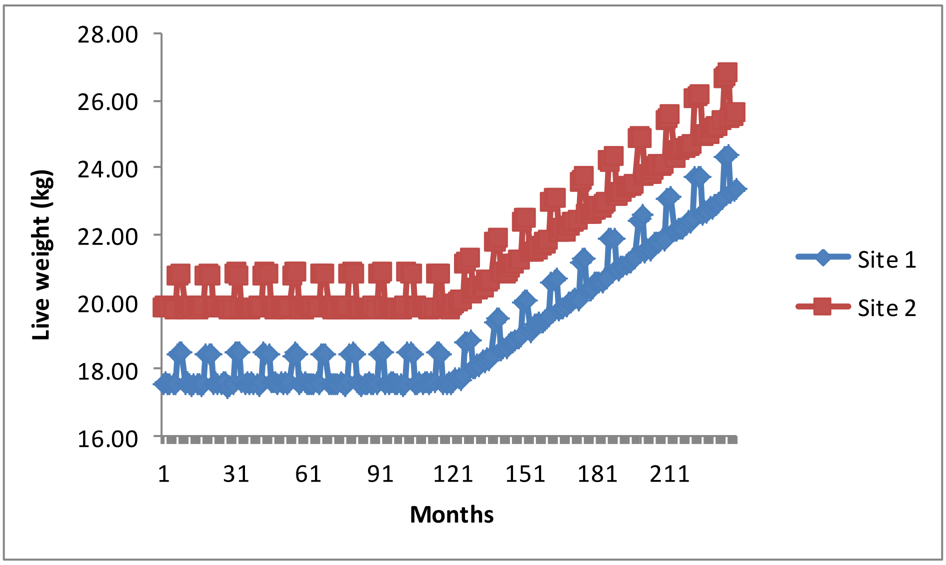

Figure 17: Simulated young ewe live weight in the baseline and genetic improvement scenario for sites 1 and 2.

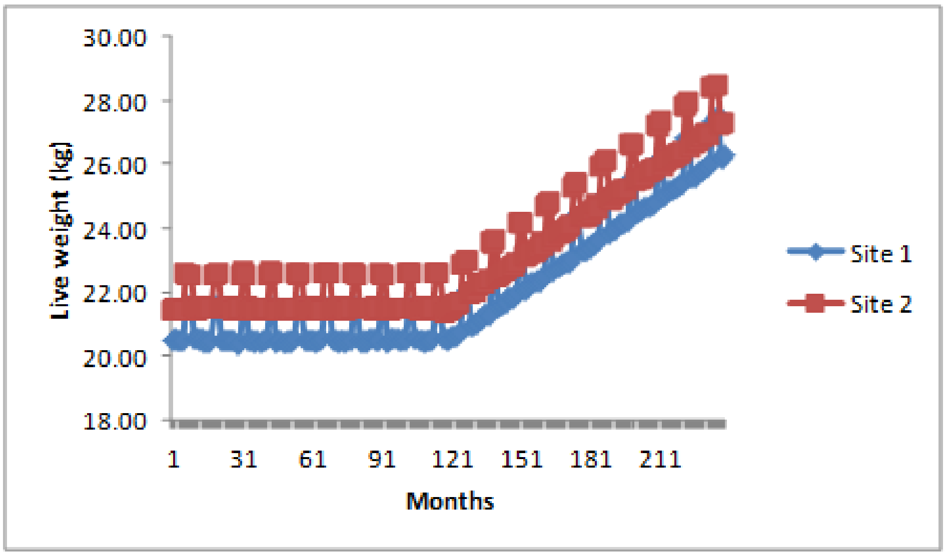

Figure 18: Simulated mature ewe live weight in the baseline and genetic improvement scenario for sites 1 and 2.

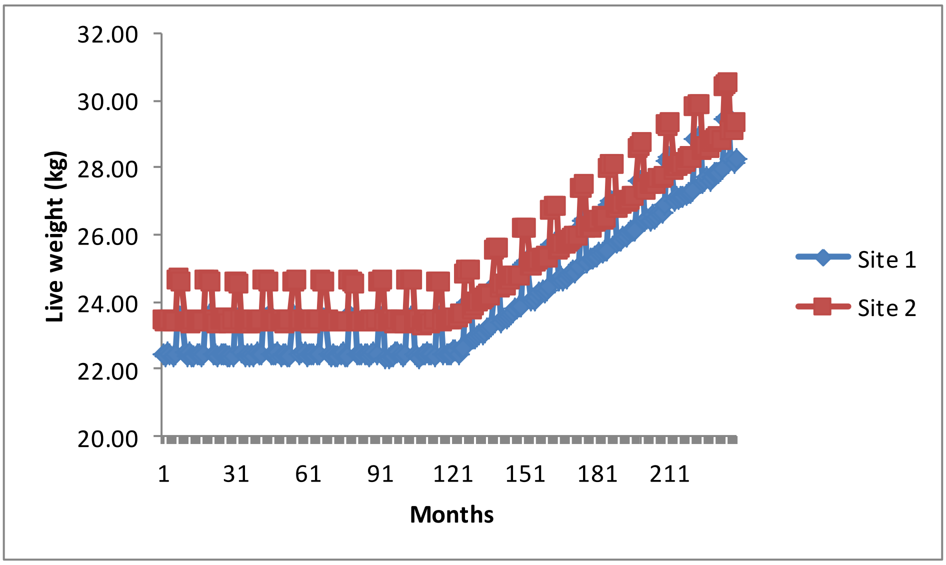

Figure 19: Simulated ram live weight in the baseline and genetic improvement scenario for sites 1 and 2.

Seasonal feed supply had no impact on fattening animals since they were fed for fat deposit and then a clear steep increase in live weight was observed in both sites (Figure 20 and 21). The first 120 months showed the baseline scenario where farmers fattened culled breeding rams, and the last 120 months showed fattening of culled breeding rams (scenario I) and six month lambs (scenario II). Negussie et al. (2003) and Ermias et al. (2002) have discussed that due to seasonal fluctuation in feed availability, animals lose weight during the dry season and gain weight during vegetative season. In other words, animals deposit fat during the vegetative season and mobilize during the dry season. Furthermore, Hassen et al. (2002) and Mukasa-Mugerwa et al. (2000) conferred that, at a given age, season had a considerable effect on both birth weight and average live weight due to a decline of rainfall and a reduction of feed resources in the dry season. This is in agreement with the simulation results presented here. However, it should be noted that animals may respond differently to periodic nutritional stress due to genetic factors, the age at which restriction is imposed, the severity and duration of restriction, the quality of the feed and lastly, the duration of re-feeding (Benschop, 2000; Lawrence and Fowler, 2002). Inclusion of those factors in further development of the model can result in a more accurate description of the production system in Menz highlands.

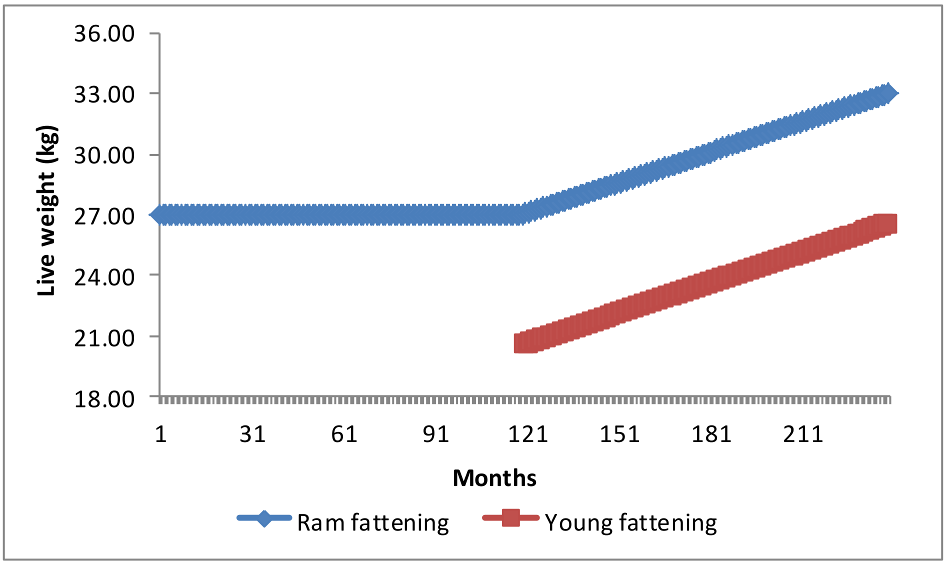

Figure 20: Simulated live weight for fattened ram (RF) and fattened young (YF) in the baseline, scenario I and scenario II for site 1.

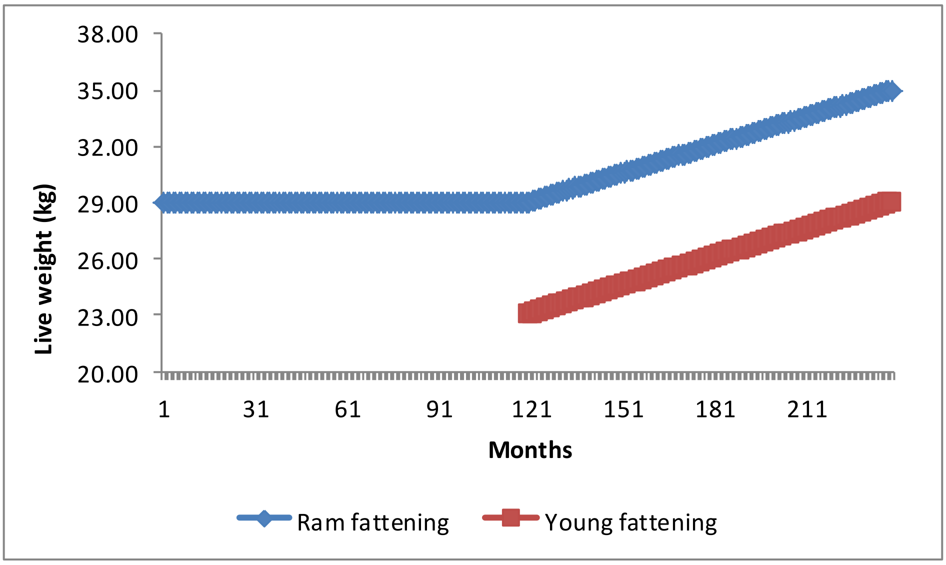

Figure 21: Simulated live weight for fattened ram (RF) and fattened young (YF) in the baseline, scenario I and scenario II for site 2.

In most of the livestock simulation models such as in (e.g. Guimarães et al., (2009); Parsons et al., (2011); Tedeschi et al., (2011); Mulindwa et al., (2011)) periodic variation in livestock performance and population size due to environmental conditions is not accounted. The merit of the simulation model is to provide insight into how periodic nutritional stress could have a large impact on livestock performance and population size in areas where livestock production is directly linked to the environmental conditions: the tropics and sub-tropics. It is also documented that animals which are kept in the subsistence low-input production systems are limited to express their genetic potential due to the poor nutritional conditions

(Yapi-Gnaoré et al., 2001).The simulation results also indicate that genetic progress can be achieved in community-based breeding programs by balancing the number of animals with the available resources and voluntary culling of unproductive animals from the herd. In the simulation model nutrient deficiency was observed in the dry season due to the higher availability of dry standing pasture compare to the green pasture. Therefore, further development of the model in order to account nutrient supply and demand is required.

Table 7 provides an overview of profit calculations for the baseline, scenario I and scenario II. A gross profit of €124(± €62) and €143(± €98) per herd size and month was shown in the baseline scenario for site 1 and 2 respectively. In the baseline scenario the average herd size was 163(±19) and 216(±20) respectively, for site 1 and 2. This resulted in a benefit cost ratio (BCR) of 2.80(±0.97) and 2.81(±1.30) respectively, implying that €1.00 investment on inputs for sheep production can provide €2.80 and €2.81 of returns respectively. Thus where BCR is greater than 1, it indicates the good investment. Site 2 was considerably more profitable than site 1 and this is due to the higher initial herd size and body weight (Table 3), resulting in higher returns from sale of more and heavier animals.

Table 7: Gross profit and benefit cost ratio for sites 1 and 2.

Scenarios	Gross profit (€/herd size/month)		Benefit cost ration (BCR)	
	Site 1	Site 2	Site 1	Site 2
Baseline	124(62)	143(98)	2.80(0.97)	2.81(1.30)
Scenario I	144(67)	168(98)	3.10(1.10)	3.20(1.40)
Scenario II	179(68)	193(67)	3.32(0.99)	4.00(1.20)

[a]Figures in brackets are standard deviation

The introduction of genetic selection for body weight resulted in an increase of gross profit and BCR for both sites. Scenario II was more profitable than scenario I with gross profit of €179(±68) and €193(±67) respectively, for site 1 and 2 respectively. The higher gross profit in scenario II is caused by the higher growth rate and weight gain efficiency (kg of feed/kg of weight gain) in lambs compared to matured rams. Furthermore, the lower dry matter intake in young animals compared to bigger animals decreases feed cost and maximizes the total revenue. A higher BCR 4.0(±1.2) was observed for site 2 than for site 1. Overall, the simulation results show that both genetic selection and fattening strategies contribute to an increase of profitability. Habtemariam et al. (2012) reported that the sheep sub-sector in Ethiopia has a higher economical contribution with gross profit of 1007.4 birr per household per year in comparison to other livestock sectors. Figure 22 and 23 present the profit per herd size per year for baseline, scenario I and scenario II for site 1 and 2 respectively. The profit is calculated as a difference between discounted returns and costs of the model. All scenarios resulted in a positive profit and the scenarios with genetic selection for body weight resulted in a higher profit when compared to the baseline scenario.

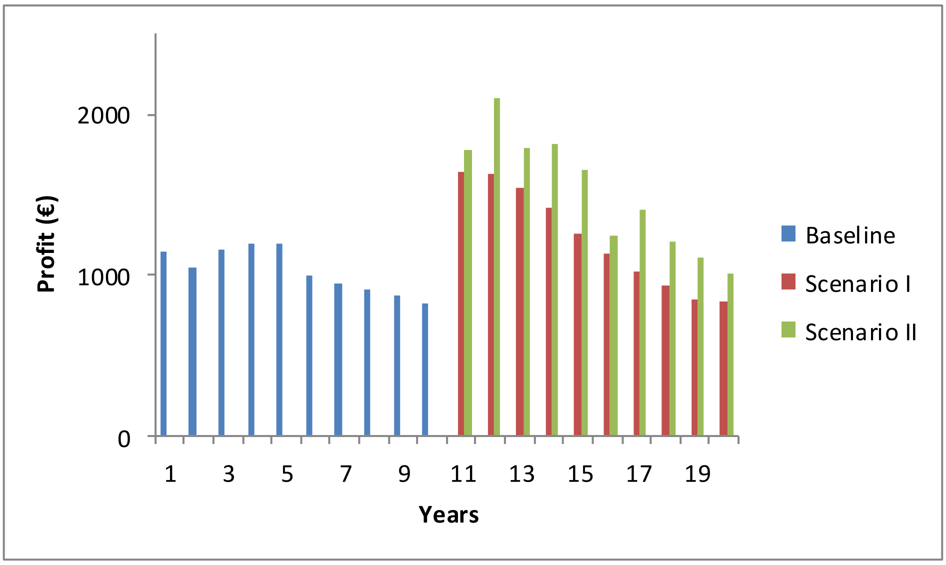

Figure 22: Simulated profit per year for baseline, scenario I and scenario II for site 1.

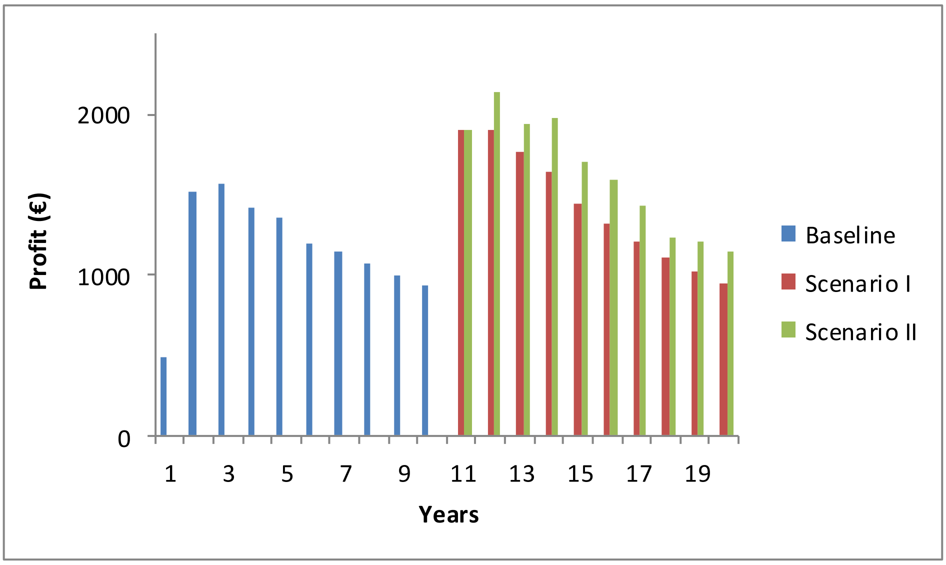

Figure 23: Simulated profit per year for baseline, scenario I and scenario II for site 2.

Thornton and Herrero (2001) discussed that even where there is adequate understanding of the involved biophysical processes, integrated crop-livestock models still may be constrained by lack of reliable data for calibration and validation of simulation models. There are no simulation models that can model a system completely to reality (Grant et al., 1997; Kikuhara et al., 2009). Thus, models should be further developed and continuously updated by incorporating recent knowledge and information. The current simulation model, presented in this study, is built upon a strong base of existing knowledge and is a potentially valuable tool for representing the sheep production system in Menz area. However, with further development and evaluation through model verification and validation against field results, more complete models can be produced.

4.1.2- Sensitivity analyses

A sensitivity analysis of live weight price, feed cost and open period resulted in a change of the gross profits and BCRs, but did not change patterns of behaviour in the model, because there was no feedback of economic (feed and live weight price) to management decisions of the model. The change in open period also did not change patterns of behaviour in the model, since herd size was set at equilibrium. The sensitivities are discussed relative to the gross profit and BCRs provided in Table 7 for baseline, scenario I and scenario II for sites 1 and 2. Table 8 provides gross profits and BCRs for the baseline, scenario I and scenario II in change of live weight price, feed cost and open period for sites 1 and 2. In both sites the model was sensitive to a change in live weight price, resulting in an increase of gross profit while live weight price increased by 20%, and in a decrease of gross profit when live weight price decreased with the same rate.

Overall, the sensitivity analysis revealed that changes in the marketing price of live animals can affect the profitability of sheep production at smallholder level. Largely, animal prices depend on supply and demand, which are in turn heavily influenced by season (Ayele et al., 2006; Kassa et al., 2011) and the occurrence of religious and cultural festivals or drought and weather shocks. The sensitivity analysis carried out for live weight price is particularly useful for the inference that research and policy options that can potentially enhance sheep markets are necessary. Moreover, the analysis indicated that the model was relatively robust for change in open period and feed cost.

Table 8: Gross profit and Benefit cost ratio for baseline, scenario I and scenario II with changes in price level of feed and live weight prices, and change in length of open period for sites 1 and 2.

		Gross profit (€/herd/month)			Benefit cost ratio (BCR)		
	Level	Baseline	Scenario I	Scenario II	Baseline	Scenario I	Scenario II
Site 1							
Feed cost (€)	+15%	120(65)	137(69)	179(72)	2.60(1.20)	2.90(1.00)	3.10(0.90)
	-15%	132(64)	149(69)	198(73)	3.10(1.50)	3.45(1.20)	3.73(1.20)
Live weight price (€)	+20%	165(76)	185(82)	243(86)	3.38(1.60)	3.78(1.30)	4.02(1.30)
	-20%	88(52)	101(56)	137(59)	2.26(1.10)	2.50(0.90)	2.71(0.80)
Open period (Months)	1-3	129(66)	149(72)	198(75)	2.83(1.30)	3.17(1.10)	3.38(1.00)
	2-6	120(66)	144(72)	179(70)	2.73(1.30)	3.10(1.00)	3.31(0.90)
Site 2							
Feed cost (€)	+15%	136(97)	158(99)	181(64)	2.66(0.90)	2.91(1.30)	3.65(1.10)
	-15%	151(96)	172(99)	193(64)	3.20(1.10)	3.47(1.50)	4.38(1.30)
Live weight price (€)	+20%	189(115)	213(118)	273(75)	3.40(1.20)	3.78(1.70)	4.77(1.40)
	-20%	116(113)	129(116)	138(53)	2.30(0.80)	2.55(1.10)	3.20(1.00)
Open period (Months)	1-3	147(99)	171(103)	194(67)	2.90(1.00)	3.20(1.40)	4.00(1.20)
	2-6	137(96)	164(98)	187(67)	2.80(1.00)	3.10(1.30)	3.84(1.00)

[a]Figures in brackets are standard deviation

4.1.3- Smallholder farmers' feedback on the simulation model

Workshops were held from the 17th to 18th of June 2013 in both research sites to gain feedback on the developed simulation model. The developed dynamic simulation model, balance the dry matter supply and demand by reducing flock size utilizing the available feed resources, like free grazing (all year round) and crop residue (in dry season) was presented and discussed with farmers regarding the possible opportunities and challenges.The results of the model were presented to the smallholders in a simple and understandable way.

The results of the simulation model were quite accepted by smallholder farmers in both reference sites. Smallholders were aware with the reduction in the herd size since they keep sheep for multiple reasons (social and economic). But, smallholders also witnessed that improvement in body weight, survival and health of their sheep herd has been achieved since the community-based sheep breeding program started. Smallholders were positive with breeding for bigger animals, because of the higher income generated in the ongoing breeding program. The smallholders' strong motive from discussion of the simulation model results was to keep small flocks of healthy animals which earn good price because of the better feeding and large body size. Regarding the fattening strategies, smallholder farmers are familiar with fattening of culled breeding rams for religious festivals. Fattened rams are heavier in weight and fetch good price compared to the young ones. Young lamb fattening was perceived as regular cash generation. Smallholder farmers discussed that fattening both culled rams and young rams can be valuable in their system, since there is a demand for matured fattened rams in the market and as a way of regular income generation.

However, smallholder farmers doubt that due to the small flock size, large proportions of animals might die in extreme situation (e.g. drought). Smallholders also claimed that feed shortage cannot be avoided even they reduce their flock, since they keep cattle and equines in addition to the sheep population. On the other hand, smallholder farmers mentioned that during the dry season animals are sold with a lower price which is quite a challenge to the benefit from the sheep herd. They suggest that the situation model need to be further improved in order to account the seasonal sheep price to get more picture of the profitability from sheep production.

4.2- Evaluation of alternative management systems

4.2.1- Model behaviour

In spite of the serious feed shortage which is hampering the livestock productivity in the highlands of Ethiopia, pasture land management and improved forage crop production at smallholder level is limited (Gebremedhin et al., 2007; Bogale et al., 2008; Gizaw et al., 2010a). Deterioration both in the size of the communal pastureland and in the quality of pasture is affecting the performance of livestock which are dependent on it (Bogale et al., 2008; Tegegne et al., 2011). As a measure to this challenge, it is often suggested that the low productivity of livestock can be boosted by producing improved forage crops (Abate et al., 2003; Tegegne et al., 2011; Beshir, 2014). The production of improved forage can increase the productivity of livestock by closing the feed gap. But, improved forage production also require input supplies (Gebremedhin et al., 2003). This increases the production costs of the farm (fertilizer, forage seed and labour cost) due to additional inputs to grow forage (Shapiro et al., 1994).

Thus, this study focuses on evaluating the impact of increase in feed supply due to forage production on herd dynamics and profitability. In this case system dynamic methodology is a powerful tool to evaluate the management interventions that are expected to boost animal productivity and farm income. As a result the comprehensive and dry matter driven simulation model that mimics the sheep production system in the Menz highland areas was further developed in order to account for forage production. For the simulation purposes, production of vetch forage was introduced and the simulated yield (ton DM/ha) for the considered time horizon is presented in Figure 24. The vetch yield is directly related to the rainfall received.

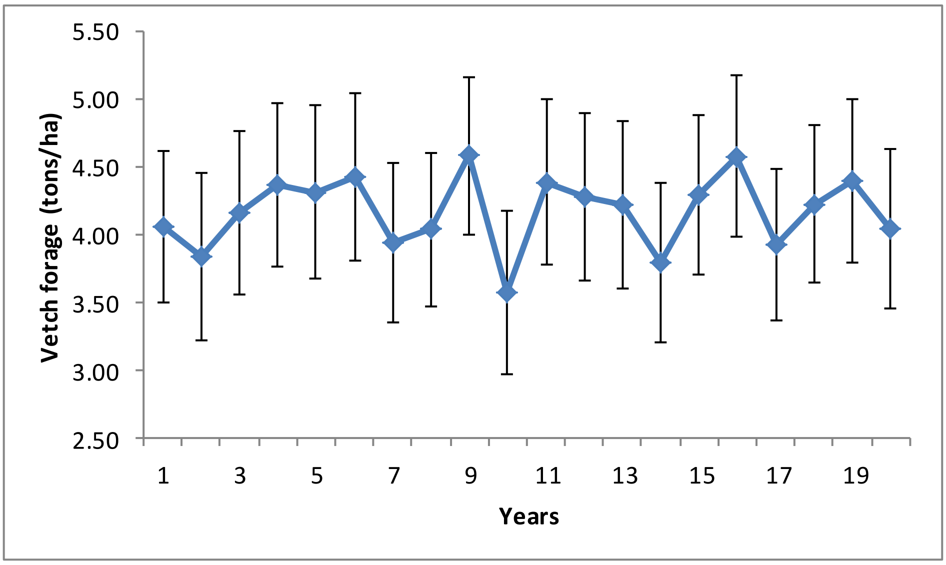

Figure 24: Simulated vetch yield (DM/ha) with respective standard deviations for site 1.

For the economic analysis purpose, barley production was also simulated because part of the crop land is used for forage production. Figure 25 shows the barley grain yield (kg/ha) throughout the time horizon. The simulated barley residue is the same amount as the simulated barley grain yield, since the conversion factor is 1. Similar to the forage production the barley yield corresponds to the rainfall received. The simulated vetch hay and barley grain are more or less related to the real values set prior simulation, which were sourced from agricultural offices of the reference sites and Debre-Berhan agricultural research center.

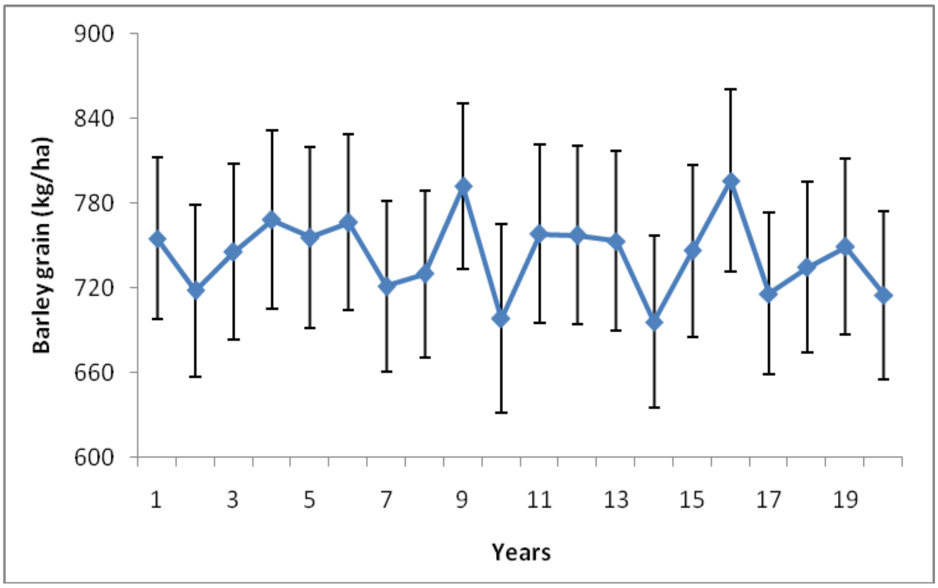

Figure 25: Simulated barley grain yield with respective standard deviations for site 1.

As expected, increase in feed supply results in increase of the herd size to some extent, when AMS I and AMS II are applied in both study sites. But still the simulation model remains to be goal seeking archetype as it has been formulated to balance the dry matter supply and demand of the herd. In both reference sites the herd size respond to the increase in feed supply in the same pattern and are presented in Figure 26 and 27. In the figures the first 10 years show the baseline scenario and the last 10 years represent scenario I, where the model accounts for the genetic merit of animals. Breeding ewes represent a high proportion of the herd in baseline, scenario I and scenario II, followed by young (0 to 6 months) and young ewes (6 to 12 months). The proportions of breeding rams and young rams (6 to 12 months) are small, which is quite realistic. Smallholders do not keep more young male animals except the replacements for breeding rams, since they are sold for meat in religious festivals.

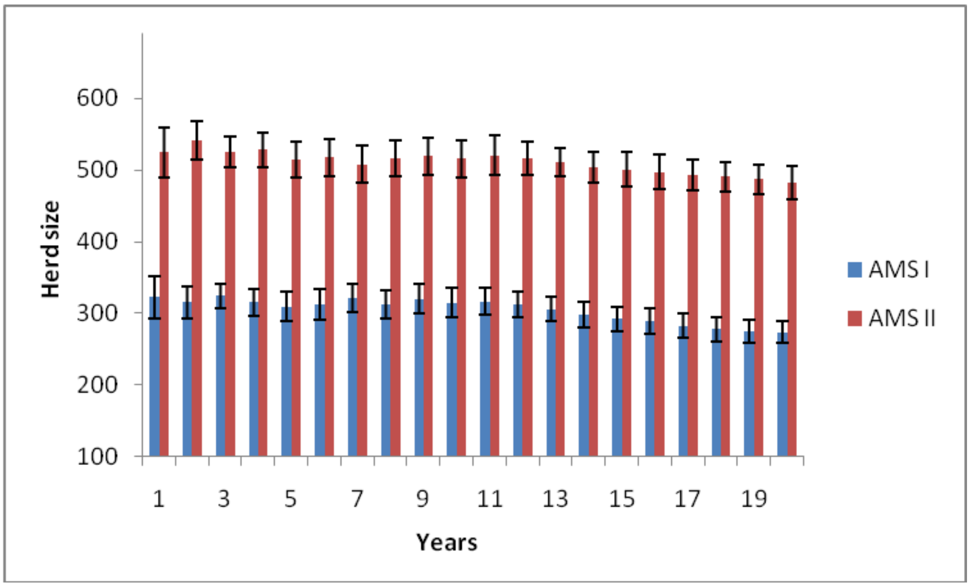

Figure 26: Simulated herd dynamics with respective standard deviations in the evaluated alternative management systems for site 1.

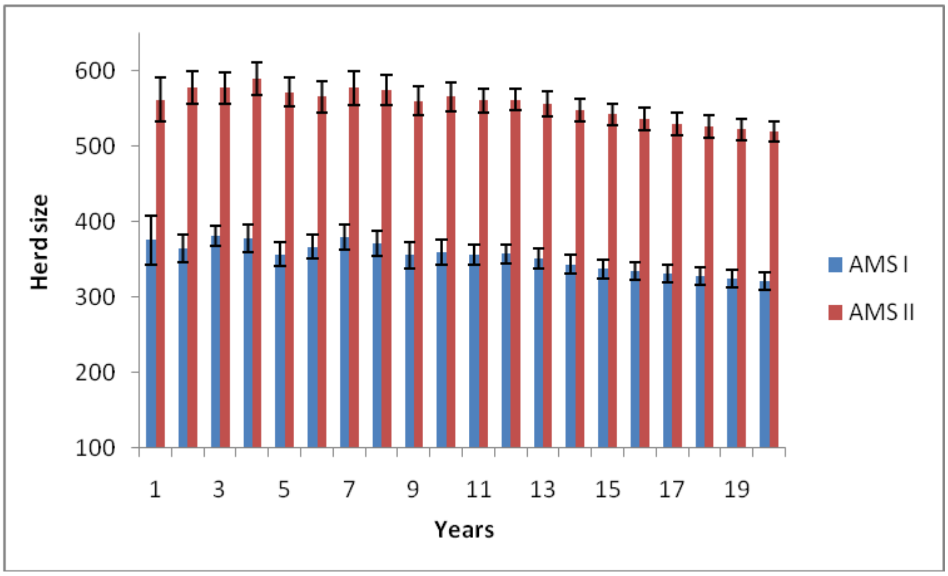

Figure 27: Simulated herd dynamics with respective standard deviations in the evaluated alternative management systems for site 2.

The herd composition was more or less similar in both sites and Figure 28 summarizes the herd composition in AMS I for site 1. The change in average herd size, gross profit and benefit cost ratio for the alternative management systems are provided in Table 9 for sites 1 and 2. The herd size is determined based on the dry matter supply from vetch, pastureland and barley residue in a specific month of the year. Whiles the model accounts for forage production, the barely residue supply decreases. Unlike the baseline scenario and scenario I, the simulation model responds with higher gross profit in both alternative management systems where young lamb fattening (scenario II) is simulated. The lower economic responses in the baseline scenario and scenario I can be due to the additional costs for growing forage and lower returns from sale of fattened rams. The average number of fattened culled rams per month was 3 and 7 in AMS I and AMS II, which is small to compensate the additional forage growing costs.

In scenario II, on average 12 and 18 fattened young lambs per month were sold in AMS I and AMS II respectively. In this scenario the production costs are compensated by selling large number of fattened young lambs which results in increase of the gross profit. However, there is no significant difference in gross profit between AMS I and AMS II; this could be caused due to the higher production cost in AMSII for growing forage and the higher barley opportunity cost, as 50% of the total crop land was allocated to forage production.

Shapiro et al. (1994) also discussed that small ruminant fattening with grazing plus supplementation of forage might not be potentially profitable due to the increase in costs for growing forage. Small ruminant fattening exercise using concentrate supplementation has been also resulted in a negative profit (Miklyaev and Jenkins, 2012) and the authors discussed that supplementation with farm products such as crop residue can improve the profitability of small ruminant fattening. Fattening trails in the study area revealed that young fattening using grazing; crop residue and vetch supplementation has resulted in positive profit (Yeheyis et al., 2004).

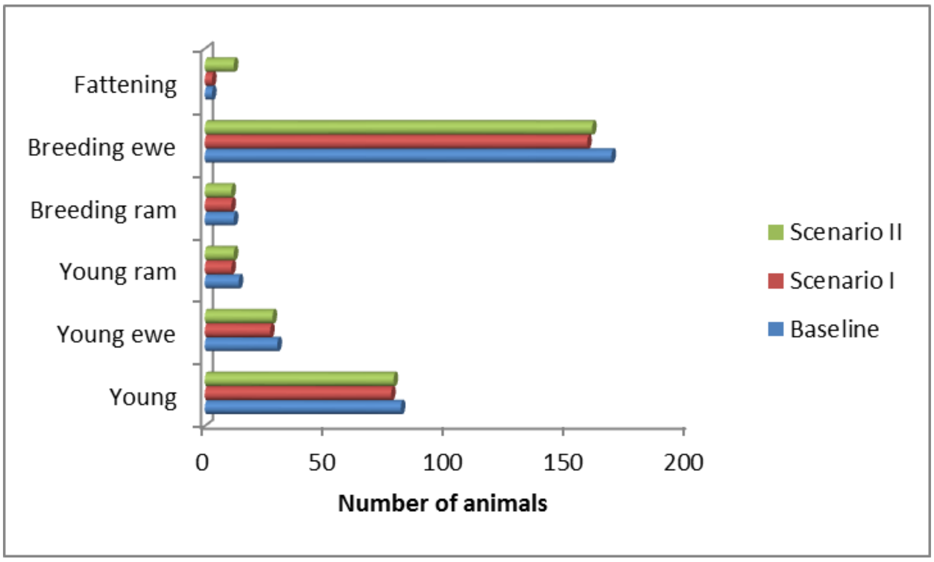

Figure 28: Simulated number of animals in different age groups in the baseline, scenario I and scenario II in AMS I for site 1.

In AMS I, the simulation model shows that 54% of the production costs were from feed which includes pastureland, crop residue and vetch growing cost, followed by 31% management cost (labour, health and housing) and 9% barley opportunity cost. In this study death of animals was tread as a cost due to the economic losses, therefore, 6% of the production costs estimated to be due to loss of animals. However, in the case of AMS II, the feed and barley opportunity costs are increased due to increase in herd size and land for forage production. The proportion and sources of returns are similar in both alternative management systems and Figure 29 shows the proportion and source of return in the baseline, scenario I and II respectively, for AMS I in both sites.

Table 9: Average herd size, gross profit and benefit cost ratio for alternative management systems in sites 1 and 2.

Parameters	AMS I			AMS II		
	Baseline	Scenario I	Scenario II	Baseline	Scenario I	Scenario II
Site 1						
Mean herd size (sheep/month)	308(24)	291(26)	301(31)	513(33)	499(32)	507(30)
Gross profit (€/herd si e /month)	130(103)	148(101)	232(160)	135(128)	153(123)	274(172)
Benefit cost ratio	1.80(0.77)	1.90(0.80)	2.30(0.63)	1.60(0.52)	1.70(0.54)	2.25(0.60)
Site 2						
Mean herd size (sheep/month)	357(24)	339(19)	347±23	565(26)	551(22)	558(32)
Gross profit (€/herd si e /month)	131(102)	154(93)	264(114)	180(136)	192(153)	284(172)
Benefit cost ration	1.58(0.50)	1.72(0.50)	2.30(0.60)	1.52(0.43)	2.00(0.54)	2.25(0.60)

[a]Figures in brackets are standard deviation

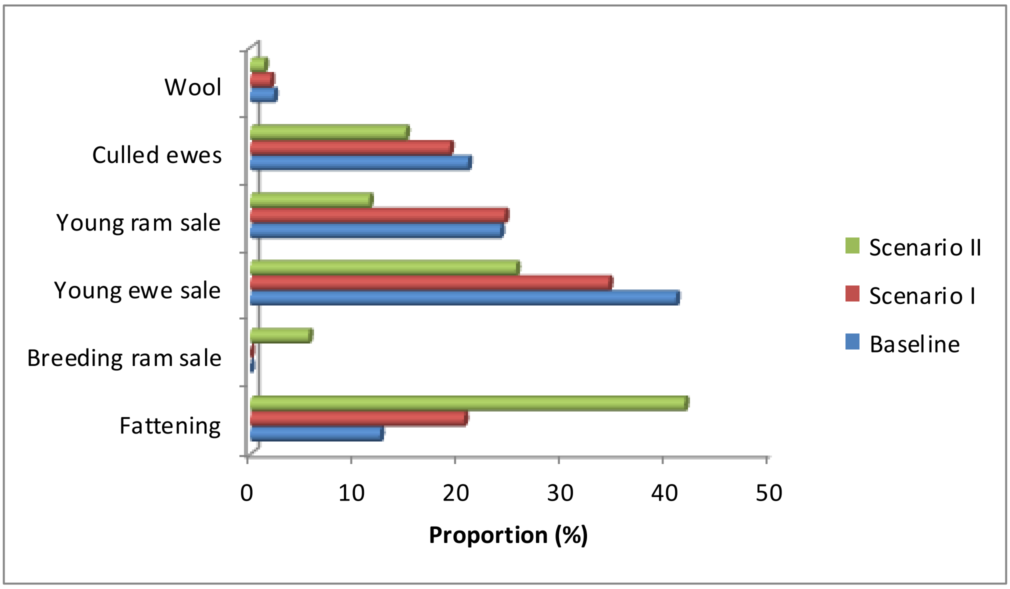

Figure 29: The proportion and source of returns in AMS I for the baseline, scenario I and scenario II for sites 1 and 2.

In the baseline and scenario I, the main sources of return are sale of young ewes and young rams. It should be noted that the returns from the young ewes also include the returns from sale of young ewes due to feed shortage as the simulation model is dry matter driven and whenever the herd dry matter demand exceeds the dry matter supply, young ewes were discarded from the system to close the feed dry matter gap. The returns from sale of fattened culled rams cover 12% and 22% in baseline and scenario I. In both scenarios return from sale of breeding rams are null, this is due to the reason that breeding rams which are culled were transitioning directly into the fattening stage, since fattening of culled rams was considered.

In scenario II, the major sources of the return are from sale of fattened young lambs which covers almost 43%, followed by sale of young ewes close to 25%. In this scenario sale from breeding rams was practiced because culled rams were directly sold to the market and contributed to 7% of the returns. Therefore, the higher gross profit achieved in this scenario is related to the young fattening which contributes to higher returns by minimizing the production costs. Figure 30 and 31 present the profit per herd size per year for baseline, scenario I and scenario II in AMS I respectively, for sites 1 and 2. The profit is calculated as a difference between discounted returns and costs of the model. The profits are positive in all the scenarios and are much higher in scenario II, where young lamb fattening was simulated.

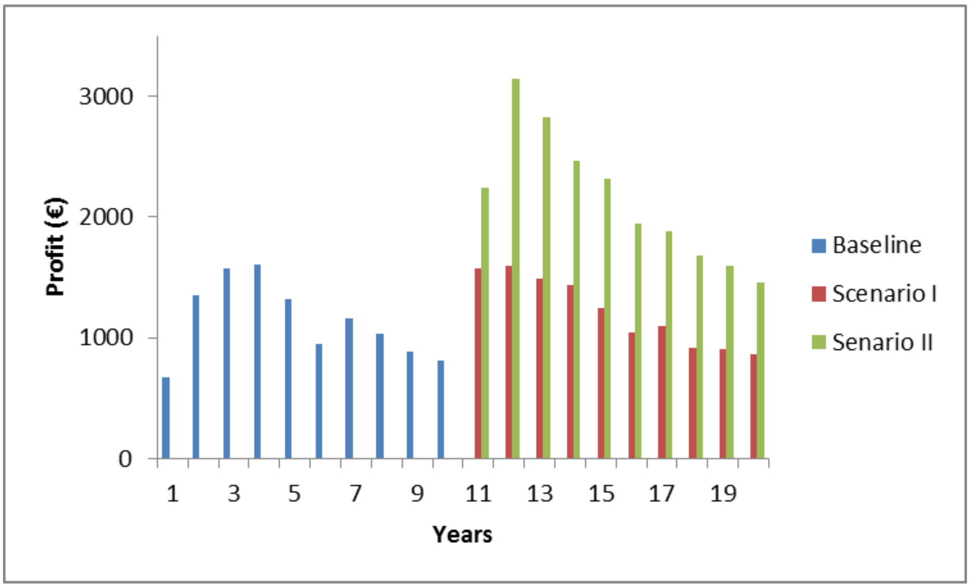

Figure 30: Simulated profit per year for baseline, scenario I and scenario II in AMS I for site 1.

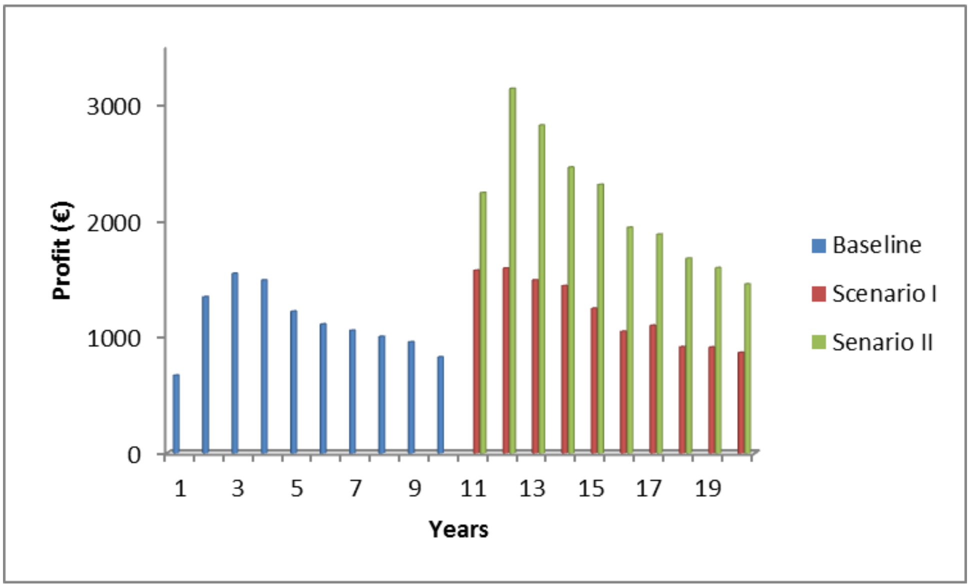

Figure 31: Simulated profit per year for baseline, scenario I and scenario II in AMS I for site 2.

Similarly Figure 32 and 33 show the profit per herd size per year for baseline, scenario I and scenario II in AMS II respectively, for sites 1 and 2. In the study area extreme temperature is limiting crop production; as a result the importance of sheep production to the livelihood of smallholder farmers is increasing. Therefore, AMS II was used to represent the sheep production system. However, the simulation model revealed that shifting toward the strong sheep breeding system might not be potentially profitable as AMS I, due to the higher input costs to grow vetch and higher barley opportunity cost. Based on the model results it can be understood that allocating small part of crop land to forage production combined with the young lamb fattening can result in a reasonable profit.

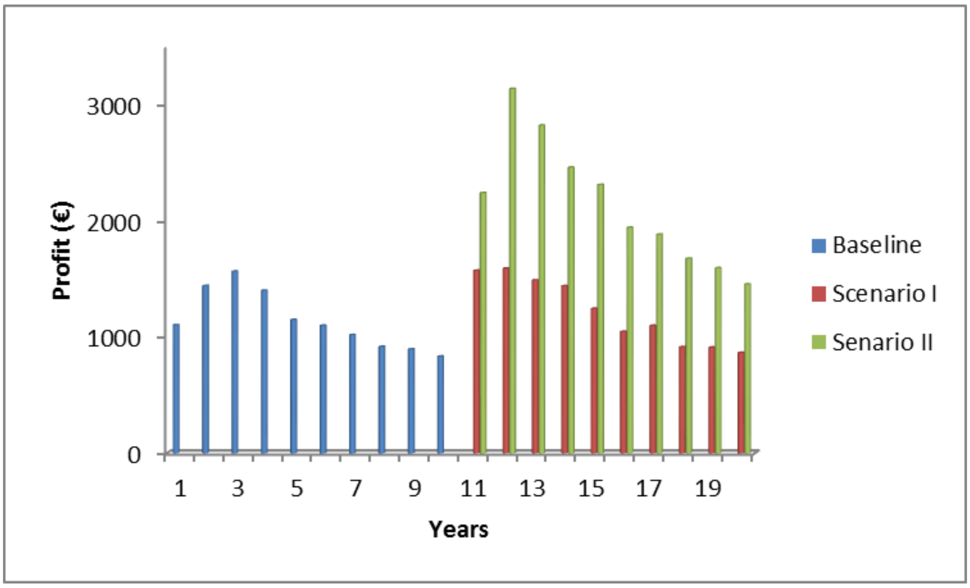

Figure 32: Simulated profit per year for baseline, scenario I and scenario II in AMS II for site 1.

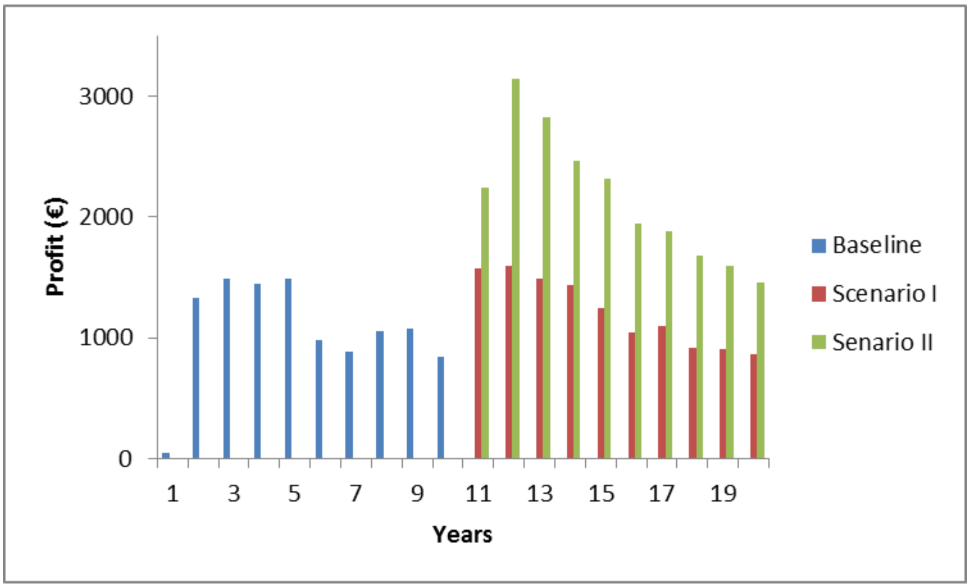

Figure 33: Simulated profit per year for baseline, scenario I and scenario II in AMS II for site 2.

Overall, the simulation model demonstrates that increase in feed supply and increase in herd size alone do not result in increase of income. Therefore, production of improved forage crops has to be combined with appropriate finishing technology. This result of the model was supported by Abegaz et al. (2004), where the authors recommend introduction of finishing technology such as fattening of young sheep and selling animals after attaining optimum desired market weight to enhance the economic benefit of sheep production. The marketing price of animals is dependent on supply and demand, which is heavily influenced by the occurrence of religious and cultural festivals or occurrence of drought and weather shocks (Kassa et al., 2011). Therefore, the fattening program should coincide with socio-cultural and religious ceremonies to market sheep with better price. It has been recommended to use improved forage crop production as an appropriate measure to boost animal production and overall agricultural productivity under the existing farming systems in Ethiopia (Getenet et al., 2011). However, according to the model it has to be incorporated with appropriate fattening strategies that can reduce production costs and result in higher returns. Tegegne et al., (2011) have reported that improved forage production with appropriate finishing technology has significantly resulted in increase of smallholder farmers' income.

4.2.2- Sensitivity analyses

In order to evaluate the robustness of the simulation model results a sensitivity analysis of labour cost, live weight price and proportion of young fattening was carried out. The sensitivity analysis for labour cost and live weight price resulted in a change of the gross profits and BCRs, but did not change patterns of behaviour, because there was no feedback of economic (labour cost and live weight price) to the management decisions of the model. However, in addition to the change in gross profit and BCRs, the change in the proportion of young fattening resulted in a slight change of the herd composition, but the trend of herd size remained the same since the simulation model was balancing the herd dry matter demand and supply. In scenario II, it was formulated that half of the male lambs go to fattening and the other half proceed to the young ram stage to replace culled breeding rams and to be sold as male replacements. As a result the sensitivity analysis, the proportion of young fattening affects the number of young rams which further affects the number of breeding rams.

The sensitivities are discussed relative to the gross profit and BCRs provided in Table 9 for baseline, scenario I and scenario II for sites 1 and 2. Table 10 and 11 provide gross profits and BCRs for the baseline, scenario I and scenario II in change of labour cost, live weight price, and proportion of young fattening for sites 1 and 2 respectively, in AMS I and AMS II. The model was sensitive to the change in the model variables. The increase in labour cost resulted in decrease of the gross profit and BCRs. In both sites the model was very sensitive to a change in live weight price, resulting in an increase of gross profit while live weight price increased by 20%, and in a decrease of gross profit when live weight price decreased with the same rate. The higher sensitivity of the model to live weight price is caused by the fact that live weight price does not has any influence on the model variables that can affect the model decisions such as costs or number of animals. So it affects only the revenue from sold animals and the costs remain unaffected. The increase in live weight price in AMS II resulted in a higher gross profit which can be explain by the sale of more animals when compare to

AMS I due to the larger herd size in AMS II. The sensitivity to the live weight price indicates that smallholder farmers can increase their income if they sell their animals at higher prices. However this is not always true since formal and systematic small ruminant marketing strategy is lacking (Gizaw et al., 2010a). Most often small holder farmers sell their animals in emergency cash need with lower price due to the higher flock supply to the market (Ayele et al., 2006; Kassa et al., 2011).

The model was also somehow sensitive to the changes in proportion of young fattening that resulted in increase of the gross profit, when the proportion of young fattening was increased by 20%. An alternative to be benefited more from the young lamb fattening scenario can be selling of fattened animals in socio-cultural and religious ceremonies, when animal can be sold with good price for meat. But, the increase in proportion of young fattening has to be consistent with the available number of breeding rams, since it can result in subsequent shortage of breeding rams in the long run. Overall, the sensitivity analysis revealed that changes in the marketing price of live animals and labour cost can affect the profitability of sheep production at smallholder level. The sensitivity of proportion of young fattening indicated that young fattening was the important scenario to boost the profitability of the system. It also shows that smallholder farmers can benefit from fattening of young animals rather than marketing young male animals as replacement, which is the current practice.

Table 10: Gross profit and Benefit cost ratio for baseline, scenario I and scenario II with changes in labour cost, live weight price and proportion of YF (young fattening) in alternative management system I (AMS I) for sites 1 and 2.

		Gross profit (€/herd size/month)			Benefit cost ratio (BCR)		
	Level	Baseline	Scenario I	Scenario II	Baseline	Scenario I	Scenario II
Site 1							
Labour cost (€)	+20%	128(98)	142(95)	183(86)	1.8(0.64)	1.86(0.67)	2.14(0.58)
	-20%	157(96)	169(95)	242(87)	2.24(0.81)	2.40(0.86)	2.60(0.75)
Live weight price (€)	+20%	195(113)	212(111)	291(99)	2.31(0.81)	2.51(0.87)	2.72(0.74)
	-20%	81(79)	93(78)	124(71)	1.57(0.55)	1.70(0.58)	1.84(0.51)
Proportion of YF (%)	+20%	-	-	257(88)	-	-	2.39(0.62)
	-20%	-	-	179(85)	-	-	2.15(0.63)
Site 2							
Labour cost (€)	+20%	101(95)	133(99)	236(110)	1.45(0.45)	1.61(0.48)	2.08(0.53)
	-20%	137(98)	165(96)	268(107)	1.73(0.55)	1.90(0.56)	2.46(0.63)
Live weight price (€)	+20%	179(125)	221(115)	341(133)	1.86(0.64)	2.09(0.61)	2.68(0.69)
	-20%	54(76)	82(77)	164(88.1)	1.27(0.39)	1.42(0.40)	1.83(0.47)
Proportion of YF (%)	+20%	-	-	299(104)	-	-	2.30(0.59)
	-20%	-	-	211(101)	-	-	2.06(0.53)

[a]Figures in brackets are standard deviation

Table 11: Gross profit and Benefit cost ratio for baseline, scenario I and scenario II with changes in labour cost, live weight price and proportion of YF (young fattening) in alternative management system II (AMS II) for sites 1 and 2.

		Gross profit (€/herd si e/month)			Benefit cost ratio (BCR)		
	Level	Baseline	Scenario I	Scenario II	Baseline	Scenario I	Scenario II
Site 1							
Labour cost (€)	+20%	124(129)	130(122)	211(154)	1.50(0.49)	1.56(0.51)	2.13(0.57)
	-20%	163(130)	170(122)	324(153)	1.79(0.60)	1.88(0.62)	2.54(0.69)
Live weight price (€)	+20%	210(156)	218(147)	350(179)	1.87(0.62)	1.98(0.64)	2.69(0.71)
	-20%	63(103)	73(101)	200(123)	1.28(0.42)	1.35(0.44)	1.82(0.49)
Proportion of YF (%)	+20%	-	-	301(143)	-	-	2.30(0.60)
	-20%	-	-	255(148)	-	-	2.11(0.63)
Site 2							
Labour cost (€)	+20%	124(153)	147(145)	251(167)	1.36(0.42)	1.44(0.43)	1.82(0.50)
	-20%	187(149)	194(144)	307(167)	1.52(0.48)	2.15(0.48)	2.29(0.58)
Live weight price (€)	+20%	222(167)	258(175)	346(192)	1.68(0.50)	1.82(0.56)	2.27(0.63)
	-20%	65(117)	72(114)	168(135)	1.15(0.35)	1.24(0.36)	1.55(0.45)
Proportion of YF (%)	+20%	-	-	313(151)	-	-	2.33(0.52)
	-20%	-	-	246(172)	-	-	1.80(0.55)

[a]Figures in brackets are standard deviation

4.2.3- Smallholder farmers' perception on the alternative management systems

The challenges and opportunities of the alternative management systems were discussed with smallholder farmers on the workshop held in June 2013. The main focus of AMS I is to increase the dry matter supply by introducing improved forage production, thus smallholders can keep large herd size and increase their income due to genetic selection. This scenario is accepted by some resourceful farmers from site 2. However, this alternative management system is not well perceived by the smallholder farmers from site 1. Smallholder farmers are aware that with increase feed supply the body condition of their animals can be improved; this can result in good marketing price, better wool production and skin quality. However, forage seed shortage, high seed cost and additional forage production costs (labour) are some of the constraints mentioned by smallholder farmers. In addition to this, small land holding and extended family size are the challenges for feasibility of management system.

Crop failure and drought due to the extreme and unpredicted weather conditions in Menz area, sheep production can be a potential, since Menz sheep is well adapted to this harsh environment. In addition to this, smallholders in both reference sites witnessed that since the community-based sheep breeding started they have seen positive change in body size and health condition of their sheep herd which led to generation of better income. Therefore, it was assumed that AMS II can represent a system with strong sheep breeding and limited crop production. Smallholder farmers are aware that with the reduction trend in crop production and the high potential of sheep production in the area, this management system can have a positive impact. Smallholder farmers mention that rotation of crop and forage production can lead to improved fertility of soil that can result in increase of yield. However, this management system is not considered to be feasible by the smallholder farmers in both sites due to the challenges mentioned for AMS I and the higher competition for land by forage and crop.

In addition to the improvement in livestock productivity, Getenet (1999), Kassie (2011) and Tegegne et al. (2011) reported that forage development increases groundcover and protects soil from rainwater run-off and encourages water infiltration, which improves the soil fertility. On the other hand, expansion of forage development technologies can promote the introduction of market-oriented livestock production systems (Getahun, 2008). In this case young fattening can emerge as key business oriented commodity which might be result in significant changes in the income of smallholder farmers. The challenges mentioned by the smallholders for forage production were supported by Benin et al. (2002), Gebremedhin et al. (2003) and Abule et al. (2011) were the small land owned by smallholders, the higher dependence of communal resources and the insufficient knowledge and awareness has contributed to poor adoption of improved forage crop production. On the other hand, forage legume intercropping with cereals has shown improvement in fodder quantity and quality (Kassie, 2011).

Smallholder farmers mention that they can benefit from young lamb fattening and sale of female replacement together with production of improved forage. However, smallholder farmers discussed that natural disasters such as drought, frost and shortage of rain will affect also the forage production as it affects the barley crop production. According to a review by Nardone et al. (2010), due to climate change a relevant increase of drought is expected across the world that would affect forage and crop production. Therefore, introduction of drought and frost resistant forge crops are very crucial. As Gebremedhin et al. (2003) suggested development and use of high-yielding crop varieties and intensive crop management practices can enhance the use of improved forage production by releasing land for forage production.

Overall, moving towards the strong sheep production with limited crop production was not well perceived by smallholder farmers in the study area, due to the competition for resources (land, labour and seed cost) with crop production and the extended family size. In addition, lack of input supply is mentioned as a challenge that limits the feasibility of forage production at smallholder level. Yet, smallholder farmers are aware of the positive impact of additional feed supply on their herd.

4.3- Prediction of genetic gain in Menz sheep population

4.3.1- Baseline scenario

Based on the selection, genetic, biological and economic variables used, the model predicts annual genetic gain for the breeding goal traits considered in this simulation. It also calculates the rate of inbreeding and profit per ewe per year. For the baseline scenario the proportion of selected (%) male and female animals are approximated to 25-26 and 74-75. This also corresponds to the existing situation when farmers select rams based on the information from the herd-book and physical appearance of the animal. However, at the moment there is no selection on the female animals. The reason for inclusion of female replacement selection in this study is that, according to a recently held workshop, farmers are very willing to include female replacement selection in their sheep breeding program. The detailed description of the community-based sheep breeding program for this particular study site is documented in Mirkena (2010) and Gizaw et al. (2013a).

The breeding ewe and ram population shows a trend to decrease (Figure 34) throughout the simulation period. This is because of the predicted annual genetic gain for six month weight was additive to the initial values given prior simulation starts. This results in an accumulated increase of body weight and dry matter intake. Therefore, whenever the dry matter demand exceeds the dry matter supply young ewes were discarded from the system to establish the herd at equilibrium by balance the dry matter demand and supply. However, the genetic selection for fertility rate and pre-weaning survival rate does not result in increase of the sheep population beyond the optimum due to the goal seeking archetype of the simulation model. But, it results in increase of young animals sold because of the increase in the number of lambs born and lambs weaned. An oscillation pattern of behaviour is observed in the sheep population in a monthly basis, which is due to the seasonal feed supply which led to increase and decrease of the sheep population in the vegetative and dry season respectively.

The simulated male and female generation interval was 2.60 year and 3.50 year respectively, which resulted in 3.05 year of average generation interval. The predicted annual genetic gain for six month weight (kg) ranges from 0.213 to 0.214 and is presented in Figure 35 with respective standard deviations. Gizaw et al. (2009) calculated an annual genetic gain of 0.30 for six month weight (kg) in Washera sheep breed reared under subsistence production systems, where 3-6 month lambs are produced for sale.

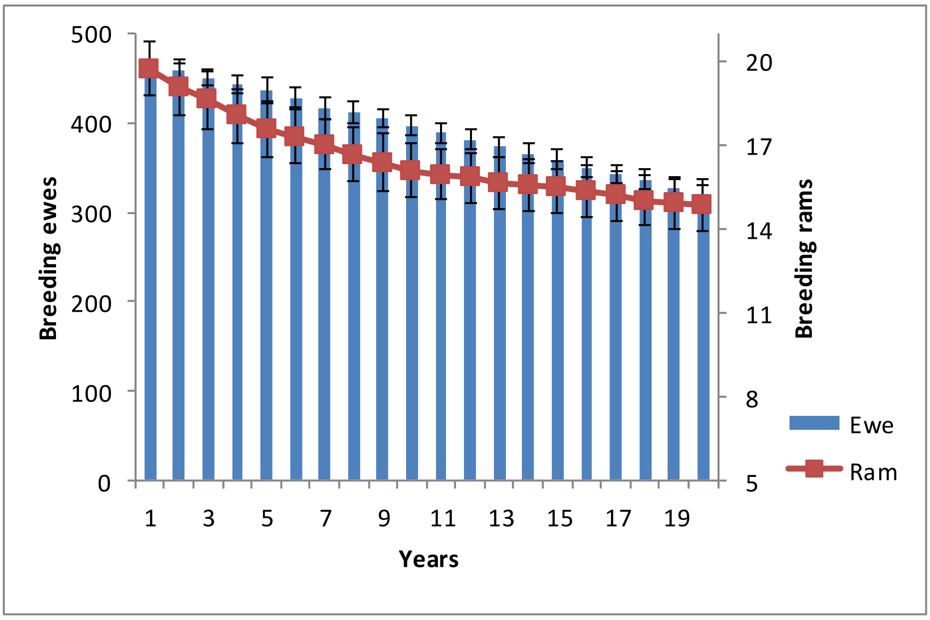

Figure 34: Simulated breeding ewe and breeding ram population with respective standard deviations in the baseline scenario.

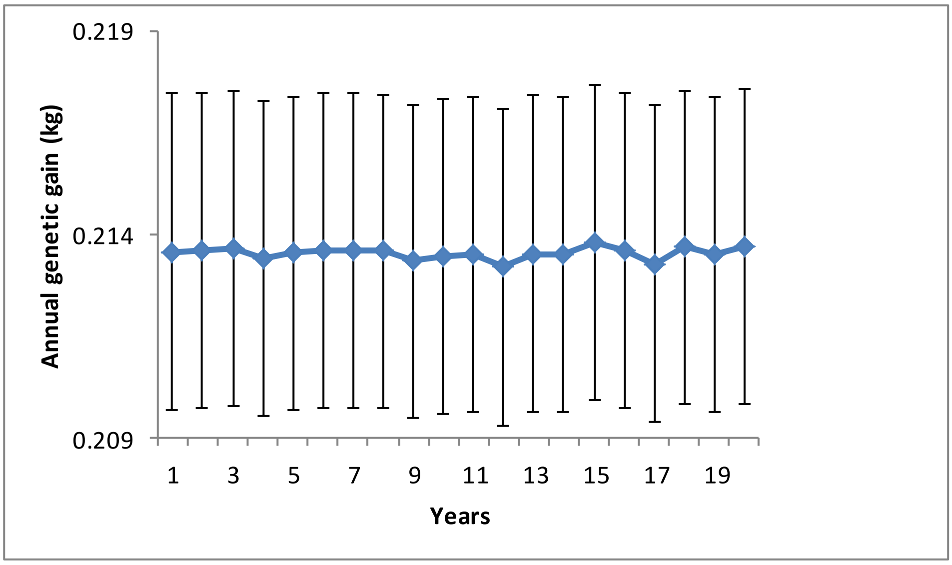

Figure 35: Simulated annual genetic gain for six month weight with respective standard deviations in the baseline scenario.

Figure 36 and 37 present the simulated annual genetic gain for pre-weaning survival and fertility rate with respective standard deviations. The estimated annual genetic gain for pre-weaning survival rate (%) was between 0.255 and 0.256 and is higher in this study compared to estimates for Washera sheep breed (Gizaw, et al. 2010b). This could be probably related to the higher additive genetic standard deviation, which was calculated from the herd-book in this study. An annual genetic gain of 0.063(±0.001) is predicted for fertility rate (%).

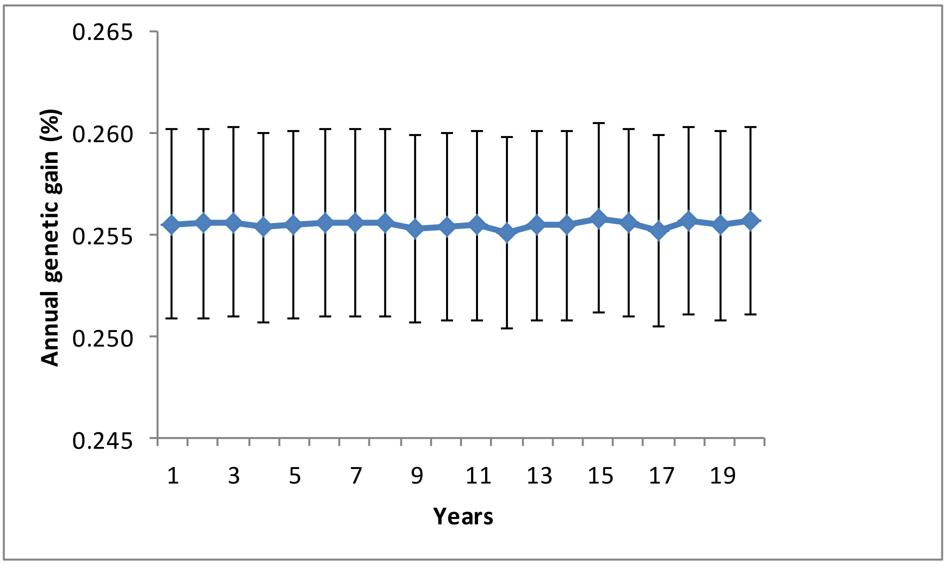

Figure 36: Simulated annual genetic gain for pre-weaning survival with respective standard deviation the baseline scenario.

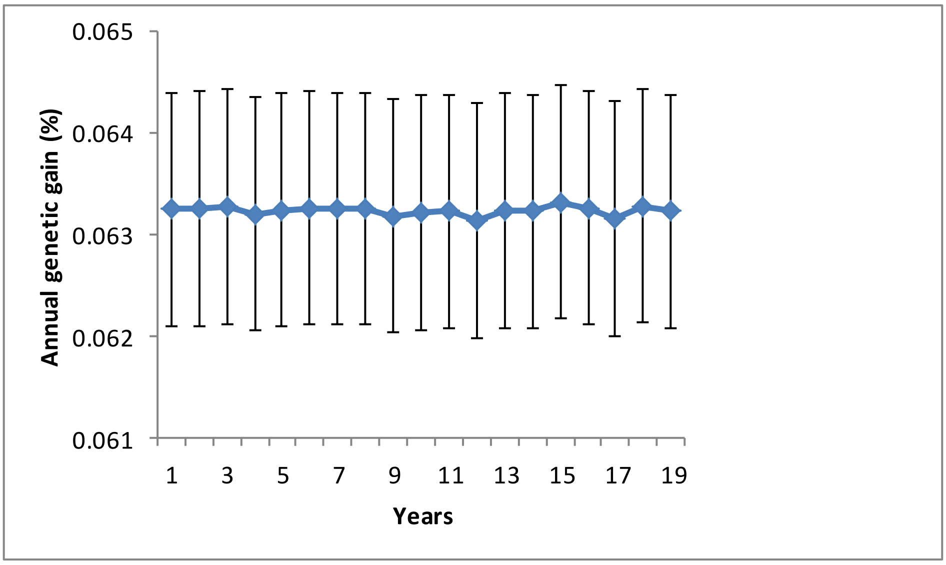

Figure 37: Simulated annual genetic gain for fertility rate with respective standard deviation the baseline scenario.

In contrast to the six month weight and pre-weaning survival rate, the predicted annual genetic gain of fertility rate was lower. This is due to the low heritability of the trait that is more controlled by the management practices (Safari et al., 2005). Therefore, by improving the animal husbandry practices (feeding and health) in combination to the genetic selection more benefit can be gained from this functional trait. In general, the simulation model demonstrates a reasonable annual genetic gain that can be achieved under farm level in community-based sheep breeding programs.

Six month weight (kg) is improved from 18.48(±0.060) to 22.76(±0.065) in 20 years of selection period. Correspondingly, pre-weaning survival (%) and fertility rate (%) are increased from 93.77(±0.41) to 98.88(±0.41) and 88.02(±0.02) to 89.28(±0.02) in 20 years of genetic selection. This indicates that considering the available resources and management systems a reasonable change in average performance of a sheep herd due to genetic selection can be achieved in community-based sheep breeding schemes under smallholder circumstance. However, smallholder farmers tend to sell the best male animals of the herd because they fetch good price. This can result in lack of genetic progress at the smallholder levels where subsistence low-input production systems are practiced. In order to avoid this, ram selection events are carried out at least three times a year before the major festivals to retain the best male animals in the village herd as a breeding rams.

According to Simm (2000) the number of selected male and female animals or male and female animals entering the population every year, are used to calculate the rate of inbreeding per year and are presented in Figure 38. The decreasing trend in number of selected animals observed corresponds to the decreased number of breeding ewes and then results in smaller numbers of candidate animals. Figure 39 shows the simulated rate of inbreeding (%) and effective population size in the simulation period of 20 years. The predicted rate of inbreeding (ΔF) per year is ranging from 0.094 % to 0.116%. An increase trend in rate of inbreeding is observed due to the steady rate decrease the herd size as a result of genetic selection.

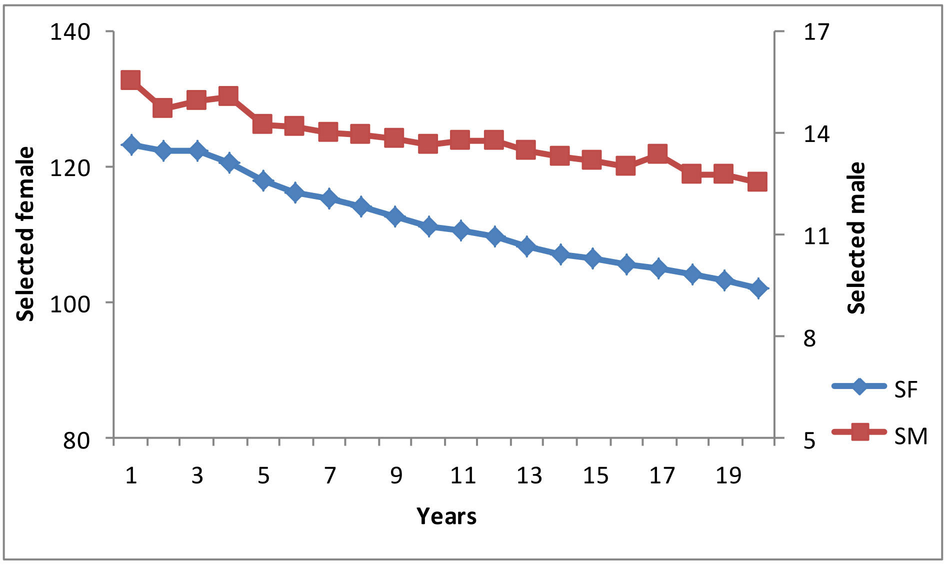

Figure 38: Simulated number of selected male (SM) and female (SF) animals in the baseline scenario.

The simulated effective population size in this study ranges from 76 to 57 under the proportion of 25%-26% and 74%-75% male and female selected respectively. Gizaw et al.

(2009) reported an effective population size ranging between 121.9 and 18.5 varying in the proportion of rams selected from 30% to 5%. The estimated rate of inbreeding presented in this study is lower than the accepted level per generation which is 1%. Acceptable levels of inbreeding are difficult to determine and following to Gizaw et al. (2009), Mirkena et al. (2012) and Wurzinger et al. (2008), in this study 1% rate of inbreeding per year is taken as acceptable level. Mirkena et al. (2012) estimated 0.33 and 0.50 rate of inbreeding per generation under 10% and 15% of ram selection proportion. An inbreeding rate of 1.35% under 10% of selection proportion was also estimated in village-based sheep breeding scheme (Gizaw et al., 2009). Wurzinger et al. (2008) reported 0.08 to 0.32% of inbreeding rate per generation for different schemes in a breeding program designed for Bolivian llama, where the proportion of selected males was ranging from 4.4% to 18.9%.

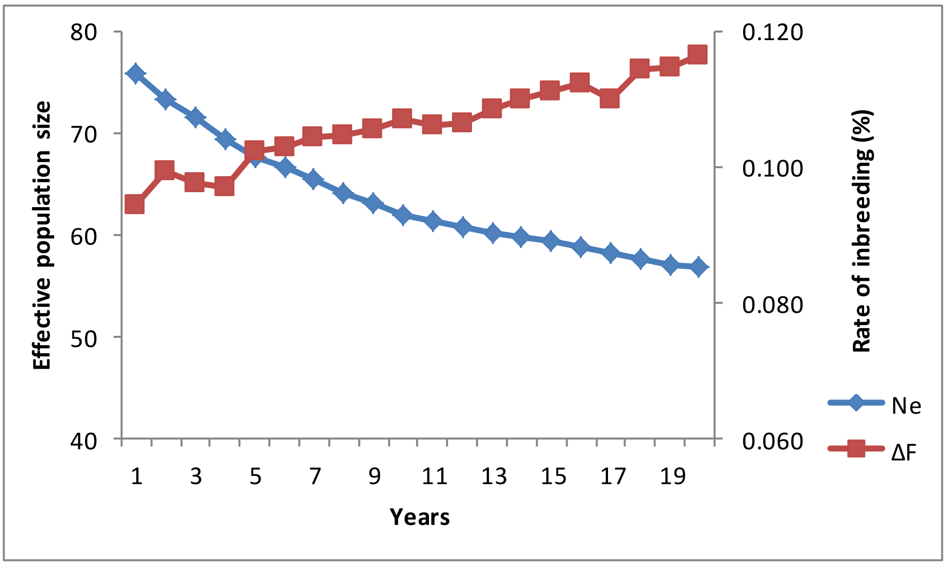

Figure 39: Simulated effective population size (N_e) and rate of inbreeding (ΔF) in the baseline scenario.

Figure 40 shows the profit per ewe per year throughout the selection period. The profit is obtained from the difference between returns and costs. Therefore, the returns do not include the whole returns obtained from the farm output, but the extra returns obtained as a result of the genetic selection. The predicted profit per ewe per year is 0.11(±0.01) €. As discussed in the methodology part the economic response is directly linked to the predicted annual genetic gain, as it was obtained as multiplication product of annual genetic gain and economic value. The estimated profit in this study is lower when compared to estimates for Menz sheep breed (Mirkena et al., 2012) and Washera sheep breed (Gizaw et al., 2010b). This can be explained by the difference in predicted annual genetic gain and used economic weights.

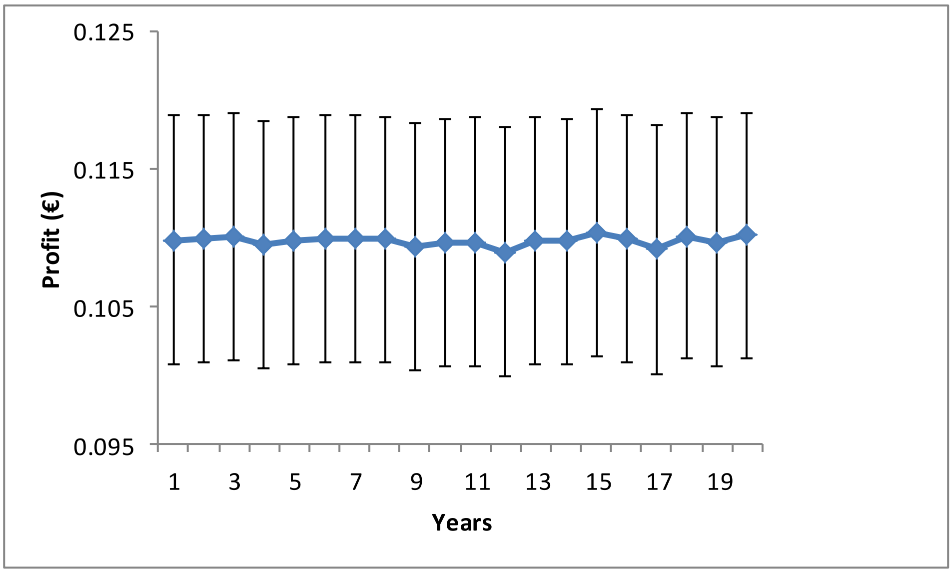

Figure 40: Simulated profit per year per ewe (€) with respective standard deviations in the baseline scenario.

4.3.2- Scenario analyses

Two scenarios were simulated to evaluate the effect of strict and loose selection intensities on the estimates of annual genetic gain, rate of inbreeding and profit per ewe per year. The proportion of selected male and female animals were decreased and increased by 10% to enable the model to capture the reality as much as possible. At smallholders' level, there is no fixed selection intensity and the proportion of selected individuals varies from one selection event to the other. Therefore, the stochasticity of the simulation model and the scenario analysis captures the diverse situation of smallholders and represents the reality as close as possible.

The simulated proportions of selected male and female animals are presented in Table 12. Since more strict selection was applied in scenario I, the proportions of selected male and female animals (%) decrease to 14-15 and 64-65, respectively. In Scenario II, the proportions of selected male and female animals (%) are increased to values of 34-35 and 84-85 respectively. The results from the scenario analysis are discussed relative to the baseline scenario. A higher number of breeding ewes and breeding rams are obtained in the scenario II (Figure 41 and 42), when proportions of selected male and female animals increase by 10%.

Table 12: Proportion of selected male and female animals (%) in the scenario I and II.

Years	Scenario I		Scenario II		Years	Scenario I		Scenario II	
	Male	Female	Male	Female		Male	Female	Male	Female
1	14	64	34	84	11	15	64	34	84
2	14	64	35	84	12	15	64	35	84
3	14	65	34	84	13	14	65	35	85
4	14	64	34	85	14	15	65	35	84
5	14	64	34	85	15	14	64	35	84
6	15	65	35	85	16	15	65	35	85
7	15	65	35	85	17	14	65	35	84
8	15	65	35	84	18	15	64	34	85
9	14	65	35	85	19	15	65	35	84
10	15	65	35	84	20	15	64	34	85

[a]Figures in brackets are standard deviation

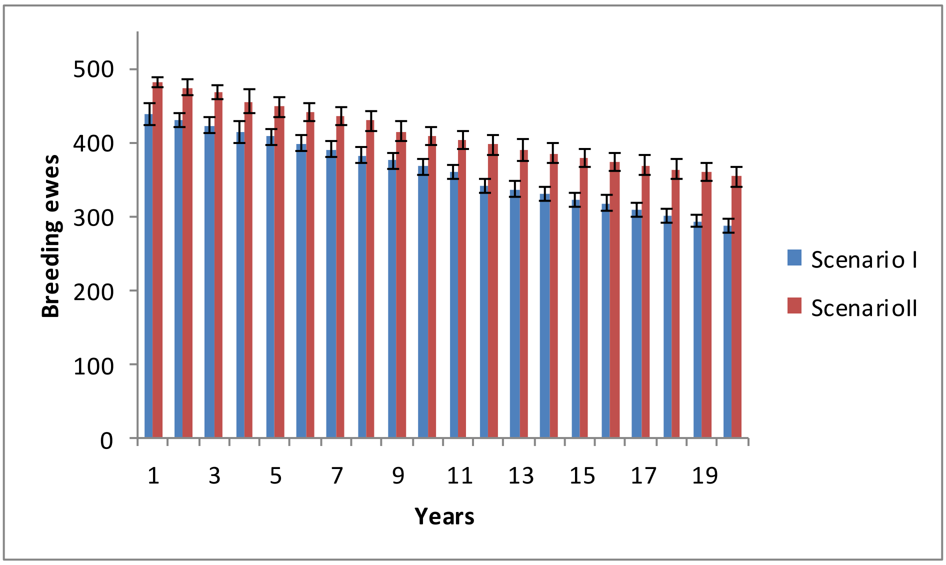

Figure 41: Simulated breeding ewe population with respective standard deviation in scenario I and II.

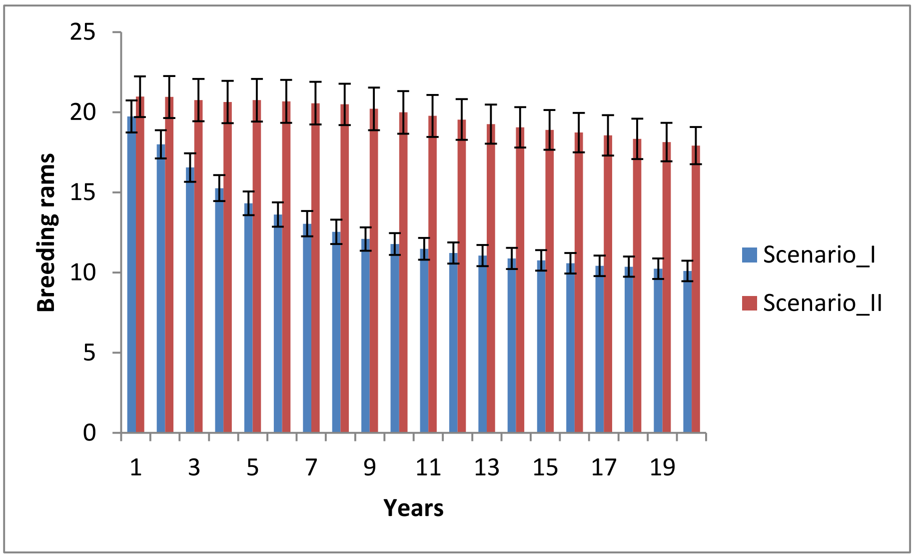

Figure 42: Simulated breeding ram population with respective standard deviation in scenario I and II.

The numbers of selected male and female animals joining the breeding population in the period of simulation are presented in Table 13. In contrast to the baseline scenario the number of male and female animals decrease with the strict selection and the opposite was true in scenario II.

Table 13: The number of male and female animals joining the breeding population every year in the scenario I and II.

Years	Scenario I		Scenario II		Years	Scenario I		Scenario II	
	Male	Female	Male	Female		Male	Female	Male	Female
1	8(1)	99(1)	23(3)	151(1)	11	7(1)	83(1)	21(3)	135(1)
2	8(1)	97(1)	23(3)	150(1)	12	7(1)	82(1)	20(3)	133(1)
3	8(1)	96(1)	23(3)	150(1)	13	7(1)	81(1)	20(3)	132(1)
4	8(1)	94(1)	22(3)	148(1)	14	7(1)	80(1)	20(3)	130(1)
5	8(1)	91(1)	22(3)	144(1)	15	7(1)	79(1)	20(3)	129(1)
6	7(1)	90(1)	21(3)	141(1)	16	7(1)	78(1)	19(3)	128(1)
7	7(1)	88(1)	21(3)	142(1)	17	7(1)	76(1)	19(3)	127(1)
8	7(1)	88(1)	21(3)	139(1)	18	6(1)	76(1)	19(3)	127(1)
9	7(1)	86(1)	21(3)	137(1)	19	6(1)	75(1)	19(3)	125(1)
10	7(1)	84(1)	21(3)	136(1)	20	6(1)	74(1)	19(3)	126(1)

[a]Figures in bracket are standard deviations

Table 14 shows change in annual genetic gain of six month weight and pre-weaning survival rate in scenarios I and II. Higher genetic gain is obtained with more strict selection. The annual genetic gains from six month weight (kg) and pre-weaning survival rate (%) are raised to 0.23(±0.03) and 0.277(±0.004) respectively. Six month weight (kg) is improved to 23.21(±0.07) and to 22.35(±0.062) in scenario I and II respectively (Figure 43). Pre-weaning survival rate (%) is also improved to 100(±0.28) and 97.72(±0.21) both in scenario I and II (Figure 44).

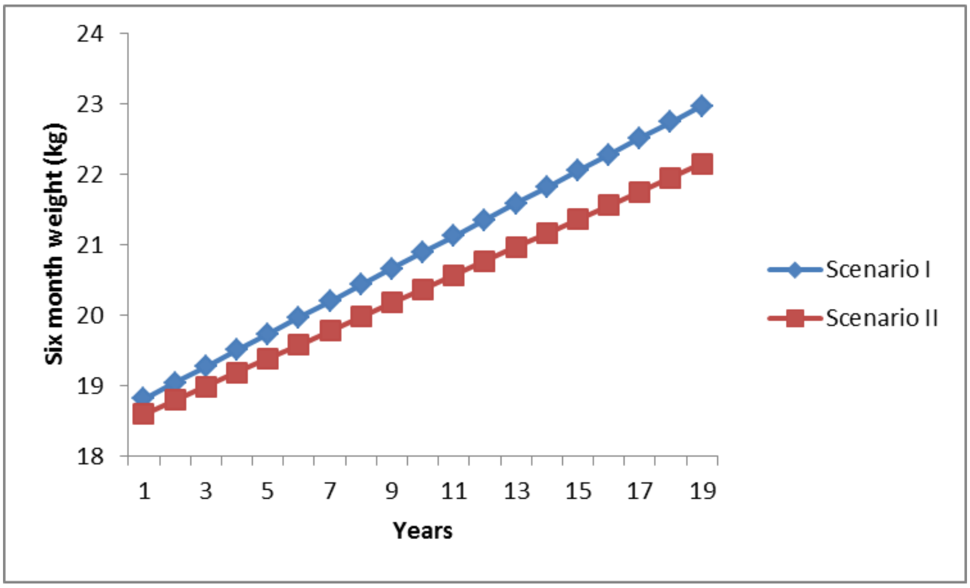

Figure 43: Simulated genetic improvement trend for six month weight in scenario I and II.

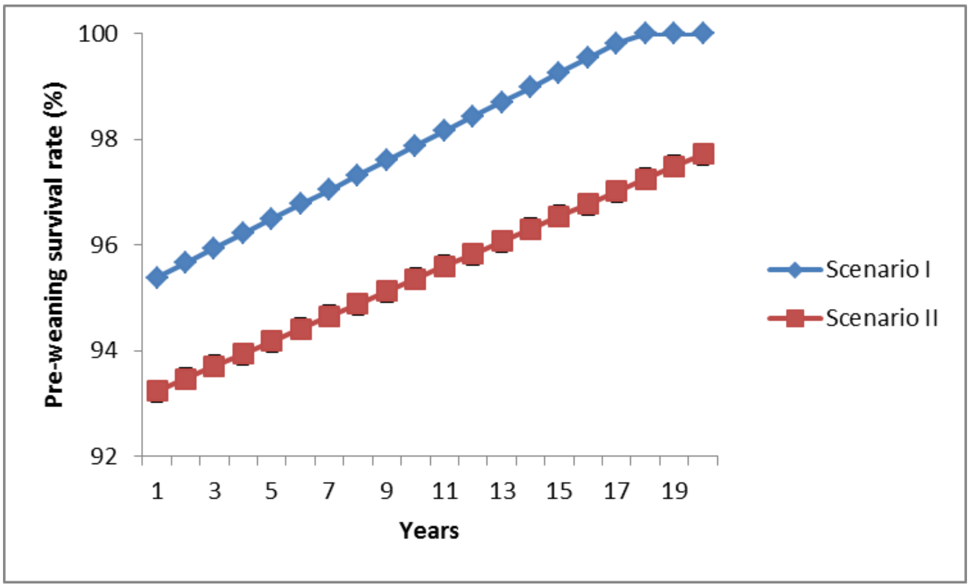

Figure 44: Simulated genetic improvement trend for pre-weaning survival rate in scenario I and II.

Table 14: Simulated annual genetic gain of six month weight (kg) and pre-weaning survival rate (%) in scenario I and II.

Year	Six month weight		Pre-weaning survival rate		Year	Six month weight		Pre-weaning survival rate	
	Scenario I	Scenario II	Scenario I	Scenario II		Scenario I	Scenario II	Scenario I	Scenario II
1	0.232(0.003)	0.198(0.004)	0.277(0.004)	0.237(0.005)	11	0.232(0.003)	0.198(0.004)	0.277(0.004)	0.237(0.005)
2	0.231(0.003)	0.198(0.004)	0.277(0.004)	0.237(0.005)	12	0.232(0.003)	0.198(0.004)	0.277(0.004)	0.237(0.005)
3	0.232(0.003)	0.198(0.004)	0.277(0.004)	0.236(0.005)	13	0.231(0.003)	0.198(0.004)	0.277(0.004)	0.236(0.005)
4	0.232(0.003)	0.198(0.004)	0.277(0.004)	0.237(0.005)	14	0.232(0.003)	0.198(0.004)	0.277(0.004)	0.237(0.005)
5	0.232(0.003)	0.198(0.004)	0.277(0.004)	0.236(0.005)	15	0.232(0.003)	0.198(0.004)	0.277(0.004)	0.236(0.005)
6	0.231(0.003)	0.198(0.004)	0.277(0.004)	0.236(0.005)	16	0.232(0.003)	0.198(0.004)	0.277(0.004)	0.236(0.005)
7	0.231(0.003)	0.197(0.004)	0.277(0.004)	0.236(0.005)	17	0.231(0.003)	0.198(0.004)	0.277(0.004)	0.237(0.005)
8	0.231(0.003)	0.198(0.004)	0.277(0.004)	0.237(0.005)	18	0.232(0.003)	0.198(0.004)	0.277(0.004)	0.236(0.005)
9	0.232(0.003)	0.198(0.004)	0.277(0.004)	0.237(0.005)	19	0.231(0.003)	0.198(0.004)	0.277(0.004)	0.237(0.005)
10	0.231(0.003)	0.198(0.004)	0.277(0.004)	0.237(0.005)	20	0.232(0.003)	0.197(0.004)	0.277(0.004)	0.236(0.005)

[a]Figures in bracket are standard deviations

The simulated annual genetic gain for fertility rate and the profit per ewe per year are presented in Table 15. Similarly, higher annual genetic gain in scenario I (0.069±0.001) and lower annual genetic gain in scenario II (0.059±0.001) are achieved for fertility rate (%). Fertility rate (%) is also increased to 89.45(±0.001) and 89.25(±0.001) in scenario I and II respectively (Figure 45). The simulated profit per ewe per year (€) is much higher with scenario I ranging between 0.151(±0.007) to 0.152(±0.007). The lowest profit per ewe per year (0.069-0.075€) is observed in scenario II when proportions of selected animals were increased. The lowest rate of inbreeding (%) per year and the highest effective population size are observed in scenario II. In contrast, the rate of inbreeding increases to about 0.224% and the effective population size decreases to about 39 in scenario I, when selection intensity of animals was increased. A summary of this is given in Table 16.

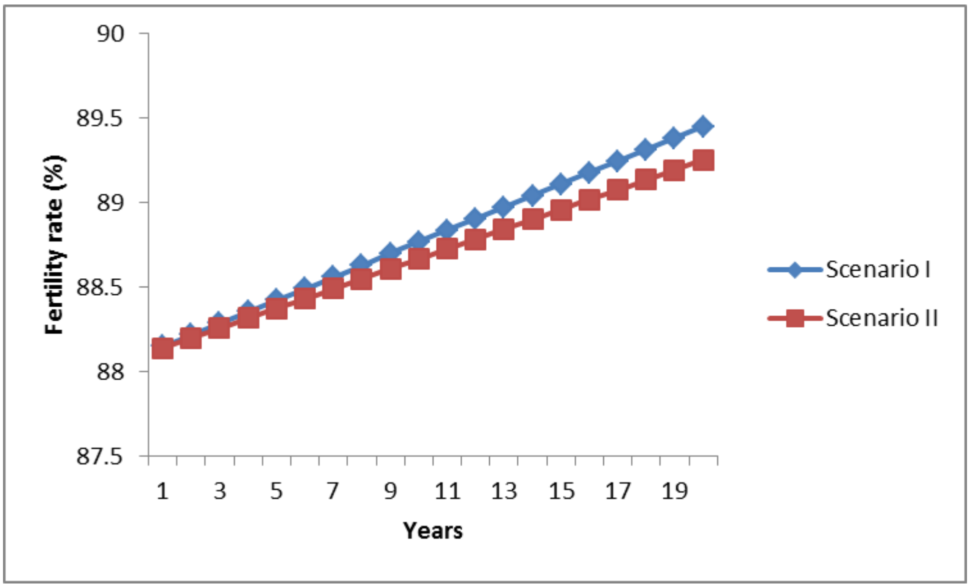

Figure 45: Simulated genetic improvement trend for fertility rate in scenario I and II.

Table 15: Simulated annual genetic gain of fertility rate and simulated profit per ewe per year in scenario I and II.

Year	Fertility rate		Profit		Year	Fertility rate		Profit	
	Scenario I	Scenario II	Scenario I	Scenario II		Scenario I	Scenario II	Scenario I	Scenario II
1	0.069(0.001)	0.059(0.001)	0.151(0.007)	0.084(0.010)	11	0.069(0.001)	0.059(0.001)	0.152(0.007)	0.084(0.010)
2	0.068(0.001)	0.059(0.001)	0.151(0.007)	0.084(0.010)	12	0.069(0.001)	0.059(0.001)	0.152(0.007)	0.084(0.010)
3	0.069(0.001)	0.059(0.001)	0.152(0.007)	0.083(0.010)	13	0.068(0.001)	0.059(0.001)	0.151(0.007)	0.083(0.010)
4	0.069(0.001)	0.059(0.001)	0.152(0.007)	0.084(0.010)	14	0.069(0.001)	0.059(0.001)	0.152(0.007)	0.084(0.010)
5	0.069(0.001)	0.059(0.001)	0.152(0.007)	0.083(0.010)	15	0.069(0.001)	0.059(0.001)	0.152(0.007)	0.083(0.010)
6	0.069(0.001)	0.059(0.001)	0.151(0.007)	0.083(0.010)	16	0.069(0.001)	0.059(0.001)	0.151(0.007)	0.083(0.010)
7	0.069(0.001)	0.058(0.001)	0.151(0.007)	0.083(0.010)	17	0.068(0.001)	0.059(0.001)	0.151(0.007)	0.084(0.010)
8	0.068(0.001)	0.059(0.001)	0.151(0.007)	0.084(0.010)	18	0.069(0.001)	0.059(0.001)	0.152(0.007)	0.083(0.010)
9	0.069(0.001)	0.059(0.001)	0.152(0.007)	0.084(0.010)	19	0.068(0.001)	0.059(0.001)	0.151(0.007)	0.084(0.010)
10	0.069(0.001)	0.059(0.001)	0.151(0.007)	0.084(0.010)	20	0.069(0.001)	0.058(0.001)	0.152(0.007)	0.083(0.010)

[a]Figures in bracket are standard deviations

Table 16: Simulated effective population size and rate of inbreeding per year (%) in the scenario I and II.

Year	Effective population size		Rate of inbreeding		Year	Effective population size		Rate of inbreeding	
	Scenario I	Scenario II	Scenario I	Scenario II		Scenario I	Scenario II	Scenario I	Scenario II
1	76	80	0.169	0.066	11	44	79	0.200	0.073
2	69	82	0.176	0.068	12	43	78	0.202	0.073
3	64	84	0.176	0.065	13	43	77	0.203	0.074
4	59	83	0.180	0.067	14	42	76	0.212	0.075
5	55	83	0.185	0.068	15	42	76	0.205	0.076
6	53	83	0.189	0.070	16	41	75	0.209	0.077
7	50	83	0.191	0.069	17	40	74	0.215	0.077
8	49	82	0.192	0.071	18	40	73	0.218	0.078
9	47	81	0.198	0.072	19	40	73	0.215	0.079
10	46	80	0.198	0.072	20	39	72	0.224	0.078

The simulated rate of inbreeding and the effective population size in this study are under the assumption of random mating and could be underestimated. The simulation outputs indicate that reasonable genetic gain with acceptable rate of inbreeding could obtain under farm level. As expected, the simulation model was responsive to strong selection and use of few breeding rams which results in higher annual genetic gain, rate of inbreeding per year and profit per ewe per year. Smallholders can benefit from scenario I in gaining higher genetic gain which will lead to higher income. However, the predicted rate of inbreeding was also slightly higher in this scenario and can increase even more in the long-term selection. In this case exchange of breeding rams among the community members is advisable as it is practiced currently, for both controlling inbreeding and for dissemination of genetic gain among all community members. Hence, it has to be clearly defined that for how long farmers can keep a breeding ram in their herd and then transferred it to another herd. It is necessary to have ram exchange rules and regulations in the community for equal distribution and efficient use of selected breeding rams by all members of the community based sheep breeding scheme. The community in collaboration with experts from Debre-Berhan research centre carried out ram selection at least three times a year, and thus live weight and physical appearance are some of the selection criteria used to select best animals for breeding.

The simulation model demonstrates that smallholder farmers can increase their income by selecting superior replacements from better performing parents and culling inferior and low producing animals from the herd. Maintaining low performing animals that do not contribute to increase in economic response resulted in loss of profit. It is obvious that the performance of an animal is determined by the genetic merit of the animal and the production environment it is kept in (Yapi-Gnaoré et al., 2001; Gizaw et al., 2009). Therefore, in addition to the genetic selection based on the performance records, the animal husbandry system has to be improved. The feed gap needs to be filled by reducing flock size or by allocation of additional resources (Tibbo et al., 2006; Bogale et al., 2008). Traditional management practices and marketing systems have to be improved for better performance of animals and have higher profit (Ayalew et al., 2003; Gebremedhin et al., 2007; Gizaw et al., 2010a; Tegegne et al., 2011).

The simulation herd model presented here is built based on the existing flock structure and breeding strategies in the Menz highland areas. The model explains the existing situation and the important feature of this model is the goal seeking archetype that resulted in a herd size at equilibrium. This means that the model is more usage driven and users can determine their maximum flock size based on the resource they have. The herd model is dry matter driven and when the herd dry matter demand exceeds the dry matter supply, the model sells the young female animals to establish the herd at equilibrium. This can result in subsequent shortage of female replacements in the long run, but this can be also easily modified based on the interest of the user.

The simulation model is potentially valuable in demonstrating the smallholders' circumstance in breeding, feeding and animal disposals in its stochastic feature. At smallholder level there is no strict selection, thus allowing the model to use random values is quite realistic. The model uses real data and selection is done based on the performance of the population obtained from the data. This is one of the benefits of this model rather than using fixed values of input variables. Users can define the time unit and selection period and the herd model can perform more than one round of selection.

The simulation model is convenient for further designing of breeding strategies and population structures, which can be easily plugged in to the existing model. Generally, the simulation model is simple, flexible and usage driven. Unlike the genetic gain calculated with deterministic models, additional information such as standard deviations and variances can be calculated from the outputs of the simulation model. This can be used for further interpretation of the model outputs.

Therefore, the simulation model used in this study has the potential to capture the real situation at smallholder level and the variability in breeding measures. It should be noted that to achieve higher genetic progress management aspects are crucial in addition to the genetic selection, since livestock production in the tropics is much linked to the environmental conditions. In this simulation model input parameters are not fixed values as in the case of the deterministic approach. This enables the model to capture the reality as much as possible. The simulation model describes the breeding, feeding and economic components of the breeding program; this also shows the valuable potential of system dynamics methods in describing complex systems, such as community-based breeding schemes.

4.4- Contribution and further development of the model

Computer simulation software tools are important in developing and applying scientific knowledge, which facilitate the learning of science. They provide opportunities to explore concepts and models which are not readily accessible or expensive to perform. Describing a system in a mathematical model is a very essential way of representing the linkages and interactions that make up a real-life system, which is very difficult to grasp via experiments (Ford, 1999; Deaton and Winebrake, 2000; Garcia, 2006). As a result each simulation model has advantages and disadvantages. No one model or method is universally applicable, and the applicability of a model is heavily influenced by the nature of the problem, outcomes of interest, the information and level of understanding already available, and the financial and human resources available (Nicholson, 2007). Therefore, multiple modelling approaches are can be used to build up the confidence of a model.

The simulation model developed in this study is based on a strong knowledge on the production system, breeding strategies and husbandry system of the Ethiopian highlands. It follows the stochastic approach to mimic the reality as close as possible, which is an accurate way to model complex systems. The stochastic feature of the developed simulation model used to describe the situation by generating normally distributed variations on the reproductive, mortality and live weight parameters depending on the resource supply. Comprehensive livestock simulation models have been developed to demonstrate production systems, herd dynamics and economic responses (Guimaraes et al., 2009; Mulindwa et al., 2011; Parsons et al., 2011; Tedeschi et al., 2011). However, in the simulation models the impact of seasonal feed fluctuation on population, reproductive performance and body condition of animals is inadequate, which is the main challenge to improve livestock productivity in the tropics and sub-tropical environments (Gatenby, 1986; Mapiliyao et al., 2012; Mapiye et al., 2009) was often missing.

A sheep population is a result of the relationship between births, deaths, purchases, sales, exchanges and consumptions (Mapiliyao et al., 2012). The simulation model handles those factors in a form of sheep inflows and outflows. The inflow accounted in this simulation model was birth, which resulted in increase of the sheep population. In addition to birth, it is documented that smallholders purchase animals in the early rainy season to compensate the animals disposed during the dry season (Getachew, 2008), which was lacking in this model. The outflows of the simulation model were deaths, culling and disposal of animals due to shortage of feed. However the simulation model does not account for purchase, exchange and home consumption of animals, in order to keep the model as simple as possible. Therefore, the model can be further more developed in order to include the additional sheep inflow and outflow measures. This shall lead to complete demonstration of the population dynamics.

It is clearly not possible to develop improved production systems without first studying the existing traditional system that provides a baseline standard with which to compare the proposed alternative management system. Besides, an understanding of the resource requirements and constraints of the existing system provides guidance as to which of the possible alternative technologies are appropriate and worth pursuing, and which are not. The simulation model also shows the impact of forage production on herd dynamics and it also evaluates the gross profit obtained due to improvement in livestock productivity because of the increase in feed supply. The economic analysis in the simulation model was general and only estimates the gross profit. Therefore more breakdowns of the costs and returns are required to get implication in the future perspective.

The simulation model also revealed the potential of system dynamics modelling methodologies in designing a breeding program. When it comes to breeding measures at smallholder level in the subsistence and low input production systems, they are not fixed unlike the commercial and well organized breeding companies. The stochastic feature of this model captured the existing breeding practices in the Menz area. The sale of best young male animals for meat contributes to lack of genetic progress at smallholder level. Thus, the simulation model captured this phenomenon by selecting animals before the religious festivals to retain the best male animals in the sheep herd as a breeding rams. The simulation model that dealt with exploring the potential of system dynamics in designing breeding program used as initial point and can be more developed to model different breeding strategies, population structures and alternative breeding plans in the community-based breeding of livestock populations.

There is a genetic correlation of body weight with wool yield (Gizaw et al., 2007a), which was not accounted by the simulation model. In the study area, there is significant seasonal difference in sheep price (Ayele et al., 2006) and the months where highest sheep price recorded are in September, December, January, March, and April/May due to the religious festival occurrence (Kassa et al., 2011). The simulation model used fixed sheep prices (€/kg of weight) which were generated from the questionnaire. The questionnaire regarding the sheep price was collected in the month of November, which can represent the season when farmers sell their animal with lower price. Therefore, formulating the model with updated seasonal price it might result in increase of the gross profit. However, the simulation model has to be improved in order to capture the correlated response in wool yield as selecting for live weight and the influence of season on sheep marketing price. In the mixed crop livestock production systems, smallholder farmers keep diversified livestock species (cattle, equines and small ruminants) (Getachew, 2008; Bogale et al., 2008) for multiple roles. This study focused on sheep production for the ease of modelling. Further development of the model could be done to be able to account for other livestock species in the study area. The model is dry matter driven and can be further formulated in order to account for nutrient supply and demand of the herd.

Model verification and validation has a critical importance in evaluating the relevance of the model in solving the objective of the model development (Ford, 1999; Mulindwa et al., 2011; Sterman, 2000; Deaton and Winebrake, 2000). However, model evaluation under tropical production systems can be a challenge since data availability and quality is limited. In this study evaluation of the model was based on technical behaviour, logic test and sensitivity analysis. Therefore, it is recommended to further work on the evaluation and validation of the model against field results to confirm the confidence of the model in describing the system as accurate as possible. In this case the complete feature of the model can be identified and a more refined model can be produced.

Models are simplifications of reality and none of the models demonstrate the reality complete. Therefore, the simulation model developed in this study was potentially useful in solving the research questions. Moreover, with further development and improvement a more complete and refined model can be produced.

Chapter 5- Conclusions and Recommendations

A dynamic, stochastic simulation herd model was developed adopting a system dynamics modelling approach. Matching herd size with available resources was a very important feature of the simulation model. The simulation model demonstrates that breeding for heavier animals has an impact on the herd dynamics and profitability of the system. As body weight increases through genetic selection, smallholders should keep smaller flocks unless feed resources are increased. Smallholders could increase income by fattening young animals coinciding with genetic selection. Based on the results of the model, it is recommended that voluntary culling of animals can be used as a measure to balance dry matter supply with dry matter demand of the herd to keep productive animals in the herd. However, this can be challenging for smallholder farmers since sheep are kept for multiple reasons. In this case alternative allocation of resources to young and highly productive groups of animals can be used in order to keep large flocks. The simulation model was well perceived by smallholder farmers. Smallholder farmers were aware of matching the herd size with available resource, and willing to reduce the flock as to benefit from sale of heavier animals.

Forage production was simulated by allocating a proportion of the crop land to vetch forage production to increase the feed supply of the system eventually which increases the herd size. Fattening of young animals was profitable when compared to the culled breeding ram fattening. This shows that smallholder farmers can gain more income by fattening young animals which resulted in decrease of costs of production (health, housing and labour) and feed compared to culled breeding ram fattening. However, there was no significant difference in gross profit from the young fattening scenario in both alternative management systems (AMS I and AMS II). The competition for resources (land and labour) with crop production, forage seed shortage and extended family size were the challenges raised by smallholders for growing forage. However, the simulation model showed that increase in feed supply with the appropriate fattening strategy can lead to regular income generation which might alleviate the disposal of animals with lower price. It has to be noted that introduction of improved forages to the community is quite dependent on other input services which are lacking now. Therefore, this model serves as a starting point and needs to be further developed.

System dynamics methodology has been widely used in other sectors but its application is limited in the context of designing breeding programs. The simulation model uses a stochastic simulation method which is an accurate approach to model complex systems such as breeding programs. In this simulation model input parameters are not fixed values as in the case of the deterministic approach, which enable the model to describe a system close to reality. The simulation model describes the complex setting of a breeding program and additional model outputs (standard deviation and variance) can be obtained, which can be used in further interpretation of the model outputs. The developed simulation model is very suitable for smallholders' situation, where animal breeding is linked to the environment, and where culling measurements and selection intensities are not constant from one section period to the other. The simulation model is also potentially valuable when more than one selection round is performed and to evaluate the genetic gain and rate of inbreeding trough out the simulation period step by step. As expected, the outputs of the simulation model were more or less influenced by the proportion of selected animals. The baseline scenario predicts reasonable annual genetic gain, rate of inbreeding and profit per ewe per year. The fastest progress in annual genetic gain and profit per ewe per year are achieved in scenario I with more strict selection. The developed herd model is simple, flexible and usage driven. It is valuable in mimicking the reality as much as possible. Therefore, it can be concluded that system dynamics modelling is a valuable tool to describe complex breeding programs.

Overall, the simulation model describes the production environment, breeding practices and feed resources in the Menz highlands of Ethiopia. The simulation model can be used as a first step for further demonstration of production systems and breeding practices in Ethiopia. Further work is needed in development and evaluation of the model which shall lead to further refinement. This shall eventually aid in the further evaluation of genetic selection in the Menz sheep population, helping smallholders to increase income.

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Appendices

Appendix 1: Equations used in the simulation model arranged in order of execution.

{VERSION 9.0.2, INITIALIZATION EQUATIONS}

{TIME SPECS: STARTTIME=0, STOPTIME=240, DT=0.25, INTEGRATION=EULER, RUNMODE=NORMAL, PAUSEINTERVAL=INF}

{ INITIALIZATION EQUATIONS }

: c Gestation_period = 5 {months}

: c Lactation_period = 3 {months}

: c months = COUNTER(1,13)

: c Dry_period = RANDOM (Min_Dry_months, Max_Dry_months)

: c Fattening_period = 6 {months}

: l Fattening = 0 {sheep}

TRANSIT TIME = Fattening_period

: l Pregnant_1 = 5 {sheep}

TRAN[1]SIT TIME = Gestation_period

: l Party_1 = 7 {sheep}

TRANSIT TIME = Lactation_period

: l Dry_ewe_1 = 3 {sheep}

TRANSIT TIME = Dry_period

: l Parity_2 = 8 {sheep}

TRANSIT TIME = Lactation_period

: l Pregnant_2 = 10 {sheep}

TRANSIT TIME = Gestation_period

: l Dry_ewe_2 = 5 {sheep}

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[1] *c = Converter   f = Flow   s = Stock   l = Conveyer*

TRANSIT TIME = Dry_period

: I Parity_3 = 8 {sheep}

TRANSIT TIME = Lactation_period

: I Dry_ewe_3 = 3 {sheep}

TRANSIT TIME = Dry_period

: I Pregnant_4 = 12 {sheep}

TRANSIT TIME = Gestation_period

: I Parity_4 = 10 {sheep}

TRANSIT TIME = Lactation_period

: I Dry_ewes_4 = 5 {sheep}

TRANSIT TIME = Dry_period

: I Pregnant_3 = 10 {sheep}

TRANSIT TIME = Gestation_period

: I pregnant_5 = 8 {sheep}

TRANSIT TIME = Gestation_period

: I Parity_5 = 10 {sheep}

TRANSIT TIME = Lactation_period

: c Lactating_ewe_LW = IF (TIME < 120) THEN (22.6) ELSE IF (TIME >= 120) THEN (22.6 + STEP(0.6,120) + STEP(0.6,132) + STEP(0.6,144) + STEP(0.6,156) + STEP(0.6,168) + STEP(0.6,180) + STEP(0.6,192) + STEP(0.6,204) + STEP(0.6,216) + STEP(0.6,228) + STEP(0.6,240)) ELSE 22.6 {kg}

: c Actual_lact_LW = IF(months =1) THEN (Lactating_ewe_LW*0.9) ELSE IF (months = 2) THEN (Lactating_ewe_LW*0.9) ELSE IF(months =3) THEN (Lactating_ewe_LW*0.95) ELSE IF(months = 4) THEN (Lactating_ewe_LW*0.95) ELSE IF(months = 5) THEN(Lactating_ewe_LW*0.95) ELSE IF(months = 6) THEN (Lactating_ewe_LW*0.95) ELSE IF(months = 7) THEN (Lactating_ewe_LW) ELSE IF(months = 8) THEN (Lactating_ewe_LW) ELSE IF(months = 9) THEN (Lactating_ewe_LW) ELSE IF(months =

10) THEN (Lactating_ewe_LW*0.95) ELSE IF(months =11) THEN(Lactating_ewe_LW*0.9) ELSE IF(months=12)THEN (Lactating_ewe_LW*0.9) ELSE (Lactating_ewe_LW)

: c DDMI_lactating_ewe = Actual_lact_LW*0.025

: c Monthly_DMI_lactating = DDMI_lactating_ewe*30.4

: c Lactating_ewes = Party_1+Parity_2+Parity_3+Parity_4+Parity_5 {sheep}

: c TDMI_lactating_ewe = Monthly_DMI_lactating*lactating_ewes

: c Pregnant_ewe_LW = IF (TIME < 120) THEN (24) ELSE IF (TIME >= 120) THEN (24 + STEP(0.6,120) + STEP(0.6,132) + STEP(0.6,144) + STEP(0.6,156) + STEP(0.6,168) + STEP(0.6,180) + STEP(0.6,192) + STEP(0.6,204) + STEP(0.6,216) + STEP(0.6,228) + STEP(0.6,240)) ELSE 24 {month}

: c Actual_Preg_LW = IF(months =1) THEN (Pregnant_ewe_LW*0.9) ELSE IF (months = 2) THEN (Pregnant_ewe_LW*0.9) ELSE IF(months =3) THEN (Pregnant_ewe_LW*0.95) ELSE IF(months = 4) THEN (Pregnant_ewe_LW*0.95) ELSE IF(months = 5) THEN(Pregnant_ewe_LW*0.95) ELSE IF(months = 6) THEN (Pregnant_ewe_LW*0.95) ELSE IF(months = 7) THEN (Pregnant_ewe_LW) ELSE IF(months = 8) THEN (Pregnant_ewe_LW) ELSE IF(months = 9) THEN (Pregnant_ewe_LW) ELSE IF(months = 10) THEN (Pregnant_ewe_LW*0.95) ELSE IF(months =11) THEN(Pregnant_ewe_LW*0.9) ELSE IF(months=12)THEN (Pregnant_ewe_LW*0.9) ELSE (Pregnant_ewe_LW)

: c DDMIpregnant_ewe = Actual_Preg_LW*0.025

: c Monthly_DMI_pregnant = DDMIpregnant_ewe*30.4

: c Pregnant_ewes = Pregnant_2+Pregnant_3+Pregnant_4+pregnant_5+Pregnant_1{sheep}

: c TDMI_pregnant_ewe = Monthly_DMI_pregnant*pregnant_ewes

: c Ram_FattenLW = GRAPH(Counter (0,6) + STEP(+0.025,120) + STEP(+0.025,126) + STEP(+0.025,132) + STEP(+0.025,138) + STEP(+0.025,144) + STEP(+0.025,150) + STEP(+0.025,156) + STEP(+0.025,162) + STEP(+0.025,168) + STEP(+0.025,174) + STEP(+0.025,180) + STEP(+0.025,186) + STEP(+0.025,192) + STEP(+0.025,198) + STEP(+0.025,204) + STEP(+0.025,210) + STEP(+0.025,216) + STEP(+0.025,222) + STEP(+0.025,228) + STEP(+0.025,234) + STEP(+0.025,240) {month})

(0.00, 24.0), (0.5, 25.0), (1.00, 25.5), (1.50, 26.0), (2.00, 26.5), (2.50, 27.0), (3.00, 27.5), (3.50, 28.0), (4.00, 28.3), (4.50, 28.5), (5.00, 28.8), (5.50, 29.0), (6.00, 35.0)

: c Daily_DMIfatten = Ram_FattenLW*0.025 {Kg DM/day}

: c Monthly_DMIFatten = Daily_DMIfatten*30.4 {Kg DM/month}

: c TDMI_fatten = Fattening*Monthly_DMIFatten

: s Breeding_female_replacement = 20 {sheep}

: c Young_ewe_LW = GRAPH(COUNTER(0,12) + STEP(0.05,120) + STEP(0.05,132) + STEP(0.05,144) + STEP(0.05,156) + + STEP(0.05,168) + STEP(0.05,180) + STEP(0.05,192) + STEP(0.05,204) + STEP(0.05,216) + STEP(0.05,228) + STEP(0.05,240) {month})

(0.00, 13.4), (0.5, 15.0), (1.00, 15.5), (1.50, 15.8), (2.00, 16.0), (2.50, 16.3), (3.00, 16.5), (3.50, 16.8), (4.00, 17.0), (4.50, 17.3), (5.00, 17.5), (5.50, 17.8), (6.00, 18.0), (6.50, 18.2), (7.00, 18.4), (7.50, 18.6), (8.00, 18.8), (8.50, 19.0), (9.00, 19.2), (9.50, 19.4), (10.0, 19.6), (10.5, 19.8), (11.0, 20.0), (11.5, 20.3), (12.0, 26.3)

: c Actual_YE_LW = IF(months =1) THEN (Young_ewe_LW*0.9) ELSE IF (months = 2) THEN (Young_ewe_LW*0.9) ELSE IF(months =3) THEN (Young_ewe_LW*0.95) ELSE IF(months = 4) THEN (Young_ewe_LW*0.95) ELSE IF(months = 5) THEN(Young_ewe_LW*0.95) ELSE IF(months = 6) THEN (Young_ewe_LW*0.95) ELSE IF(months = 7) THEN (Young_ewe_LW) ELSE IF(months = 8) THEN (Young_ewe_LW) ELSE IF(months = 9) THEN (Young_ewe_LW) ELSE IF(months = 10) THEN (Young_ewe_LW*0.95) ELSE IF(months =11) THEN(Young_ewe_LW*0.9) ELSE IF(months=12)THEN (Young_ewe_LW*0.9) ELSE (Young_ewe_LW)

: c DDMI_YE = Actual_YE_LW*0.025

: c Monthly_DMI_EL = DDMI_YE*30 {Kg DM/month}

: c TDMI_EL = (breeding_female_replacement)*Monthly_DMI_EL

: s Breeding_ram = 5 {sheep}

: c Ram_LW = GRAPH(COUNTER(0,12) + STEP(0.05,120) + STEP(0.05,132) + STEP(0.05,144) + STEP(0.05,156) + + STEP(0.05,168) + STEP(0.05,180) + STEP(0.05,192) + STEP(0.05,204) + STEP(0.05,216) + STEP(0.05,228) + STEP(0.05,240) {month})

(0.00, 21.4), (0.5, 22.4), (1.00, 22.1), (1.50, 22.2), (2.00, 22.3), (2.50, 22.4), (3.00, 22.5), (3.50, 22.6), (4.00, 22.7), (4.50, 22.8), (5.00, 22.9), (5.50, 23.0), (6.00, 23.1), (6.50, 23.2), (7.00, 23.3), (7.50, 23.4), (8.00, 23.5), (8.50, 23.6), (9.00, 23.7), (9.50, 23.8), (10.0, 23.8), (10.5, 23.9), (11.0, 23.9), (11.5, 24.0), (12.0, 30.0)

: c Actual_Ram_LW = IF(months =1) THEN (Ram_LW*0.9) ELSE IF (months = 2) THEN (Ram_LW*0.9) ELSE IF(months =3) THEN (Ram_LW*0.95) ELSE IF(months = 4) THEN (Ram_LW*0.95) ELSE IF(months = 5) THEN(Ram_LW*0.95) ELSE IF(months = 6) THEN (Ram_LW*0.95) ELSE IF(months = 7) THEN (Ram_LW) ELSE IF(months = 8) THEN (Ram_LW) ELSE IF(months = 9) THEN (Ram_LW) ELSE IF(months = 10) THEN (Ram_LW*0.95) ELSE IF(months =11) THEN(Ram_LW*0.9) ELSE IF(months=12)THEN (Ram_LW*0.9) ELSE (Ram_LW)

: c DMIram = Actual_Ram_LW*0.025

: c Monthly_DMIram = DMIram*30.4

: c TDMI_ram = Breeding_ram*Monthly_DMIram

: S Young = 50 {sheep}

: c Lamb_age = COUNTER(0,6) {month}

: c Lamb_LW = GRAPH(Counter (0,6) + STEP(+0.024,120) + STEP(+0.024,126) + STEP(+0.024,132) + STEP(+0.024,138) + STEP(+0.024,144) + STEP(+0.024,150) + STEP(+0.024,156) + STEP(+0.024,162) + STEP(+0.024,168) + STEP(+0.024,174) + STEP(+0.024,180) + STEP(+0.024,186) + STEP(+0.024,192) + STEP(+0.024,198) + STEP(+0.024,204) + STEP(+0.024,210) + STEP(+0.024,216) + STEP(+0.024,222) + STEP(+0.024,228) + STEP(+0.024,234) + STEP(+0.024,240) {month})

(0.00, 2.20), (0.5, 2.86), (1.00, 3.00), (1.50, 3.50), (2.00, 4.50), (2.50, 6.00), (3.00, 7.50), (3.50, 10.5), (4.00, 11.5), (4.50, 12.5), (5.00, 13.0), (5.50, 13.4), (6.00, 19.6)

: c Actual_Lamb_LW = IF(months =1) THEN (Lamb_LW*0.9) ELSE IF (months = 2) THEN (Lamb_LW*0.9) ELSE IF(months =3) THEN (Lamb_LW*0.95) ELSE IF(months = 4) THEN (Lamb_LW*0.95) ELSE IF(months = 5) THEN(Lamb_LW*0.95) ELSE IF(months = 6) THEN (Lamb_LW*0.95) ELSE IF(months = 7) THEN (Lamb_LW) ELSE IF(months = 8) THEN (Lamb_LW) ELSE IF(months = 9) THEN (Lamb_LW) ELSE IF(months = 10) THEN (Lamb_LW*0.95) ELSE IF(months =11) THEN(Lamb_LW*0.9) ELSE IF(months=12)THEN (Lamb_LW*0.9) ELSE (Lamb_LW)

: c DDMI_Young = If (Lamb_age<1) THEN (0) ELSE (Actual_Lamb_LW*0.025) {Kg DM/day}

DOCUMENT: lambs starting consuming dry matter when they are 1 month old

: c Monthly_DMI_Young = DDMI_Young*30.4 {Kg DM/Young/month}

: c TDMI_young = Young*Monthly_DMI_Young {Kg DM/month}

: s Young_Ram = 5 {sheep}

: c Young_Ram_LW = GRAPH(COUNTER(0,12) + STEP(0.05,120) + STEP(0.05,132) + STEP(0.05,144) + STEP(0.05,156) + + STEP(0.05,168) + STEP(0.05,180) + STEP(0.05,192) + STEP(0.05,204) + STEP(0.05,216) + STEP(0.05,228) + STEP(0.05,240) {kg})

(0.00, 13.4), (0.5, 16.0), (1.00, 16.5), (1.50, 16.8), (2.00, 17.0), (2.50, 17.3), (3.00, 17.5), (3.50, 17.8), (4.00, 18.0), (4.50, 18.3), (5.00, 18.5), (5.50, 18.8), (6.00, 19.0), (6.50, 19.3), (7.00, 19.5), (7.50, 19.8), (8.00, 20.0), (8.50, 20.2), (9.00, 20.4), (9.50, 20.6), (10.0, 20.8), (10.5, 21.0), (11.0, 21.2), (11.5, 21.4), (12.0, 27.4)

: c Actual_YR_LW = IF(months =1) THEN (Young_ram_LW*0.9) ELSE IF (months = 2) THEN (Young_ram_LW*0.9) ELSE IF(months =3) THEN (Young_ram_LW*0.95) ELSE IF(months = 4) THEN (Young_ram_LW*0.95) ELSE IF(months = 5) THEN(Young_ram_LW*0.95) ELSE IF(months = 6) THEN (Young_ram_LW*0.95) ELSE IF(months = 7) THEN (Young_ram_LW) ELSE IF(months = 8) THEN (Young_ram_LW) ELSE IF(months = 9) THEN (Young_ram_LW) ELSE IF(months = 10) THEN (Young_ram_LW*0.95) ELSE IF(months =11) THEN(Young_ram_LW*0.9) ELSE IF(months=12)THEN (Young_ram_LW*0.9) ELSE (Young_ram_LW) {Kg}

: c DDMI_YR = Actual_YR_LW*0.025

: c Monthly_DMI_YR = DDMI_YR*30.4 {Kg DM/YR/month}

: c TDMI_YR = Young_Ram*Monthly_DMI_YR {Kg DM/month}

: c Ewe_LW = GRAPH(COUNTER(0,12) + STEP(0.05,120) + STEP(0.05,132) + STEP(0.05,144) + STEP(0.05,156) + + STEP(0.05,168) + STEP(0.05,180) + STEP(0.05,192) + STEP(0.05,204) + STEP(0.05,216) + STEP(0.05,228) + STEP(0.05,240) {kg})

(0.00, 20.3), (0.5, 21.3), (1.00, 21.4), (1.50, 21.4), (2.00, 21.4), (2.50, 21.5), (3.00, 21.5), (3.50, 21.5), (4.00, 21.5), (4.50, 21.5), (5.00, 21.6), (5.50, 21.6), (6.00, 21.6), (6.50, 21.6), (7.00, 21.6), (7.50, 21.6), (8.00, 21.6), (8.50, 21.6), (9.00, 21.6), (9.50, 21.6), (10.0, 21.6), (10.5, 21.7), (11.0, 21.7), (11.5, 22.0), (12.0, 28.0)

: c Actual_Dry_ewe_LW = IF(months =1) THEN (Ewe_LW*0.9) ELSE IF (months = 2) THEN (Ewe_LW*0.9) ELSE IF(months =3) THEN (Ewe_LW*0.95) ELSE IF(months = 4) THEN (Ewe_LW*0.95) ELSE IF(months = 5) THEN(Ewe_LW*0.95) ELSE IF(months = 6) THEN (Ewe_LW*0.95) ELSE IF(months = 7) THEN (Ewe_LW) ELSE IF(months = 8) THEN (Ewe_LW) ELSE IF(months = 9) THEN (Ewe_LW) ELSE IF(months = 10) THEN

(Ewe_LW*0.95) ELSE IF(months =11) THEN(Ewe_LW*0.9) ELSE IF(months=12)THEN (Ewe_LW*0.9) ELSE (Ewe_LW) {Kg}

: c DDMI_dry_ewe = Actual_Dry_ewe_LW*0.025 {Kg DM/dry_ewe/day}

: c Monthly_DMI_dry_ewe = DDMI_dry_ewe*30 {Kg DM/dry_ewe/month}

: c Dry_ewes = Dry_ewe_1+Dry_ewe_2+Dry_ewe_3+Dry_ewes_4 {sheep}

: c TDMI_dery_ewes = Monthly_DMI_dry*Dry_ewes {Kg DM/month}

: c Total_Herd_DM_Demand = SUM(TDMI_lactating_ewe,TDMI_pregnant_ewe,TDMI_fatten,TDMI_YE,TDMI_ram,TDMI_young,TDMI_YR,TDMI_dery_ewes) {kg DM/month}

: c Grazing_area = MAX(28.26) {ha}

: c Total_herd_DD_per_Ha = Total_Herd_DM_Demand/(Grazing_area) {kg DM/ha}

: s Dry_standing_vegetation = 400 {Kg DM/ha}

: s Green_standing_vegetation = 200 {Kg DM/ha}

DOCUMENT: Green Standing Forage is converted to dry standing crop via Frosts and senescence.

: c Total_Standing_vegetation = Dry_standing_vegetation+Green_standing_vegetation {kg DM/month/ha}

: c RIF = GRAPH(Total_Standing_vegetation)

(0.00, 0.00), (438, 0.2), (875, 0.5), (1313, 0.8), (1750, 0.9), (2188, 1.00), (2625, 1.00), (3063, 1.00), (3500, 1.00)

: c RIF1 = IF(RIF>=1) THEN(1) ELSE(RIF)

DOCUMENT: Restricted intake of Forage

: c Pasture_Actual_DM_per_ha = Total_herd_DD_per_Ha*(RIF1) {kg DM/ha}

: c MPPT_RF = RANDOM(0,1)

: c Jan = if (MPPT_RF<0.03) then 0 else if (MPPT_RF<0.1) then 5.4 else if (MPPT_RF<0.29) then 12.2 else if (MPPT_RF<0.52) then 17.1 else if (MPPT_RF<0.71) then 20.3 else if (MPPT_RF<0.87) then 25.9 else if (MPPT_RF<1) then 37.3 else 0

: c Feb = if (MPPT_RF<0.04) then 0 else if (MPPT_RF<0.13) then 5.1 else if (MPPT_RF<0.37) then 12.4 else if (MPPT_RF<0.62) then 19.1 else if (MPPT_RF<0.84) then 22.9 else if (MPPT_RF<1) then 27.1 else 0

: c Mar = if (MPPT_RF<0.01) then 0 else if (MPPT_RF<0.26) then 5.8 else if (MPPT_RF<0.44) then 34.1 else if (MPPT_RF<0.76) then 75.5 else if (MPPT_RF<0.84) then 77.8 else if (MPPT_RF<1) then 98.6 else 0

: c Apr = if (MPPT_RF<0.02) then 0 else if (MPPT_RF<0.16) then 8.7 else if (MPPT_RF<0.28) then 27.3 else if (MPPT_RF<0.51) then 32.3 else if (MPPT_RF<0.68) then 49.1 else if (MPPT_RF<0.81) then 60 else if (MPPT_RF<1) then 94.1 else 0

: c May = if (MPPT_RF<0.01) then 0 else if (MPPT_RF<0.08) then 6 else if (MPPT_RF<0.13) then 11.5 else if (MPPT_RF<0.21) then 11.8 else if (MPPT_RF<0.36) then 18.4 else if (MPPT_RF<0.54) then 27 else if (MPPT_RF<0.76) then 54.4 else if (MPPT_RF<0.84) then 64.5 else if (MPPT_RF<1) then 82 else 0

: c Jun = if (MPPT_RF<0.05) then 0 else if (MPPT_RF<0.13) then 7.6 else if (MPPT_RF<0.22) then 14.7 else if (MPPT_RF<0.35) then 31.3 else if (MPPT_RF<0.63) then 40.8 else if (MPPT_RF<0.75) then 54.4 else if (MPPT_RF<0.83) then 59.7 else if (MPPT_RF<0.90) then 71.4 else if (MPPT_RF<1) then 100 else 0

: c Jul = if (MPPT_RF<0.1) then 240.2 else if (MPPT_RF<0.15) then 245 else if (MPPT_RF<0.23) then 250 else if (MPPT_RF<0.31) then 259.8 else if (MPPT_RF<0.39) then 266.4 else if (MPPT_RF<0.48) then 302.8 else if (MPPT_RF<0.59) then 341.5 else if (MPPT_RF<0.7) then 358.8 else if (MPPT_RF<0.84) then 449.1 else if (MPPT_RF<1) then 524.6 else 0

: c Aug = if (MPPT_RF<0.1) then 187.5 else if (MPPT_RF<0.15) then 229.6 else if (MPPT_RF<0.23) then 240 else if (MPPT_RF<0.32) then 243 else if (MPPT_RF<0.4) then 244.9 else if (MPPT_RF<0.49) then 245.9 else if (MPPT_RF<0.58) then 272.6 else if (MPPT_RF<0.68) then 286.8 else if (MPPT_RF<0.81) then 370.4 else if (MPPT_RF<1) then 533.4 else 0

: c Sep = if (MPPT_RF<0.03) then 33.3 else if (MPPT_RF<0.06) then 34.6 else if (MPPT_RF<0.11) then 47.9 else if (MPPT_RF<0.16) then 58.8 else if (MPPT_RF<0.41) then 60 else if (MPPT_RF<0.67) then 62.8 else if (MPPT_RF<0.83) then 68.1 else if (MPPT_RF<0.91) then 80 else if (MPPT_RF<1) then 112.8 else 0

: c Oct = if (MPPT_RF<0.01) then 0 else if (MPPT_RF<0.3) then 3.6 else if (MPPT_RF<0.08) then 5.8 else if (MPPT_RF<0.13) then 6.8 else if (MPPT_RF<0.2) then 9 else if

(MPPT_RF<0.35) then 9.3 else if (MPPT_RF<0.43) then 10 else if (MPPT_RF<1) then 32 else 0

: c Nov = if (MPPT_RF<0.05) then 0 else if (MPPT_RF<0.18) then 3.2 else if (MPPT_RF<0.35) then 5.9 else if (MPPT_RF<0.58) then 7.3 else if (MPPT_RF<0.75) then 31.3 else if (MPPT_RF<1) then 71.8 else 0

: c Dec = if (MPPT_RF<0.01) then 0 else if (MPPT_RF<0.05) then 3.4 else if (MPPT_RF<0.16) then 7.4 else if (MPPT_RF<0.36) then 14 else if (MPPT_RF<1) then 21.7 else 0

: c Monthly_rainfall = IF(months=1) THEN(Jan) ELSE IF(months=2) THEN (Feb) ELSE IF(months=3) THEN (Mar) ELSE IF(months=4)THEN(Apr) ELSE IF(months=5) THEN (May) ELSE IF(months=6) THEN (Jun) ELSE IF(months=7) THEN (Jul) ELSE IF(months=8) THEN (Aug) ELSE IF(months=9) THEN (Sep) ELSE IF(months=10) THEN (Oct) ELSE IF(months=11) THEN (Nov) ELSE IF(months=12) THEN (Dec) ELSE 0 {mm/month}

: c Rain_use_effeciency = 4 {kg DM/mm}

: c Selectivity_Parameter = (111.9)/(1+106.2*EXP(-0.0022*Monthly_rainfall*Rain_use_effeciency))

DOCUMENT: Kms is a threshold that changes with the Aboveground Net forage Production. Above some upper threshold green forage availability does not limit intake, however, as the availability of green forage decreases below that threshold, its harvestablity decreases.

: c Hrvestablity_of_Green_Vegetation = (1.1*Green_standing_vegetation)/(Selectivity_Parameter+Green_standing_vegetation)

: c Harvestablity_of_Green_Vegetation1 = IF(Hrvestablity_of_Green_Vegetation>1) THEN (1) ELSE(Hrvestablity_of_Green_Vegetation)

: c DM_digestablity_of_GV = IF(months =1) THEN (0.4114) ELSE IF (months = 2) THEN (0.5638) ELSE IF(months =3) THEN (0.6584) ELSE IF(months = 4) THEN (0.6559) ELSE IF(months = 5) THEN(0.4116) ELSE IF(months = 6) THEN (0.6553) ELSE IF(months = 7) THEN (0.6788) ELSE IF(months = 8) THEN (0.6788) ELSE IF(months = 9) THEN (0.6783) ELSE IF(months = 10) THEN (0.5128) ELSE IF(months =11) THEN(0.5126) ELSE IF(months=12)THEN (0.5128) ELSE 0

: c GVCFD = 1.67*(DM_digestablity_of_GV-0.34)

: c Crude_protien_GF = IF(months =1) THEN (0.0375) ELSE IF (months = 2) THEN (0.027) ELSE IF(months =3) THEN (0.0295) ELSE IF(months = 4) THEN (0.0375) ELSE IF(months =

5) THEN(0.0535) ELSE IF(months = 6) THEN (0.0315) ELSE IF(months = 7) THEN (0.039) ELSE IF(months = 8) THEN (0.04) ELSE IF(months = 9) THEN (0.0365) ELSE IF(months = 10) THEN (0.04) ELSE IF(months =11) THEN(0.0625) ELSE IF(months=12)THEN (0.044) ELSE 0

: c GVCFP = 3.509*(Crude_protien_GF-0.015)

: c GFDESI = GVCFD*GVCFP

: c crude_protien_DV = 0.039

: c DVCFP = 3.509*(crude_protien_DV-0.015)

: c Digestablity_DV = 0.42

: c DVCFD = 1.67*(Digestablity_DV-0.34)

: c DVDESI = DVCFP*DVCFD

: c SUMDESI = DVDESI+GFDESI

: c Preferance_for__Green_Vegetation = GFDESI/SUMDESI

DOCUMENT: sheep preferance to consume green pasture

: c Proportion_of_Green_Vegetation_in_Diet = (Harvestablity_of_Green_Vegetation1*Preferance_for_Green_Vegetation)

: s Pasture_condition = 0.75

DOCUMENT: Pasture condition grades are 0.5, 0.75, 1 and 1.25, which are poor, fair, good and excellent respectively.

: f Monthly_Vegetation_growth = DELAY1 (Monthly_rainfall*Rain_use_effeciency*Range_condition,1) {kg DM /ha/month}

: f Green_Standing_Vegetation_Consumed = (Pasture_Actual_DM_per_ha*Proportion_of_Green_Vegetation_in_Diet) {kg DM/month}

DOCUMENT: this is Green standing forage which is consumed by sheep (or grazed by sheep)

: s AGE = 0.05

: c SA = 0.018*30.4+0.000075*30.4*AGE

DOCUMENT: RS is similarly to S which is an index related to month of the year.

: f GSCSin = (Green_standing_vegetation-Green_Stading__Vegetation_Consumed)*SA {kg DM/month}

DOCUMENT: Green_pasture*SA {kg DM/month}

: c Mean_Monthly_Temperature = IF(months =1) THEN (12.3) ELSE IF (months = 2) THEN (13.3) ELSE IF(months =3) THEN (13.6) ELSE IF(months = 4) THEN (13.6) ELSE IF(months = 5) THEN(14.1) ELSE IF(months = 6) THEN (14.1) ELSE IF(months = 7) THEN (12.8) ELSE IF(months = 8) THEN (12.6) ELSE IF(months = 9) THEN (12.4) ELSE IF(months = 10) THEN (0) ELSE IF(months =11) THEN(0) ELSE IF(months=12)THEN (11.6) ELSE 0

DOCUMENT: Frost was assumed in October and November

: f Being_frost = (Green_standing_vegetation-Green_Stading_Vegetation_Consumed-GSCSin)*Mean_Monthly_Temprature

: s Senescence = 0 {kg DM/ha}

: f GSCOUT = 0.7*Senescence

: s Vegetation_frost = INIT(Being_frost)

: f Being_dry = 0.7*Vegetation_frost

: f Dry_standing_vegetation_Consumed = Pasture_Actual_DM_per_ha-Green_Standing_Vegetation_Consumed {kg DM/ha}

DOCUMENT: This is dry standing forage which is consumed by sheep (grazed by sheep)

: c Dead_rate = 1-EXP(-0.003077*Monthly_rainfall)+0.0005*Mean_monthly_temperature

: f Dry_vegetation__decomposition = Dead_rate*(Dry_standing_vegetation-Dry_stading_vegetation_Consumed) {Kg DM /ha}

: c AGEP = AGE-1

: f AGEIN = If Green_standing_vegetation= 0 then AGE= 0 else Min (((Green_standing_vegetation-Monthly_Vegetation_growth)/Green_standing_vegetation)*AGEP+1, 3)

: f AGEOUT = IF(AGE>3)THEN(AGE) ELSE(0)

: s Annual_Aboveground_Net_Vegetation_Consumed = 0 {kgDM/month}

: f TMVC = (Dry_stading_vegetation_Consumed+Green_Stading_Vegetation_Consumed) {kgDM/month/ha}

: f TANVC = IF(months=12) THEN(Annual_Aboveground_Net_Vegetation_Consumed) ELSE(0) {kgDM/year}

: s Annual_Abovegraound_Net_Vegetation_Production = 100 {kg DM/ha/month}

: f NPM = Monthly_Vegetation_growth {KgDM/ha/month}

: f NPY = IF (months=12) THEN (Annual_Abovegraound_Net_Vegetation_Production) ELSE (0) {Kg DM/year}

: s Grazing_Efficiency = 0.15

DOCUMENT: Grazing Efficiency levels are 10, 12.5 and 15% which corresponds to 40, 50 and 60% of total forage disappearance respectively.

: c GU = IF (months=12) THEN ((TANVC/NPY)*100) ELSE (0)

: f INTL = GU

: f OUTL = IF (months=12) THEN (Grazing_Efficiency) ELSE (0)

: s Annual_Rainfall = 0 {mm}

: f MRF = Monthly_rainfall {mm/month}

: f TANRF = IF (months=12) THEN (Annual_Rainfall) ELSE (0)

: s Green_standing_Barley = 50 {kg DM/ha}

DOCUMENT: Green Standing Forage is converted to dry standing crop via Frosts and senescence.

: c Maturation_period = 4 {month}

: f Barley_growth = DELAY (Monthly_rainfall*Rain_use_effeciency,1) {kg DM /ha/month}

: f maturation = Green_standing_Barley/Maturation_period

DOCUMENT: Green_forage*SA {kg DM/month}

: f Vegetation_Being_Frost = (Green_standing_Barley-maturation)*Mean_Monthly__Temperature

: c Ram_service_period = 24 {months}

: c YR_maturation_age = 12 {months}

: f YR_matured = Young_Ram/YR_maturation_age {sheep/month}

: f Ram_to_fattening = Breeding_ram/Ram_service_period

: c Ram_mortality_rate = IF(months =1) THEN (0.1) ELSE IF (months = 2) THEN (0.1) ELSE IF(months =3) THEN (0.1) ELSE IF(months = 4) THEN (0.1) ELSE IF(months = 5) THEN(0.1) ELSE IF(months = 6) THEN (0.05) ELSE IF(months = 7) THEN (0.01) ELSE IF(months = 8) THEN (0.01) ELSE IF(months = 9) THEN (0.01) ELSE IF(months = 10) THEN (0.01) ELSE IF(months =11) THEN(0.05) ELSE IF(months=12)THEN (0.1) ELSE 0

: f Ram_deaths = Breeding_ram*Ram_mortality_rate {sheep/month}

: c ram_selling_rate = IF(months =1) THEN (0.5) ELSE IF (months = 2) THEN (0.5) ELSE IF(months =3) THEN (0.5) ELSE IF(months = 4) THEN (0.5) ELSE IF(months = 5) THEN(0.4) ELSE IF(months = 6) THEN (0.2) ELSE IF(months = 7) THEN (0.1) ELSE IF(months = 8) THEN (0.1) ELSE IF(months = 9) THEN (0.1) ELSE IF(months = 10) THEN (0.15) ELSE IF(months =11) THEN(0.4) ELSE IF(months=12)THEN (0.5) ELSE 0

: f Ram_sold = Breeding_ram*ram_selling_rate {sheep/month}

: c Conceiption_rate = IF(months =1) THEN (0.6) ELSE IF (months = 2) THEN (0.6) ELSE IF(months =3) THEN (0.6) ELSE IF(months = 4) THEN (0.6) ELSE IF(months = 5) THEN(0.5) ELSE IF(months = 6) THEN (0.75) ELSE IF(months = 75) THEN (0.8) ELSE IF(months = 8) THEN (0.8) ELSE IF(months = 9) THEN (0.8) ELSE IF(months = 10) THEN (0.7) ELSE IF(months =11) THEN(0.6) ELSE IF(months=12)THEN (0.6) ELSE 0

: s Young_Ewe = 25 {sheep}

: c EL_mortality_rate = IF(months =1) THEN (0.15/12) ELSE IF (months = 2) THEN (0.1/12) ELSE IF(months =3) THEN (0.1/12) ELSE IF(months = 4) THEN (0.1/12) ELSE IF(months = 5) THEN(0.1/12) ELSE IF(months = 6) THEN (0.08/12) ELSE IF(months = 7) THEN (0.05/12) ELSE IF(months = 8) THEN (0.05/12) ELSE IF(months = 9) THEN (0.05/12) ELSE IF(months = 10) THEN (0.08/12) ELSE IF(months =11) THEN(0.1/12) ELSE IF(months=12)THEN (0.15/12) ELSE 0

: c Selling_rate = IF(months =1) THEN (0.15) ELSE IF (months = 2) THEN (0.15) ELSE IF(months =3) THEN (0.15) ELSE IF(months = 4) THEN (0.1) ELSE IF(months = 5) THEN(0.1) ELSE IF(months = 6) THEN (0.05) ELSE IF(months = 7) THEN (0) ELSE IF(months = 8) THEN (0) ELSE IF(months = 9) THEN (0) ELSE IF(months = 10) THEN (0.05) ELSE IF(months =11) THEN(0.1) ELSE IF(months=12)THEN (0.15) ELSE 0

: c Breeeding_requirtment_rate = 1-YE_mortality_rate-Selling_rate

: c Age_first_service = 12

: f Female_maturation = (Young_Ewe*Breeding_requirtment_rate)/Age_first_service

: f Conceived = breeding_female_replacement*Conceiption_rate

: c Culling_rate = IF (TIME < 120) THEN (0) ELSE IF (TIME >= 120) THEN (0.02) ELSE IF (TIME >= 180) THEN (0.02) ELSE 0

: f BF_culled = breeding_femal_replacement*Culling_rate

: s Matured_Barley = 0

: c Harvesting_period = 1 {month}

: f GSCOUT_2 = 0.8*Matured_Barley/Harvesting_period

: s Harvested_barley = 400 {kg DM/ha}

: c stubble_rate = 0.05

: s Barley_frost = 0 {kg DM/ha}

: f barley_being_dry = Barley_frost*0.8

: f stubble = Harvested_barley*stubble_rate {kg DM/ha}

: c residue_rate = 0.45

: f Residue = Harvested_barley*residue_rate {kg DM/ha}

: c yield_rate = 0.5

: f Grain = Harvested_barley*yield_rate {kg/ha}

: s Annual_Crop_Residue_produced = 0 {kgDM/month}

: c Crop_area = MAX(60) {ha}

: c Total_residue_Production = Residue*Crop_area {kg DM}

: c Total_Stubble_production = stubble*Crop_area {kg DM}

: f TMCRP = (Total_residue_Production*0.25)+Total_Stubble_production {kgDM/month/ha}

: f TANCRP = IF (months=12) THEN (Annual_Crop_Residue_produced) ELSE (0) {kgDM/year}

: f Lambing_1 = CONVEYOR OUTFLOW

TRANSIT TIME = Gestation_period

: c Ewe_mortality = IF(months =1) THEN (0.02/12) ELSE IF (months = 2) THEN (0.01/12) ELSE IF(months =3) THEN (0.01/12) ELSE IF(months = 4) THEN (0.01/12) ELSE IF(months = 5) THEN(0.01/12) ELSE IF(months = 6) THEN (0.01/12) ELSE IF(months = 7) THEN (0) ELSE IF(months = 8) THEN (0) ELSE IF(months = 9) THEN (0) ELSE IF(months = 10) THEN (0.01/12) ELSE IF(months =11) THEN(0.02/12) ELSE IF(months=12)THEN (0.02/12) ELSE 0

: f P1_deaths = LEAKAGE OUTFLOW

LEAKAGE FRACTION = Party_1*ewe_mortality {sheep/month}

: f Lactation_1 = CONVEYOR OUTFLOW

TRANSIT TIME = Lactation_period

: f Lambing_2 = CONVEYOR OUTFLOW

TRANSIT TIME = Gestation_period

: c Ewe_Culling_rate = IF (TIME < 120) THEN (0) ELSE IF (TIME >= 120) THEN (0.03/12) ELSE IF (TIME >= 180) THEN (0) ELSE 0 {1/month}

: f ewe_1_culled = LEAKAGE OUTFLOW

LEAKAGE FRACTION = Dry_ewe_1*Ewe_Culling_rate {sheep/month}

: f Concieved_2 = CONVEYOR OUTFLOW

TRANSIT TIME = Dry_period

: f P2_deaths = LEAKAGE OUTFLOW

LEAKAGE FRACTION = Parity_2*ewe_mortality

: f Lactation_2 = CONVEYOR OUTFLOW

TRANSIT TIME = Lactation_period

: f Lambing_3 = CONVEYOR OUTFLOW

TRANSIT TIME = Gestation_period

: f P3_deaths = LEAKAGE OUTFLOW

LEAKAGE FRACTION = Parity_3*ewe_mortality

: f Lactation_3 = CONVEYOR OUTFLOW

TRANSIT TIME = Lactation_period

: f ewe_3_culled = LEAKAGE OUTFLOW

LEAKAGE FRACTION = Dry_ewe_3*Ewe_Culling_rate {sheep/month}

: f Concieved_4 = CONVEYOR OUTFLOW

TRANSIT TIME = Dry_period

: f Lambing_4 = CONVEYOR OUTFLOW

TRANSIT TIME = Gestation_period

: f P4_deaths = LEAKAGE OUTFLOW

LEAKAGE FRACTION = Parity_4*ewe_mortality

: f Lactation_4 = CONVEYOR OUTFLOW

TRANSIT TIME = Lactation_period

: f Ewe_2_culled = LEAKAGE OUTFLOW

LEAKAGE FRACTION = Dry_ewe_2*Ewe_Culling_rate {sheep/month}

: f Concieved_3 = CONVEYOR OUTFLOW

TRANSIT TIME = Dry_period

: f Ewe_4_culled = LEAKAGE OUTFLOW

LEAKAGE FRACTION = Dry_ewes_4*Ewe_Culling_rate {sheep/month}

: f Concieved_5 = CONVEYOR OUTFLOW

TRANSIT TIME = Dry_period

: f Lambing_5 = CONVEYOR OUTFLOW

TRANSIT TIME = Gestation_period

: c TLU = ((Breeding_ram*(Actual_Ram_LW/250))+(Fattening*(Ram_FattenLW/250))+(Young_Ram*(Actual_YR_LW/250))+(Young*(Actual_Lamb_LW/250))+(lactating_ewes*(Actual_lact_LW/250))+(pregnant_ewes*(Actual_Preg_LW/250))+(Dry_ewes*(Actual_Dry_ewe_LW/250))*((Young_Ewe+breeding_femal__replacement)*(Actual_YE_LW/250)))

: c Carrying_Capacity = TLU/Grazing_area {TLU/ha}

: c Utilisation_effect = GRAPH(OUTL)

(0.00, 0.05), (5.00, 0.0333), (10.0, 0.0167), (15.0, 0.00), (20.0, -0.00714), (25.0, -0.0143), (30.0, -0.0214), (35.0, -0.0286), (40.0, -0.0357), (45.0, -0.0429), (50.0, -0.05)

DOCUMENT: UE stands for Utilization Effect or estimated annual adjustment

: f Cumu_Pasture_condition = IF(months=12) AND (Pasture_condition<1.26 AND Pasture_condition >0.49)THEN (Pasture_condition*Utilisation_effect) ELSE(0)

: c MEYRm = 1.4+(0.15*Actual_YR_LW) {MJME/day}

: c MEYEm = 1.4+(0.15*Actual_YE_LW) {MJME/day}

: c MERm = (0.43*Actual_Ram_LW^0.75)*30 {MJME/month}

: c Young_Ram_MWG = 30*30.4 {gram/day}

: c Young_Ewe_MWG = 30*30.4 {gram/day}

: c NEg_YE = (1.11*LOG10(Young_Ewe_MWG) + 0.04*Actual_YE_LW-2.1)

: c NEg_YR = (1.11*LOG10(Young_Ram_MWG) + 0.04*Actual_YR_LW-2.1)

: c M_D = 9.61

: c Kg = 0.0435*M_D

: c MEg_YR = NEg_YR/Kg

: c MEg_YE = NEg_YE/Kg

: c Fatten_MWG = 35*40.4 {gram/day}

: c NEg_Fatten = (1.11*LOG10(Fatten_MWG) + 0.04*Ram_FattenLW-2.1)

: c Lamb_MWG = if (Lamb_age<3) then (75.92*15.2) else if (Lamb_age<=6) then (33.65*15.2) else 0

: c NEg_Young = (1.11*LOG10(Lamb_MWG) + 0.04*Actual_Lamb_LW-2.1)

: c Residue_Produced_per_ha = Residue+stubble {KgDM/ha}

: c Residue_Actual__DMI_per_ha = IF(months=1) THEN(Residue_Produced_per_ha*0.4) ELSE IF(months=2) THEN (Residue_Produced_per_ha*0.35) ELSE IF(months=3) THEN (Residue_Produced_per_ha*0) ELSE IF(months=4)THEN(Residue_Produced_per_ha*0) ELSE IF(months=5) THEN (Residue_Produced_per_ha*0.25) ELSE IF(months=6) THEN (Residue_Produced_per_ha*0.2) ELSE IF(months=7) THEN (Residue_Produced_per_ha*0) ELSE IF(months=8) THEN (Residue_Produced_per_ha*0) ELSE IF(months=9) THEN (Residue_Produced_per_ha*0) ELSE IF(months=10) THEN (Residue_Produced_per_ha*0) ELSE IF(months=11) THEN (Residue_Produced_per_ha*0) ELSE IF(months=12) THEN (Residue_Produced_per_ha*0.3) ELSE 0 {KgDM/month}

: c Residue_CP = 0.024

: c Residue_Digestablity = IF(months =1) THEN (0.49) ELSE IF (months = 2) THEN (0.54) ELSE IF(months =3) THEN (0.54) ELSE IF(months = 4) THEN (0.54) ELSE IF(months = 5) THEN(0.49) ELSE IF(months = 6) THEN (0.54) ELSE IF(months = 7) THEN (0.73) ELSE IF(months = 8) THEN (0.73) ELSE IF(months = 9) THEN (0.73) ELSE IF(months = 10) THEN (0.54) ELSE IF(months =11) THEN(0.54) ELSE IF(months=12)THEN (0.49) ELSE 0

: c RDP_supplied_by_Crop_residue = ((Residue_Actual_DMI_per_ha*1000)*Residue_CP*Residue_Digestablity) {gram/month}

: c RDP_supplied_by_Natural_pasture = ((Pasture_Actual_DM_per_ha*1000)*Crude_protien_GF*DM_digestablity_of_GV) {gram/month}

: c RDP_supplied_by_diet = (RDP_supplied_by_Crop_residue+RDP_supplied_by_Natural_pasture)

: c MEYm = 1.4+(0.15*Actual_Lamb_LW) {MJME/month}

: c MEg_Young = NEg_Young/Kg

: c MEDm = 1.8+(0.1*Actual_Dry_ewe_LW) {MJ/day}

: c Gestation_length = 5*30.4 {day}

: c MEpr = (1.2+(0.05*Actual_Preg_LW))^(0.0072*gestation_length) {MJ/day}

: c Milk_yield = GRAPH(Counter (0,3) {month})

(0.00, 0.2), (0.211, 0.25), (0.421, 0.275), (0.632, 0.3), (0.842, 0.32), (1.05, 0.34), (1.26, 0.36), (1.47, 0.38), (1.68, 0.4), (1.89, 0.43), (2.11, 0.46), (2.32, 0.48), (2.53, 0.5), (2.74, 0.51), (2.95, 0.515), (3.16, 0.52), (3.37, 0.48), (3.58, 0.42), (3.79, 0.3), (4.00, 0.2)

: c MElac = 7.4*milk_yield {MJ/day }

: c Birth_weight_Improvement = GRAPH(TIME)

(120, 2.20), (126, 2.23), (132, 2.26), (138, 2.30), (144, 2.33), (150, 2.36), (156, 2.39), (162, 2.42), (168, 2.45), (174, 2.49), (180, 2.52), (186, 2.55), (192, 2.58), (198, 2.61), (204, 2.64), (210, 2.68), (216, 2.71), (222, 2.74), (228, 2.77), (234, 2.80), (240, 2.83) {kg}

: c MEPm = 1.8+(0.1*Actual_Preg_LW) {MJ/day}

: c MELm = 1.8+(0.1*Actual_lact_LW) {MJ/day}

: c MEg_fatten = NEg_Fatten/Kg

: c Pature_ME_intake = Pasture_Actual_DM_per_ha*M_D {MJ/month}

: c MD_Residue = 7.78

: c Residue_ME_Intake = Residue_Actual__DMI_per_ha*MD_Residue {MJ/month}

: c ME_Suppled_by_diet = Pature_ME_intake+Residue_ME_Intake {MJ/month}

: c Ewe_Pm = 0.14675*Actual_Dry_ewe_LW+3.375 {g/day }

: c Monthly_ewe_Pm = ewe_Pm*30.4

: c Dry_ewes__protien = Dry_ewes*Monthly_ewe_Pm

: c Fatten_Pg = Fatten_MWG*10^-3*(160.4-1.22*Ram_FattenLW+0.0105*Ram_FattenLW^2) {g/day}

: c Monthly_Fatten_Pg = Fatten_Pg*30.4

: c Fatten_Pm = 0.14675*Ram_FattenLW+3.375 {g/day }

: c Monthly_Fatten_Pm = Fatten_Pm*30.4

: c Fatten_protien = (Monthly_Fatten_Pg+Monthly_Fatten_Pm)*Fattening

: c Milk_Protien = 48*milk_yield {g/day}

: c Monthly_milk_Protien = Milk_Protien*30.4

: c Lactating_ewes__protien = lactating_ewes*Monthly_milk_Protien

: c Monthly_MEpr = MEpr*30

: c Pregnant_ewes__protien = pregnant_ewes*Monthly_MEpr

: c Ram_Pm = 0.14675*Actual_Ram_LW+3.375 {g/day }

: c Monthly_Ram_Pm = Ram_Pm*30.4

: c Ram_protien = Monthly_Ram_Pm*Breeding_ram

: c YE_Pg = Young_Ewe_MWG*10^-3*(156.1-1.94*Actual_YE_LW+0.0173*Actual_YE_LW^2) {g/day}

: c Monthly_YE_Pg = YE_Pg*30.4

: c YE_pm = 0.14675*Actual_YE_LW+3.375 {g/day }

: c Monthly_YE_Pm = YE_pm*30.4

: c YE_protien = (Monthly_YE_Pg+Monthly_YE_Pm)*(Young_Ewe+breeding_femal_replacement)

: c Young_Pg = Lamb_MWG*10^-3*(160.4-1.22*Actual_Lamb_LW+0.0105*Actual_Lamb_LW^2) {g/day}

: c Monthly_Young_Pg = Young_Pg*30.4

: c Young_Pm = 0.14675*Actual_Lamb_LW+3.375 {g/day }

: c Monthly_Young_Pm = Young_Pm*30.4

: c Young_protien = (Monthly_Young_Pg+Monthly_Young_Pm)*Young

: c YR_Pg = Young_Ram_MWG*10^-3*(160.4-1.22*Actual_YR_LW+0.0105*Actual_YR_LW^2) {g/day}

: c Monthly_YR_Pg = YR_Pg*30.4

: c YR_Pm = 0.14675*Actual_YR_LW+3.375 {g/day }

: c Monthly_YR_Pm = YR_Pm*30.4

: c YR_protien = (Monthly_YR_Pg+Monthly_YR_Pm)*Young_Ram

: c TP_Herd_Demand = (Dry_ewes_protien+Fatten_protien+Lactating_ewes_protien+Pregnant_ewes_protien+Ram_protien+YE_protien+Young_protien+YR_protien)*RIF {g/month}

: c TP_demand_per_ha = TP_Herd_Demand/Grazing_area {g/month/ha}

: f Births = Lambing_1+Lambing_2+Lambing_3+Lambing_4+Lambing_5 {sheep/month}

: c YE_recruitment__rate = IF(months =1) THEN (0.45) ELSE IF (months = 2) THEN (0.475) ELSE IF(months =3) THEN (0.475) ELSE IF(months = 4) THEN (0.475) ELSE IF(months = 5) THEN(0.475) ELSE IF(months = 6) THEN (0.485) ELSE IF(months = 7) THEN (0.5) ELSE IF(months = 8) THEN (0.5) ELSE IF(months = 9) THEN (0.5) ELSE IF(months = 10) THEN (0.48) ELSE IF(months =11) THEN(0.475) ELSE IF(months=12)THEN (0.45) ELSE 0

: c F_lamb_maturation_age = 6 {months}

: f YE_recruited = Young*YE_recruitment_rate/F_lamb_maturation_age {sheep/month}

: c YR_recruitment_rate = IF(months =1) THEN (0.45) ELSE IF (months = 2) THEN (0.475) ELSE IF(months =3) THEN (0.475) ELSE IF(months = 4) THEN (0.475) ELSE IF(months = 5) THEN(0.475) ELSE IF(months = 6) THEN (0.485) ELSE IF(months = 7) THEN (0.5) ELSE IF(months = 8) THEN (0.5) ELSE IF(months = 9) THEN (0.5) ELSE IF(months = 10) THEN (0.48) ELSE IF(months =11) THEN(0.475) ELSE IF(months=12)THEN (0.45) ELSE 0

: c M_lamb_maturation_age = 6 {months}

: f YR_recruited = Young*YR_recruitment_rate/M_lamb__maturation_age {sheep/month}

: f Fatten_sold = CONVEYOR OUTFLOW

TRANSIT TIME = Fattening_period

: f P5_deaths = LEAKAGE OUTFLOW

LEAKAGE FRACTION = Parity_5*ewe_mortality

: f P5_culled = CONVEYOR OUTFLOW

TRANSIT TIME = Lactation_period

: c YE_health_cost = (Young_Ewe+breeding_femal__replacement)*(0.13/12) {Euro/EL/month}

: c YE_house_cost = (Young_Ewe+breeding_femal__replacement)*(0.11/12) {Euro/EL/month}

: c YE_labour_cost = (Young_Ewe+breeding_femal__replacement)*((0.144/12) {Euro/EL/month}

: c YE_costs = YE_health_cost+YE_house_cost+YE_labour_cost {Euro/month}

: c Ewe_health_cost = ((Party_1+Parity_2+Parity_3+Parity_4+Parity_5+Pregnant_2+Pregnant_3+Pregnant_4+pregnant_5+Pregnant_1+Dry_ewe_1+Dry_ewe_2+Dry_ewe_3+Dry_ewes_4)*(0.13/12)) {Euro}

: c Ewe_house_cost = ((Party_1+Parity_2+Parity_3+Parity_4+Parity_5+Pregnant_2+Pregnant_3+Pregnant_4+Pregnant_1+pregnant_5+Dry_ewe_1+Dry_ewe_2+Dry_ewe_3+Dry_ewes_4)*(0.11/12)) {Euro}

: c Ewe_labour_cost = ((Party_1+Parity_2+Parity_3+Parity_4+Parity_5+Pregnant_2+Pregnant_3+Pregnant_4+pregnant_5+Pregnant_1+Dry_ewe_1+Dry_ewe_2+Dry_ewe_3+Dry_ewes_4)*((0.144/12)*8)) {Euro}

: c Ewe_cost = ewe_health_cost+ewe_house_cost+ewe_labour_cost {Euro}

: c Health_cost = Fattening*(0.13/12) {Euro/month}

: c Housing_cost = Fattening*(0.11/12) {Euro/month}

: c Labour_cost = Fattening*((0.144/12) {Euro/month}

: c F_costs = health_cost+housing_cost+labour_cost {Euro}

: c L_health_cost = Young*(0.3/12) {Euro/month}

: c L_house_cost = Young*(0.25/12) {Euro/month}

: c L_labour_cost = Young*((0.36/12) {Euro/month}

: c Young_Cost = L_health_cost+L_house_cost+L_labour_cost {Euro}

DOCUMENT: 50% of the matured health, housing and labour costs

: f YE_sold = Young_Ewe*Selling_rate {Sheep}

: c YR_selling_rate = IF(months =1) THEN (0.7) ELSE IF (months = 2) THEN (0.7) ELSE IF(months =3) THEN (0.7) ELSE IF(months = 4) THEN (0.7) ELSE IF(months = 5) THEN(0.6) ELSE IF(months = 6) THEN (0.5) ELSE IF(months = 7) THEN (0.6) ELSE IF(months = 8) THEN (0.6) ELSE IF(months = 9) THEN (0.6) ELSE IF(months = 10) THEN (0.6) ELSE IF(months =11) THEN(0.7) ELSE IF(months=12)THEN (0.7) ELSE 0

: f YR_sold = Young_Ram*YR_selling_rate {sheep/month}

: c Cost = 0.03 {Euro/km}

DOCUMENT: transport cost

: c km = RANDOM(2, 3) {km}

: c Marketing_cost = (YE_sold+ewe_1_culled+ewe_2_culled+ewe_3_culled+ewe_4_culled+P5_culled+YR_sold+Fatten_sold+BF_culled)*cost*km {Euro}

: c Ram_housing_cost = Breeding_ram*(0.11/12) {Euro/month}

: c Ram_health_cost = Breeding_ram*(0.13/12) {Euro/month}

: c Ram_labour_cost = Breeding_ram*((0.144/12) {Euro/month}

: c Ram_cost = ram_housing_cost+ram_health_cost+ram_labour_cost {Euro}

: c YR_house_cpst = Young_Ram*(0.11/12) {Euro/month}

: c YR_health_cost = Young_Ram*(0.13/12) {Euro/month}

: c YR_labour_cost = Young_Ram*((0.144/12) {Euro/month}

: c YR_cost = YR_house_cpst+YR_health_cost+YR_labour_cost {Euro}

: c Management_costs = YE_costs+ewe_cost+F_costs+Young_Cost+marketing_cost+ram_cost+YR_cost {Euro}

: c Residue_price = 0.20 {Euro/kgDM}

: c Daily_supplement_intake = IF(Ram_FattenLW >24) THEN (0.5) ELSE 0 {kgDM/day}

: c Monthly_suplement_intake = Daily_supplement_intake*30.4 {kgDM/month}

: c TDMI_Supplemet = Fattening*Monthly_suplement_intake

: c Barley_price = 0.40 {Euro/kg}

: c Feed_costs = (Management_costs*0.50) + (Residue_Actual_DMI_per_ha*residue_price) + (TDMI_Supplemet*barley_price) {Euro}

: c Lamb_mortality__rate = IF(months =1) THEN (0.2) ELSE IF (months = 2) THEN (0.2) ELSE IF(months =3) THEN (0.1) ELSE IF(months = 4) THEN (0.1) ELSE IF(months = 5) THEN(0.05) ELSE IF(months = 6) THEN (0.03) ELSE IF(months = 7) THEN (0) ELSE

IF(months = 8) THEN (0) ELSE IF(months = 9) THEN (0) ELSE IF(months = 10) THEN (0.02) ELSE IF(months =11) THEN(0.2) ELSE IF(months=12)THEN (0.2) ELSE 0

: c New_Mortality = Lamb_mortality_rate - (Lamb_mortality_rate*0.5)

DOCUMENT: Mortality was reduced by half with geneteic selection scenario

: f Lamb_deaths = IF (TIME < 120) THEN (Young*Lamb_mortality__rate) ELSE IF (TIME >= 120) THEN (Young*New_Mortality) ELSE 0

: f YE_mortality = Young_Ewe*YE_mortality_rate

: c Ewe_death__price = 0.25 {Euro/kg}

: c Ewe_deaths = ((P1_deaths+P2_deaths+P3_deaths+P4_deaths+P5_deaths)*Actual_lact_LW*ewe_death__price) {Sheep}

: c Fatten_price = 1.1 {Euro/kg}

: c Ram_Fatten_improvement = GRAPH(TIME)

(120, 29.0), (126, 29.3), (132, 29.6), (138, 29.9), (144, 30.2), (150, 30.5), (156, 30.8), (162, 31.1), (168, 31.4), (174, 31.7), (180, 32.0), (186, 32.3), (192, 32.6), (198, 32.9), (204, 33.2), (210, 33.5), (216, 33.8), (222, 34.1), (228, 34.4), (234, 34.7), (240, 35.0) {kg}

: c F_revenue = fatten_price*Fatten_sold*Ram_Fatten_improvement {Euro}

: c YE_price = 0.5 {Euro/kg}

: c Total_herd = ROUND(Breeding_ram+Young_Ewe+Young+Young_Ram+Dry_ewes+lactating_ewes+pregnant_ewes+Fattening+breeding_femal__replacement) {sheep}

: c Total_Actual__DM__per_ha = Pasture_Actual__DM__per_ha+Residue_Actual__DMI_per_ha

: c Herd_Equilibrium= IF (Total_Actual__DM__per_ha = Total_herd_DD_per_Ha) THEN (Total_herd) ELSE IF (Total_herd_DD_per_Ha >Total_Actual__DM__per_ha) THEN (Total_herd-(Young_Ewe)) ELSE (Total_herd)

: c YE_sold_due_to_feed = Total_herd- Herd_Equilibrium {Sheep}

: c YE_revenue = EL_price*(EL_sold+EL_sold_due_to_feed)*Actual_YE_LW {Euro}

: c Ram_price = 0.5 {Euro/kg}

: c Ram_deaths_2 = Ram_deaths*ram_price*Actual_Ram_LW

: c YR_sold_price = 0.67 {Euro/kg}

: c YR_revenue = YR_sold*YR_sold_price*Actual_YR_LW {Euro}

: c Culled_Ewe_price = 0.6 {Euro/kg}

: c Culled_ewe_revenue = ((ewe_1_culled+ewe_2_culled+ewe_3_culled+ewe_4_culled+P5_culled)*Actual_Dry_ewe_LW*culled_price) + (BF_culled*Actual_YE_LW*culled_price) {Euro}

: c Young_price = 0.1 {Euro/kg}

: c Young_deaths = Actual_Lamb_LW*lamb__deaths*young__price

: c YR_mortality_rate = IF(months =1) THEN (0.1) ELSE IF (months = 2) THEN (0.1) ELSE IF(months =3) THEN (0.1) ELSE IF(months = 4) THEN (0.05) ELSE IF(months = 5) THEN(0.03) ELSE IF(months = 6) THEN (0.03) ELSE IF(months = 7) THEN (0.01) ELSE IF(months = 8) THEN (0.01) ELSE IF(months = 9) THEN (0.01) ELSE IF(months = 10) THEN (0.05) ELSE IF(months =11) THEN(0.1) ELSE IF(months=12)THEN (0.1) ELSE 0

: f YR_mortality = Young_Ram*YR_mortality__rate {sheep/month}

: c YR_price = 0.15 {Euro/kg}

: c YR_deaths = YR_mortality*(Actual_YR_LW*YR_price)

: c YE_price = 0.1 {Euro/kg}

: c YE_deaths = YE_mortality*Actual_YE_LW*YE_price

: c Deaths = ewe_deaths+ram_deaths_2+young_deaths+YR_deaths+YE_deaths

: c Actual_DM_per_TLU = (Total_Actual_DM_per_ha/TLU)*30 { kgDM/TLU/month }

DOCUMENT: The amount of DM required by TLU/month

:c price_per_kg_of_wool = 0.25 {Euro}

:c Wool_revenue = ((Breeding_ram*price_per_kg_of_wool)+((Young_Ewe+Breeding_female__replacement)*0.5*price_per_kg_of_wool)+(Fattening*price_per_kg_of_wool)+(Young_Ram*0.5*price_per_kg_of_wool)+(Dry_ewes*0.5*price_per_kg_of_wool))/6 {Euro}

: f Revenues = culled_ewe_revenue+YE_revenue+F_revenue+YR_revenue+Wool_revenue {Euro}

: f Costs = Management_costs+feed_costs+Deaths {Euro}

: c Financial_efficiency = Revenues/Costs

: c total_ewes = Dry_ewes+lactating_ewes+pregnant_ewes+breeding_femal__replacement {sheep}

: c Total_Grain__production = Grain*Crop_area {kg}

: c Total_YE = Young_Ewe-YE_sold_due_to_feed

: c Labour_needed = 3 {days}

: c price_per_8_hr = 1 {Euro}

: c Farm_preparation_cost = (Labour_needed*price_per_8_hr) {Euro/ha}

: c Barley_Grain_Revenue = (Grain)*barley__price {Euro}

: c Barely_residue_revenue = (Residue)*residue__price {Euro}

: s Barley_Gross_Profit = 0 {Euro}

: c Barley_Stubble_Revenue = (stubble)*residue__price {Euro}

: f Barley_Revenue = Barely_residue_revenue+barley_Grain_Revenue+Barley_Stubble_Revenue

: c Harvesting__cost = (Labour_needed*price_per_8_hr) {Euro/ha}

: c Price_per_Km_per_kg = 0.001{Euro}

: c Distance = 3 {km}

: c Market_transport_cost = (Grain*Price_per_Km__per_kg*Distance) {Euro/kg}

: c weeding_cost = (Labour_needed*price_per_8_hr) {Euro/ha}

: f Barley_Costs = farm_preparation__cost+harvesting__cost+market_transport__cost+weeding__cost {Euro}

: c Total_DM_demand__per_TLU = (Total_herd_DD_per_Ha/TLU*30) { kgDM/TLU/month }

DOCUMENT: The amount of DM required by TLU/month

: c Sold_ram_price = 0.7 {Euro/kg}

: c Ram_revenue = Ram_sold*sold_ram_price*Actual_Ram_LW {Euro}

: s Gross_profit = 0 {Euro}

: c Lamb_improvement = GRAPH(TIME)

(120, 13.4), (126, 13.7), (132, 14.0), (138, 14.3), (144, 14.6), (150, 14.9), (156, 15.2), (162, 15.5), (168, 15.8), (174, 16.1), (180, 16.4), (186, 16.7), (192, 17.0), (198, 17.3), (204, 17.6), (210, 17.9), (216, 18.2), (222, 18.5), (228, 18.8), (234, 19.1), (240, 19.4) {kg}

: c Ram_improvement = GRAPH(TIME)

(120, 24.0), (132, 24.6), (144, 25.2), (156, 25.8), (168, 26.4), (180, 27.0), (192, 27.6), (204, 28.2), (216, 28.8), (228, 29.4), (240, 30.0) {kg}

: c Ewe_improvement = GRAPH(TIME)

(120, 22.0), (132, 22.6), (144, 23.2), (156, 23.8), (168, 24.4), (180, 25.0), (192, 25.6), (204, 26.2), (216, 26.8), (228, 27.4), (240, 28.0) {kg}

: c YE_improvement = GRAPH(TIME)

(120, 20.3), (132, 20.9), (144, 21.5), (156, 22.1), (168, 22.7), (180, 23.3), (192, 23.9), (204, 24.5), (216, 25.1), (228, 25.7), (240, 26.3) {kg}

: c YR_improvement = GRAPH(TIME)

(120, 21.4), (132, 22.0), (144, 22.6), (156, 23.2), (168, 23.8), (180, 24.4), (192, 25.0), (204, 25.6), (216, 26.2), (228, 26.8), (240, 27.4) {kg}

: c Gross_Profit = Revenues-Costs {Euro/month}

: c Monthly_MEYRm = MEYRm*30.4

: c Monthly_MEg_YR = MEg_YR*30.4

: c Monthly_MEYEm = MEYEm*30.4

: c Monthly_MEg_YE = MEg_YE*30.4

: c Monthly_MERm = MERm*30.4

: c Momnthly_MEYm = MEYm*30.4

: c MEFm = 1.4+(0.15*Ram_FattenLW) {MJME/month}

: c Jan_T = if (MPPT_RF<0.03) then 4 else if (MPPT_RF<0.15) then 6 else if (MPPT_RF<0.31) then 12 else if (MPPT_RF<0.48) then 13 else if (MPPT_RF<0.87) then 19 else if (MPPT_RF<=1) then 20 else 0

: c Feb_T = if (MPPT_RF<0.08) then 6 else if (MPPT_RF<0.12) then 7 else if (MPPT_RF<0.17) then 8 else if (MPPT_RF<0.42) then 13 else if (MPPT_RF<0.51) then 14 else if (MPPT_RF<=1) then 19 else 0

: c Mar_T = if (MPPT_RF<0.04) then 7 else if (MPPT_RF<0.19) then 8 else if (MPPT_RF<0.27) then 13 else if (MPPT_RF<0.52) then 14 else if (MPPT_RF<0.64) then 19 else if (MPPT_RF<=1) then 20 else 0

: c Apr__T = if (MPPT_RF<0.04) then 7 else if (MPPT_RF<0.14) then 8 else if (MPPT_RF<0.2) then 9 else if (MPPT_RF<0.28) then 13 else if (MPPT_RF<0.54) then 14 else if (MPPT_RF<0.76) then 18 else if (MPPT_RF<0.88) then 19 else if (MPPT_RF<=1) then 20 else 0

: c May_T = if (MPPT_RF<0.09) then 8 else if (MPPT_RF<0.2) then 9 else if (MPPT_RF<0.53) then 14 else if (MPPT_RF<=1) then 20 else 0

: c Jun_T = if (MPPT_RF<0.09) then 8 else if (MPPT_RF<0.2) then 9 else if (MPPT_RF<0.36) then 14 else if (MPPT_RF<0.53) then 15 else if (MPPT_RF<0.64) then 19 else if (MPPT_RF<0.76) then 20 else if (MPPT_RF<=1) then 21 else 0

: c Jul_T = if (MPPT_RF<0.24) then 8 else if (MPPT_RF<0.33) then 12 else if (MPPT_RF<0.62) then 13 else if (MPPT_RF<0.74) then 16 else if (MPPT_RF<0.87) then 17 else if (MPPT_RF<=1) then 18 else 0

: c Aug_T = if (MPPT_RF<0.21) then 8 else if (MPPT_RF<0.29) then 12 else if (MPPT_RF<0.55) then 13 else if (MPPT_RF<0.88) then 17 else if (MPPT_RF<=1) then 18 else 0

: c Sep_T = if (MPPT_RF<0.05) then 7 else if (MPPT_RF<0.21) then 8 else if (MPPT_RF<0.36) then 12 else if (MPPT_RF<0.54) then 13 else if (MPPT_RF<0.76) then 17 else if (MPPT_RF<=1) then 18 else 0

: c Oct_T = if (MPPT_RF<0.04) then 5 else if (MPPT_RF<0.08) then 6 else if (MPPT_RF<0.18) then 7 else if (MPPT_RF<0.34) then 11 else if (MPPT_RF<0.51) then 12 else if (MPPT_RF<0.63) then 16 else if (MPPT_RF<=1) then 17 else 0

: c Nov_T = if (MPPT_RF<0.02) then 3 else if (MPPT_RF<0.09) then 4 else if (MPPT_RF<0.13) then 5 else if (MPPT_RF<0.29) then 10 else if (MPPT_RF<0.46) then 11 else if (MPPT_RF<0.59) then 16 else if (MPPT_RF<=1) then 17 else 0

: c Dec_T = if (MPPT_RF<0.02) then 3 else if (MPPT_RF<0.08) then 4 else if (MPPT_RF<0.13) then 6 else if (MPPT_RF<0.20) then 10 else if (MPPT_RF<0.37) then 11 else if (MPPT_RF<0.46) then 12 else if (MPPT_RF<=1) then 18 else 0

: c Monthly_Temp = IF(months=1) THEN(Jan_T) ELSE IF(months=2) THEN (Feb_T) ELSE IF(months=3) THEN (Mar_T) ELSE IF(months=4)THEN(Apr__T) ELSE IF(months=5) THEN (May_T) ELSE IF(months=6) THEN (Jun_T) ELSE IF(months=7) THEN (Jul_T) ELSE IF(months=8) THEN (Aug_T) ELSE IF(months=9) THEN (Sep_T) ELSE IF(months=10) THEN (Oct_T) ELSE IF(months=11) THEN (Nov_T) ELSE IF(months=12) THEN (Dec_T) ELSE 0 {mm/month}

: c Monthly_MEg_Young = MEg_Young*30.4

: c Monthly_MEg_Fatten = MEg_fatten*30.4

: c Monthly_MEFm = MEFm*30.4

: c Monthly_MELm = MELm*30.4

: c Monthly_MEDm = MEDm*30.4

: c Monthly_MEPm = MEPm*30.4

: c Monthly_MElac = MElac*30.4

: c Dry_ewes_energy = Dry_ewes*Monthly_MEDm

: c Fatten_energy = (Monthly_MEFm+Monthly_MEg_Fatten)*Fattening

: c Lactating_ewes_energy = (Monthly_MElac+Monthly_MELm)*lactating_ewes

: c Pregnant_energy = Monthly_MEPm*pregnant_ewes

: c Ram_energy = Monthly_MERm*Breeding_ram

: c YE_energy = (Monthly_MEg_YE+Monthly_MEYEm)*(Young_Ewe+breeding_femal__replacement)

: c Young_energy = (Momnthly_MEYm+Monthly_MEg_Young)*Young

: c YR_energy = (Monthly_MEg_YR+Monthly_MEYRm)*Young_Ram

: c Total_Herd_ME_Demand = (dry_ewes_energy+Fatten_energy+Lactating_ewes_energy+Pregnant_energy+Ram_energy +YE_energy+Young_energy+YR_energy)*RIF {MJ/month}

: c ME_Demand_per_ha = Total_Herd__ME_Demand/Grazing_area {MJ/month/ha}

: c RDP_Required = 7.8*ME_Demand_per_ha {g/month}

: c TMP = 0.42*RDP_Required

: c Feed_Gap = ROUND(Total_Actual__DM__per_ha-Total_herd_DD_per_Ha)

: c Energy_Deficit = ME_Supplied_by_diet-ME_Demand_per_ha

: c Actual_Lamb_improvement = IF(months =1) THEN (Lamb_improvement*(RANDOM(0.95,1))) ELSE IF (months = 2) THEN (Lamb_improvement*(RANDOM(0.95,1))) ELSE IF(months =3) THEN (Lamb_improvement*(RANDOM(0.95,1))) ELSE IF(months = 4) THEN (Lamb_improvement*(RANDOM(0.95,1))) ELSE IF(months = 5) THEN(Lamb_improvement*(RANDOM(0.95,1))) ELSE IF(months = 6) THEN (Lamb_improvement*(RANDOM(0.95,1))) ELSE IF(months = 7) THEN (Lamb_improvement*(RANDOM(1,1.05))) ELSE IF(months = 8) THEN (Lamb_improvement*(RANDOM(1,1.05))) ELSE IF(months = 9) THEN (Lamb_improvement*(RANDOM(1,1.05))) ELSE IF(months = 10) THEN (Lamb_improvement*(RANDOM(0.95,1))) ELSE IF(months =11) THEN(Lamb_improvement*(RANDOM(0.95,1))) ELSE IF(months=12)THEN (Lamb_improvement*(RANDOM(0.95,1))) ELSE (Lamb_improvement) {kg}

: c Actual_Birth_Weight_Improvement = IF(months =1) THEN (Birth_weight_Improvement*(RANDOM(0.95,1))) ELSE IF (months = 2) THEN (Birth_weight_Improvement*(RANDOM(0.95,1))) ELSE IF(months =3) THEN (Birth_weight_Improvement*(RANDOM(0.95,1))) ELSE IF(months = 4) THEN (Birth_weight_Improvement*(RANDOM(0.95,1))) ELSE IF(months = 5) THEN(Birth_weight_Improvement*(RANDOM(0.95,1))) ELSE IF(months = 6) THEN (Birth_weight_Improvement*(RANDOM(0.95,1))) ELSE IF(months = 7) THEN (Birth_weight_Improvement*(RANDOM(1,1.05))) ELSE IF(months = 8) THEN (Birth_weight_Improvement*(RANDOM(1,1.05))) ELSE IF(months = 9) THEN (Birth_weight_Improvement*(RANDOM(1,1.05))) ELSE IF(months = 10) THEN (Birth_weight_Improvement*(RANDOM(0.95,1))) ELSE IF(months =11) THEN(Birth_weight_Improvement*(RANDOM(0.95,1))) ELSE IF(months=12)THEN (Birth_weight_Improvement*(RANDOM(0.95,1))) ELSE (Birth_weight_Improvement) {kg}

: c Actual_YE_improvement = IF(months =1) THEN (YE_improvement*(RANDOM(0.95,1))) ELSE IF (months = 2) THEN (YE_improvement*(RANDOM(0.95,1))) ELSE IF(months =3) THEN (YE_improvement*(RANDOM(0.95,1))) ELSE IF(months = 4) THEN (YE_improvement*(RANDOM(0.95,1))) ELSE IF(months = 5) THEN(YE_improvement*(RANDOM(0.95,1))) ELSE IF(months = 6) THEN (YE_improvement*(RANDOM(0.95,1))) ELSE IF(months = 7) THEN (YE_improvement*(RANDOM(1,1.05))) ELSE IF(months = 8) THEN (YE_improvement*(RANDOM(1,1.05))) ELSE IF(months = 9) THEN (YE_improvement*(RANDOM(1,1.05))) ELSE IF(months = 10) THEN (YE_improvement*(RANDOM(0.95,1))) ELSE IF(months =11) THEN(YE_improvement*(RANDOM(0.95,1))) ELSE IF(months=12)THEN (YE_improvement*(RANDOM(0.95,1))) ELSE (YE_improvement) {kg}

: c Actual_YR_improvement = IF(months =1) THEN (YR_improvement*(RANDOM(0.95,1))) ELSE IF (months = 2) THEN (YR_improvement*(RANDOM(0.95,1))) ELSE IF(months =3) THEN (YR_improvement*(RANDOM(0.95,1))) ELSE IF(months = 4) THEN (YR_improvement*(RANDOM(0.95,1))) ELSE IF(months = 5) THEN(YR_improvement*(RANDOM(0.95,1))) ELSE IF(months = 6) THEN (YR_improvement*(RANDOM(0.95,1))) ELSE IF(months = 7) THEN (YR_improvement*(RANDOM(1,1.05))) ELSE IF(months = 8) THEN (YR_improvement*(RANDOM(1,1.05))) ELSE IF(months = 9) THEN (YR_improvement*(RANDOM(1,1.05))) ELSE IF(months = 10) THEN (YR_improvement*(RANDOM(0.95,1))) ELSE IF(months =11) THEN(YR_improvement*(RANDOM(0.95,1))) ELSE IF(months=12)THEN (YR_improvement*(RANDOM(0.95,1))) ELSE (YR_improvement) {kg}

: c Actual_Ram_improvement = IF(months =1) THEN (Ram_improvement*(RANDOM(0.95,1))) ELSE IF (months = 2) THEN (Ram_improvement*(RANDOM(0.95,1))) ELSE IF(months =3) THEN (Ram_improvement*(RANDOM(0.95,1))) ELSE IF(months = 4) THEN (Ram_improvement*(RANDOM(0.95,1))) ELSE IF(months = 5) THEN(Ram_improvement*(RANDOM(0.95,1))) ELSE IF(months = 6) THEN (Ram_improvement*(RANDOM(0.95,1))) ELSE IF(months = 7) THEN (Ram_improvement*(RANDOM(1,1.05))) ELSE IF(months = 8) THEN (Ram_improvement*(RANDOM(1,1.05))) ELSE IF(months = 9) THEN (Ram_improvement*(RANDOM(1,1.05))) ELSE IF(months = 10) THEN (Ram_improvement*(RANDOM(0.95,1))) ELSE IF(months =11)

THEN(Ram_improvement*(RANDOM(0.95,1))) ELSE IF(months=12)THEN (Ram_improvement*(RANDOM(0.95,1))) ELSE (Ram_improvement) {kg}

: c Actaul_Ewe_improvement = IF(months =1) THEN (Ewe_improvement*(RANDOM(0.95,1))) ELSE IF (months = 2) THEN (Ewe_improvement*(RANDOM(0.95,1))) ELSE IF(months =3) THEN (Ewe_improvement*(RANDOM(0.95,1))) ELSE IF(months = 4) THEN (Ewe_improvement*(RANDOM(0.95,1))) ELSE IF(months = 5) THEN(Ewe_improvement*(RANDOM(0.95,1))) ELSE IF(months = 6) THEN (Ewe_improvement*(RANDOM(0.95,1))) ELSE IF(months = 7) THEN (Ewe_improvement*(RANDOM(1,1.05))) ELSE IF(months = 8) THEN (Ewe_improvement*(RANDOM(1,1.05))) ELSE IF(months = 9) THEN (Ewe_improvement*(RANDOM(1,1.05))) ELSE IF(months = 10) THEN (Ewe_improvement*(RANDOM(0.95,1))) ELSE IF(months =11) THEN(Ewe_improvement*(RANDOM(0.95,1))) ELSE IF(months=12)THEN (Ewe_improvement*(RANDOM(0.95,1))) ELSE (Ewe_improvement) {kg}

: c Residue_suplmented = (Residue_Actual__DMI_per_ha*100)/Total_Actual__DM__per_ha

{RUNTIME EQUATIONS}

: s Breeding_female__replacement(t) = breeding_femal__replacement(t - dt) + (Female_maturation - Conceived - BF_culled) * dt {Sheep}

: s Breeding_ram(t) = Breeding_ram(t - dt) + (YR_matured - Ram_to_fattening - Ram_deaths - Ram_sold) * dt {Sheep}

: s Young(t) = Young(t - dt) + (Births - YE_recruited - YR_recruited - lamb__deaths) * dt {Sheep}

: s Young_Ram(t) = Young_Ram(t - dt) + (YR_recruited - YR_matured - YR_sold - YR_mortality) * dt {Sheep}

: s Dry_standing_vegetation(t) = Dry_standing_vegetation(t - dt) + (GSCOUT + Being_dry - Dry_stading__vegetation_Consumed - Dry_vegetation__decomposition) * dt {kgDM}

: s Green_standing_vegetation(t) = Green_standing_vegetation(t - dt) + (Monthly_Vegetation_growth - Green_Stading__Vegetation_Consumed - GSCSin - Being_frost) * dt {kgDM}

DOCUMENT: Green Standing Forage is converted to dry stading crop via Frosts and senescence.

: s Pasture_condition(t) = Pasture_condition(t - dt) + (Cumu_Pasture_condition) * dt

DOCUMENT: Pasture condition grades are 0.5, 0.75, 1, 1.25 whire are poor, fair, good and excellent respectivelly.

: s AGE(t) = AGE(t - dt) + (AGEIN - AGEOUT) * dt

: s Senescence(t) = Senescence(t - dt) + (GSCSin - GSCOUT) * dt

: s Vegetation_frost(t) = Vegetation_frost(t - dt) + (Being_frost - Being_dry) * dt

: s Annual_Aboveground_Net__Vegetation_Consumed(t) = Annual_Aboveground_Net__Vegetation_Consumed(t - dt) + (TMVC - TANVC) * dt

: s Annual_Abovegraound_Net_Vegetation_Production(t) = Annual_Abovegraound_Net_Vegetation_Production(t - dt) + (NPM - NPY) * dt

: s Grazing_Efficiency(t) = Grazing_Efficiency(t - dt) + (INTL - OUTL) * dt

DOCUMENT: Grazing Efficency levels are 10, 12.5 and 15% whic corospondce to 40, 50 and 60% of total forage disappearnce respectivelly.

: s Annual_Rainfall(t) = Annual_Rainfall(t - dt) + (MRF - TANRF) * dt

: s Green_standing_Barley(t) = Green_standing_Barley(t - dt) + (Barley_growth - maturation - Vegetation_Being_Frost) * dt

DOCUMENT: Green Standing Forage is converted to dry stading crop via Frosts and senescence.

: s Young_Ewe(t) = Young_Ewe(t - dt) + (YE_recruited - YE_sold - YE_mortality - Female_maturation) * dt {Sheep}

: s Matured_Barley(t) = Matured_Barley(t - dt) + (maturation - GSCOUT_2) * dt

: s Harvested_barley(t) = Harvested_barley(t - dt) + (GSCOUT_2 + barley_being_dry - stubble - Residue - Grain) * dt

: s Barley_frost(t) = Barley_frost(t - dt) + (Vegetation_Being_Frost - barley_being_dry) * dt

: s Annual_Crop_Residue__produced(t) = Annual_Crop_Residue__produced(t - dt) + (TMCRP - TANCRP) * dt

: s Barley_Gross_Profit(t) = Barley_Gross_Profit(t - dt) + (Barley_Revenue - Barley_Costs) * dt

: s Gross_profit(t) = Gross_profit(t - dt) + (Revenues - Costs) * dt {Euro}

: I Fattening(t) = Fattening(t - dt) + (Ram_to_fattening - Fatten_sold) * dt {Sheep}

: I Pregnant_1(t) = Pregnant_1(t - dt) + (Conceived - Lambing_1) * dt {Sheep}

: I Party_1(t) = Party_1(t - dt) + (Lambing_1 - Lactation_1 - P1_deaths) * dt {Sheep}

: I Dry_ewe_1(t) = Dry_ewe_1(t - dt) + (Lactation_1 - Concieved_2 - ewe_1_culled) * dt {Sheep}

: I Parity_2(t) = Parity_2(t - dt) + (Lambing_2 - Lactation_2 - P2_deaths) * dt {Sheep}

: I Pregnant_2(t) = Pregnant_2(t - dt) + (Concieved_2 - Lambing_2) * dt {Sheep}

: I Dry_ewe_2(t) = Dry_ewe_2(t - dt) + (Lactation_2 - Concieved_3 - ewe_2_culled) * dt {Sheep}

: I Parity_3(t) = Parity_3(t - dt) + (Lambing_3 - Lactation_3 - P3_deaths) * dt {Sheep}

: I Dry_ewe_3(t) = Dry_ewe_3(t - dt) + (Lactation_3 - Concieved_4 - ewe_3_culled) * dt {Sheep}

: I Pregnant_4(t) = Pregnant_4(t - dt) + (Concieved_4 - Lambing_4) * dt {Sheep}

: I Parity_4(t) = Parity_4(t - dt) + (Lambing_4 - Lactation_4 - P4_deaths) * dt {Sheep}

: I Dry_ewes_4(t) = Dry_ewes_4(t - dt) + (Lactation_4 - Concieved_5 - ewe_4_culled) * dt {Sheep}

: I Pregnant_3(t) = Pregnant_3(t - dt) + (Concieved_3 - Lambing_3) * dt {Sheep}

: I pregnant_5(t) = pregnant_5(t - dt) + (Concieved_5 - Lambing_5) * dt {Sheep}

: I Parity_5(t) = Parity_5(t - dt) + (Lambing_5 - P5_culled - P5_deaths) * dt {Sheep}

: c months = COUNTER(1,13)

DOCUMENT: Month of the year (1=January, 12=December)

: f YR_matured = Young_Ram/YR_maturation_age {sheep/month}

: f Ram_to_fattening = Breeding_ram/Service_period

: c Ram_mortality_rate = IF(months =1) THEN (0.1) ELSE IF (months = 2) THEN (0.1) ELSE IF(months =3) THEN (0.1) ELSE IF(months = 4) THEN (0.1) ELSE IF(months = 5) THEN(0.1) ELSE IF(months = 6) THEN (0.05) ELSE IF(months = 7) THEN (0.01) ELSE

IF(months = 8) THEN (0.01) ELSE IF(months = 9) THEN (0.01) ELSE IF(months = 10) THEN (0.01) ELSE IF(months =11) THEN(0.05) ELSE IF(months=12)THEN (0.1) ELSE 0

: f Ram_deaths = Breeding_ram*Ram_mortality_rate {sheep/month}

: c Ram_selling_rate = IF(months =1) THEN (0.5) ELSE IF (months = 2) THEN (0.5) ELSE IF(months =3) THEN (0.5) ELSE IF(months = 4) THEN (0.5) ELSE IF(months = 5) THEN(0.4) ELSE IF(months = 6) THEN (0.2) ELSE IF(months = 7) THEN (0.1) ELSE IF(months = 8) THEN (0.1) ELSE IF(months = 9) THEN (0.1) ELSE IF(months = 10) THEN (0.15) ELSE IF(months =11) THEN(0.4) ELSE IF(months=12)THEN (0.5) ELSE 0

: f Ram_sold = Breeding_ram*ram_selling_rate {sheep/month}

: c Conceiption_rate = IF(months =1) THEN (0.6) ELSE IF (months = 2) THEN (0.6) ELSE IF(months =3) THEN (0.6) ELSE IF(months = 4) THEN (0.6) ELSE IF(months = 5) THEN(0.5) ELSE IF(months = 6) THEN (0.75) ELSE IF(months = 75) THEN (0.8) ELSE IF(months = 8) THEN (0.8) ELSE IF(months = 9) THEN (0.8) ELSE IF(months = 10) THEN (0.7) ELSE IF(months =11) THEN(0.6) ELSE IF(months=12)THEN (0.6) ELSE 0

: c EL_mortality_rate = IF(months =1) THEN (0.15/12) ELSE IF (months = 2) THEN (0.1/12) ELSE IF(months =3) THEN (0.1/12) ELSE IF(months = 4) THEN (0.1/12) ELSE IF(months = 5) THEN(0.1/12) ELSE IF(months = 6) THEN (0.08/12) ELSE IF(months = 7) THEN (0.05/12) ELSE IF(months = 8) THEN (0.05/12) ELSE IF(months = 9) THEN (0.05/12) ELSE IF(months = 10) THEN (0.08/12) ELSE IF(months =11) THEN(0.1/12) ELSE IF(months=12)THEN (0.15/12) ELSE 0

: c Selling_rate = IF(months =1) THEN (0.15) ELSE IF (months = 2) THEN (0.15) ELSE IF(months =3) THEN (0.15) ELSE IF(months = 4) THEN (0.1) ELSE IF(months = 5) THEN(0.1) ELSE IF(months = 6) THEN (0.05) ELSE IF(months = 7) THEN (0) ELSE IF(months = 8) THEN (0) ELSE IF(months = 9) THEN (0) ELSE IF(months = 10) THEN (0.05) ELSE IF(months =11) THEN(0.1) ELSE IF(months=12)THEN (0.15) ELSE 0

: c Breeeding__requirtment_rate = 1-YE_mortality_rate-Selling_rate

: f Female_maturation = (Young_Ewe*Breeeding__requirtment_rate)/First_service

: f Conceived = breeding_femal__replacement*Conceiption_rate

: f BF_culled = breeding_femal__replacement*Culling_rate

: f Lambing_1 = CONVEYOR OUTFLOW

TRANSIT TIME = Gestation_period

: c Ewe_mortality = IF(months =1) THEN (0.02/12) ELSE IF (months = 2) THEN (0.01/12) ELSE IF(months =3) THEN (0.01/12) ELSE IF(months = 4) THEN (0.01/12) ELSE IF(months = 5) THEN(0.01/12) ELSE IF(months = 6) THEN (0.01/12) ELSE IF(months = 7) THEN (0) ELSE IF(months = 8) THEN (0) ELSE IF(months = 9) THEN (0) ELSE IF(months = 10) THEN (0.01/12) ELSE IF(months =11) THEN(0.02/12) ELSE IF(months=12)THEN (0.02/12) ELSE 0

: f P1_deaths = LEAKAGE OUTFLOW

LEAKAGE FRACTION = Party_1*ewe_mortality {sheep/month}

: f Lactation_1 = CONVEYOR OUTFLOW

TRANSIT TIME = Lactation_period

: f Lambing_2 = CONVEYOR OUTFLOW

TRANSIT TIME = Gestation_period

: c Ewe_Culling_rate = IF (TIME < 120) THEN (0) ELSE IF (TIME >= 120) THEN (0.03/12) ELSE IF (TIME >= 180) THEN (0) ELSE 0 {1/month}

: f ewe_1_culled = LEAKAGE OUTFLOW

LEAKAGE FRACTION = Dry_ewe_1*Ewe_Culling_rate {sheep/month}

: f Concieved_2 = CONVEYOR OUTFLOW

TRANSIT TIME = dry_period

: f P2_deaths = LEAKAGE OUTFLOW

LEAKAGE FRACTION = Parity_2*ewe_mortality

: f Lactation_2 = CONVEYOR OUTFLOW

TRANSIT TIME = Lactation_period

: f Lambing_3 = CONVEYOR OUTFLOW

TRANSIT TIME = Gestation_period

: f P3_deaths = LEAKAGE OUTFLOW

LEAKAGE FRACTION = Parity_3*ewe_mortality

: f Lactation_3 = CONVEYOR OUTFLOW

TRANSIT TIME = Lactation_period

: f Ewe_3_culled = LEAKAGE OUTFLOW

LEAKAGE FRACTION = Dry_ewe_3*Ewe_Culling_rate {sheep/month}

: f Concieved_4 = CONVEYOR OUTFLOW

TRANSIT TIME = dry_period

: f Lambing_4 = CONVEYOR OUTFLOW

TRANSIT TIME = Gestation_period

: f P4_deaths = LEAKAGE OUTFLOW

LEAKAGE FRACTION = Parity_4*ewe_mortality

: f Lactation_4 = CONVEYOR OUTFLOW

TRANSIT TIME = Lactation_period

: f Ewe_2_culled = LEAKAGE OUTFLOW

LEAKAGE FRACTION = Dry_ewe_2*Ewe_Culling_rate {sheep/month}

: f Concieved_3 = CONVEYOR OUTFLOW

TRANSIT TIME = dry_period

: f Ewe_4_culled = LEAKAGE OUTFLOW

LEAKAGE FRACTION = Dry_ewes_4*Ewe_Culling_rate {sheep/month}

: f Concieved_5 = CONVEYOR OUTFLOW

TRANSIT TIME = dry_period

: f Lambing_5 = CONVEYOR OUTFLOW

TRANSIT TIME = Gestation_period

: f Births = Lambing_1+Lambing_2+Lambing_3+Lambing_4+Lambing_5 {sheep/month}

: c YE_recruitment__rate = IF(months =1) THEN (0.45) ELSE IF (months = 2) THEN (0.475) ELSE IF(months =3) THEN (0.475) ELSE IF(months = 4) THEN (0.475) ELSE IF(months = 5) THEN(0.475) ELSE IF(months = 6) THEN (0.485) ELSE IF(months = 7) THEN (0.5) ELSE

IF(months = 8) THEN (0.5) ELSE IF(months = 9) THEN (0.5) ELSE IF(months = 10) THEN (0.48) ELSE IF(months =11) THEN(0.475) ELSE IF(months=12)THEN (0.45) ELSE 0

: f YE_recruited = Young*YE_recruitment__rate/F_lamb__maturation_age {sheep/month}

: c YR_recruitment_rate = IF(months =1) THEN (0.45) ELSE IF (months = 2) THEN (0.475) ELSE IF(months =3) THEN (0.475) ELSE IF(months = 4) THEN (0.475) ELSE IF(months = 5) THEN(0.475) ELSE IF(months = 6) THEN (0.485) ELSE IF(months = 7) THEN (0.5) ELSE IF(months = 8) THEN (0.5) ELSE IF(months = 9) THEN (0.5) ELSE IF(months = 10) THEN (0.48) ELSE IF(months =11) THEN(0.475) ELSE IF(months=12)THEN (0.45) ELSE 0

: f YR_recruited = Young*YR_recruitment_rate/M_lamb__maturation_age {sheep/month}

: f Fatten_sold = CONVEYOR OUTFLOW

TRANSIT TIME = Fattening_period

: f P5_deaths = LEAKAGE OUTFLOW

LEAKAGE FRACTION = Parity_5*ewe_mortality

: f P5_culled = CONVEYOR OUTFLOW

TRANSIT TIME = Lactation_period

Appendix 2: Equations used in expanding the simulation model to evaluate alternative management system arranged in order of execution.

{VERSION 9.0.2, INITIALIZATION EQUATIONS}
{TIME SPECS: STARTTIME=0, STOPTIME=240, DT=0.25, INTEGRATION=EULER, RUNMODE=NORMAL, PAUSEINTERVAL=INF}
: s Matured_Barley = 0
DOCUMENT: initial value in month of January
: c Harvesting_period = 1 {month}
: f GSCOUT_2 = 0.8*Matured_Barley/Harvesting_period
: s Harvested_barley = 400 {kg Dm/ha}
: c Stubble_rate = 0.05
: s Barley_frost = 0
DOCUMENT: innital valau in month of January
: f Barley_being_dry = Barley_frost*0.8
: f Stubble = Harvested_barley*stubble_rate
: c Residue_rate = 0.45
: f Residue = Harvested_barley*residue_rate
: c Yield_rate = 0.5
: f Barley_Grain = Harvested_barley*yield_rate
: s Annual_Crop_Residue__produced = 0 {kgDM/month}
: c Crop_area = MAX(60) {ha}
: c Total_residue__Production = Residue*Crop_area {kg DM}
: c Total__Stubble__production = stubble*Crop_area {kg DM}
: f TMCRP = (Total_residue__Production*0.25)+Total__Stubble__production {kgDM/month/ha}
: f TANCRP = IF(months=12) THEN(Annual_Crop_Residue__produced) ELSE(0) {kgDM/year}
: s Green_standing_Vetch = (4000/12) {kg DM/ha}
: c Vetch_maturation_period = 3 {month}
: f Vetch_growth = DELAY (Monthly_rainfall*Rain_use_effeciency,1) {kg DM /ha/month}
: f Green_Vetch_Consumed = Green_standing_Vetch/Vetch_maturation_period
: f Vetch_Being_Frost = (Green_standing_Vetch-Green_Vetch_Consumed)*Mean_Monthly__Temprature
: s Annual_Green_Vetch_Produced = 0 {kgDM/month}
: f Consumed = Green_Vetch_Consumed
: f Frost = IF(months=12) THEN(Annual_Green_Vetch_Produced) ELSE(0) {kgDM/year}
: c Labour_needed = 3 {day}

: c Price_per_8_hr = 1 {Euro}

: c Crop_area_AMS = MAX(45) {ha}

: c Farm_preparation__cost_AMS = (Labour_needed*price_per_8_hr)*Crop_area_AMS {Euro/ha}

: c Harvesting__cost_AMS = (Labour_needed*price_per_8_hr)*Crop_area_AMS {Euro/ha}

: c Price_per_Km__per_kg = 0.001

: c Distance = 3 {km}

: c Market_transport__cost_AMS = (Barley_Grain*Price_per_Km__per_kg*Crop_area_AMS)*Distance {Euro/kg}

: c Weeding__cost_AMS = (Labour_needed*price_per_8_hr)*Crop_area_AMS {Euro/ha}

: c Residue__price = 0.20 {Euro/kgDM}

: c Barely_residue__revenue_AMS = (Residue*Crop_area_AMS)*residue__price {Euro}

: c Barley__price = 0.40 {Euro/kg}

: c Barley_Grain_Revenue_AMS = (Barley_Grain*Crop_area_AMS)*barley__price {Euro}

: c Barley_Stubble__Revenue_AMS = (stubble*Crop_area_AMS)*residue__price {Euro}

: f Barley_revenu_AMS = Barely_residue__revenue_AMS+barley_Grain_Revenue_AMS+Barley_Stubble__Revenue_AMS

: f Barley_cost_AMS = (farm_preparation__cost_AMS+harvesting__cost_AMS+market_transport__cost_AMS+weeding__cost_AMS)

: c MD_Residue = 7.78

: c Residue_ME_Intake = Residue_Actual__DMI_per_ha*MD_Residue {MJ/month}

: c Vetch_produced_pe_ha = Green_Vetch_Consumed+Vetch_Being_Frost

: c Vetch_ME_intake = Vetch_produced_pe_ha*M_D {MJ/month}

: c ME_Suppled_by_diet = Pature_ME_intake+Residue_ME_Intake+Vetch_ME_intake {MJ/month}

: c Total_Actual__DM__per_ha = Pasture_Actual__DM__per_ha+Residue_Actual__DMI_per_ha+Vetch_produced_pe_ha

: c DAP = 100 {kg/ha }

: c DAP_cost = 0.63 {Euro/kg}

: c Forage_area = MAX(15) {ha}

: c Fertilizer_cost = DAP*DAP_cost*Forage_area

: c Days = 4

: c Price_per_day = 1 {Euro/8 hr}

: c Labour_cost = Forage_area*Days*Price_per_day {Euro}

: c Price_kg_of_seed = 0.42 {Euro/kg }

: c Seed_per_ha = 30 {kg/ha}

: c Seed_cost = (Forage_area*priceper_kg_of_seed*seed_per_ha) { Euro}

: c Vetch_cost = (Fertilizer_cost+labour_cost+Seed_cost)/12 {Euro/month}

: c Barely_residue__revenue = (Residue*Crop_area)*residue__price {Euro}

: c Barley_Grain_Revenue = (Barley_Grain*Crop_area)*barley__price {Euro}

: c Barley_Stubble_Revenue = (stubble*Crop_area)*residue__price {Euro}

: f Barley_Revenue =
Barely_residue__revenue+barley_Grain_Revenue+Barley_Stubble_Revenue

: c Farm_preparation__cost = (Labour_needed*price_per_8_hr)*Crop_area {Euro/ha}

: c Harvesting__cost = (Labour_needed*price_per_8_hr)*Crop_area {Euro/ha}

: c Market_transport__cost = (Barley_Grain*Price_per_Km__per_kg*Crop_area)*Distance {Euro/kg}

: c Weeding__cost = (Labour_needed*price_per_8_hr)*Crop_area {Euro/ha}

: f Barley_Costs =
(farm_preparation__cost+harvesting__cost+market_transport__cost+weeding__cost) {Euro}

: c Total_Barley_marginal_profit = (Barley_Revenue-Barley_Costs)/12 {Euro/month}

: c Barley_marginal_profit_AMS = (Barley_revenu_AMS-Barley_cost_AMS)/12{Euro/month}

: c Barley_marginal__profit_lost_AMS = IF (TIME >= 1) THEN (Total_Barley_marginal_profit-Barley_marginal_profit_AMS) ELSE 0 {Euro}

: f Costs =
Management_costs+feed_costs+Deaths+Vetch_cost+Barley_marginal__profit_lost_AMS {Euro}

: c Befor_margiinal_profit = IF (TIME <120) THEN(Revenues-Costs) ELSE 0 {Euro}

: c Financial_efficiency = Revenues/Costs

: c Total_Grain__production = Barley_Grain*Crop_area {kg}

: c Total_EL = Young_Ewe-EL_sold_due_to_feed{Sheep}

: s Barley_Gross_Profit = 0 {Euro}

: c Total_DM_demand__per_TLU = (Total_herd_DD_per_Ha/TLU*30) { kgDM/TLU/month }

DOCUMENT: The amount of DM required by TLU/month

: c Residue_CP = 0.024

: c Residue_Digestablity = IF(months =1) THEN (0.49) ELSE IF (months = 2) THEN (0.54) ELSE IF(months =3) THEN (0.54) ELSE IF(months = 4) THEN (0.54) ELSE IF(months = 5) THEN(0.49) ELSE IF(months = 6) THEN (0.54) ELSE IF(months = 7) THEN (0.73) ELSE IF(months = 8) THEN (0.73) ELSE IF(months = 9) THEN (0.73) ELSE IF(months = 10) THEN (0.54) ELSE IF(months =11) THEN(0.54) ELSE IF(months=12)THEN (0.49) ELSE 0

: c RDP_supplied_by__Crop_residue =
((Residue_Actual__DMI_per_ha*1000)*Residue_CP*Residue_Digestablity) {g/month}

: c RDP_supplied_by__Natural_pasture =
((Pasture_Actual__DM__per_ha*1000)*Crude_protien_GF*DM_digestablity_of_GV)
{g/month}
: c CP_Vetch = 0.224
: c DM_digestablity_Vetch = 0.6733
: c RDP_supplied_by_Vetch =
((Vetch_produced_pe_ha*1000)*CP_Vetch*DM_digestablity_Vetch) {g/month}
: c RDP_supplied_by_diet =
(RDP_supplied_by__Crop_residue+RDP_supplied_by__Natural_pasture+RDP_supplied_by_Vetch)
: S Gross_profit = 0 {Euro}
: c Feed_Gap = ROUND(Total_Actual__DM__per_ha-Total_herd_DD_per_Ha)
: c Energy_Deficit = ME_Suppled_by_diet-ME_Demand_per_ha
: c Total_Vetch_Forage = Green_Vetch_Consumed*Forage_area {kg DM}
: c Total_Vetch_Frost = Vetch_Being_Frost*Forage_area {kg DM}
: s Brley_Gross_profit_AMS = 0 {Euro }
: c Lamb_Vetch__suppplemet_per_dy = 0.05 {kg/day}
: c Young_Vetch_DMI__per_month =
(Actual_Lamb_LW*Lamb_Vetch__suppplemet_per_dy*Young)*30.4 { DMkg/month}
: c Vetch_supplement__per_day = 0.01{kg/day}
: c YE_Vetch_DMI__per_month =
(Young_ewe_LW*Vetch_supplement__per_day*Young_Ewe)*30.4 { DMkg/month}
: c YR_Vetch_DMI__per_month =
(Actual_YR_LW*Vetch_supplement__per_day*Young_Ram)*30.4 { DMkg/month}
: c Ram_Vetch_DMI__per_month =
(Actual_Ram_LW*Vetch_supplement__per_day*Breeding_ram)*30.4 { DMkg/month}
: c F_Vetch_supplemt__per_day = 0.5 {kg/day}
: c Ram_Fattening__Vetch_DMI__per_month =
(Ram_FattenLW*F_Vetch_supplemt__per_day*Fattening)*30.4 { DMkg/month}
: c Ewe_Vetch_DMI__per_month =
((Dry_ewes*Vetch_supplement__per_day*Ewe_LW)+(lactating_ewes*Vetch_supplement__per_day*Lactating_ewe_LW)+(pregnant_ewes*Vetch_supplement__per_day*Pregnant_ewe_LW))*30.4
: c Total_Vech_DMI =
(Ewe_Vetch_DMI__per_month+Ram_Fattening__Vetch_DMI__per_month+Ram_Vetch_DMI__per_month+YE_Vetch_DMI__per_month+Young_Vetch_DMI__per_month+YR_Vetch_DMI__per_month) { DMkg/month}

: c Vetch_production = Vetch_produced_pe_ha*Forage_area

: c Vetch_gap = Vetch_production-Total_Vech_DMI

: c Herd = IF (Vetch_gap>= 0) THEN (Total_herd) ELSE IF (Vetch_gap<0) THEN (Total_herd-Young_Ewe) ELSE 0

{RUNTIME EQUATIONS}

: s Annual_Rainfall(t) = Annual_Rainfall(t - dt) + (MRF - TANRF) * dt

: s Green_standing_Barley(t) = Green_standing_Barley(t - dt) + (Barley_growth - maturation - Vegetation_Being_Frost) * dt

DOCUMENT: Green Standing Forage is converted to dry stading crop via Frosts and senescence.

: s Matured_Barley(t) = Matured_Barley(t - dt) + (maturation - GSCOUT_2) * dt

: s Harvested_barley(t) = Harvested_barley(t - dt) + (GSCOUT_2 + barley_being_dry - stubble - Residue - Barley_Grain) * dt

: s Barley_frost(t) = Barley_frost(t - dt) + (Vegetation_Being_Frost - barley_being_dry) * dt

: s Annual_Crop_Residue__produced(t) = Annual_Crop_Residue__produced(t - dt) + (TMCRP - TANCRP) * dt

: s Green_standing_Vetch(t) = Green_standing_Vetch(t - dt) + (Vetch_growth - Green_Vetch_Consumed - Vetch_Being_Frost) * dt

: s Annual_Green_Vetch_Produced(t) = Annual_Green_Vetch_Produced(t - dt) + (consumed - frost) * dt

: s Barley_Gross_Profit(t) = Barley_Gross_Profit(t - dt) + (Barley_Revenue - Barley_Costs) * dt

: s Gross_marginal_profit(t) = Gross_marginal_profit(t - dt) + (Revenues - Costs) * dt

: s Brley_Gross_profit_AMS(t) = Brley_Gross_profit_AMS(t - dt) + (Barley_revenu_AMS - Barley_cost_AMS) * dt

: c Total_Herd_DM_Demand = SUM(TDMI_lactating_ewe,TDMI_pregnant_ewe,TDMI_fatten,TDMI_EL,TDMI_ram,TDMI_young,TDMI_YR,TDMI_dery_ewes) {kg DM/month}

: f Barley_growth = DELAY (Monthly_rainfall*Rain_use_effeciency,1) {kg DM /ha/month}

: f Maturation = Green_standing_Barley/Maturation_period

: f Barley_being_dry = Barley_frost*0.8

: f Stubble = Harvested_barley*stubble_rate

: f Residue = Harvested_barley*residue_rate

: f Barley_Grain = Harvested_barley*yield_rate

: c Crop_area = MAX(60) {ha}

: c Total_residue__Production = Residue*Crop_area {kg DM}

: c Total__Stubble__production = stubble*Crop_area {kg DM}

: f Vetch_growth = DELAY (Monthly_rainfall*Rain_use_effeciency,1) {kg DM /ha/month}
: f Green_Vetch_Consumed = Green_standing_Vetch/Vetch_maturation_period
: f Vetch_Being_Frost = (Green_standing_Vetch-Green_Vetch_Consumed)*Mean_Monthly__Temprature
: f Consumed = Green_Vetch_Consumed
: f Frost = IF(months=12) THEN(Annual_Green_Vetch_Produced) ELSE(0) {kgDM/year}
: c Crop_area_AMS = MAX(45) {ha}
: c Farm_preparation_cost_AMS = (Labour_needed*price_per_8_hr)*Crop_area_AMS {Euro/ha}
: c Harvesting_cost_AMS = (Labour_needed*price_per_8_hr)*Crop_area_AMS {Euro/ha}
: c Market_transport_cost_AMS = (Barley_Grain*Price_per_Km_per_kg*Crop_area_AMS)*Distance {Euro/kg}
: c Weeding_cost_AMS = (Labour_needed*price_per_8_hr)*Crop_area_AMS {Euro/ha}
: c Barely_residue_revenue_AMS = (Residue*Crop_area_AMS)*residue__price {Euro}
: c Barley_Grain_Revenue_AMS = (Barley_Grain*Crop_area_AMS)*barley__price {Euro}
: c Barley_Stubble_Revenue_AMS = (stubble*Crop_area_AMS)*residue__price {Euro}
: f Barley_revenu_AMS = Barely_residue_revenue_AMS+barley_Grain_Revenue_AMS+Barley_Stubble__Revenue_AMS
: f Barley_cost_AMS = (farm_preparation_cost_AMS+harvesting_cost_AMS+market_transport_cost_AMS+weeding_cost_AMS)
: c Residue_ME_Intake = Residue_Actual_DMI_per_ha*MD_Residue {MJ/month}
: c Vetch_produced_pe_ha = Green_Vetch_Consumed+Vetch_Being_Frost
: c Vetch_ME_intake = Vetch_produced_pe_ha*M_D {MJ/month}
: c Total_herd = ROUND(Breeding_ram+Young_Ewe+Young+Young_Ram+Dry_ewes+lactating_ewes+pregnant_ewes+Fattening+breeding_femal_replacement) {sheep}
: c Total_Actual_DM_per_ha = Pasture_Actual_DM_per_ha+Residue_Actual_DMI_per_ha+Vetch_produced_pe_ha
: c DAP_cost = 0.63 {Euro/kg}
: c Forage_area = MAX(15) {ha}
: c Fertilizer_cost = DAP*DAP_cost*Forage_area
: c labour_cost = Forage_area*Days*Price_per_day
: c price_per_kg_of_seed = 0.42 {Euro/kg }
: c Seed_cost = (Forage_area*priceper_kg_of_seed*seed_per_ha) {Euro}
: c Vetch_cost = (Fertilizer_cost+labour_cost+Seed_cost)/12 {Euro/month}

: c Barely_residue_revenue = (Residue*Crop_area)*residue__price {Euro}
: c barley_Grain_Revenue = (Barley_Grain*Crop_area)*barley__price {Euro}
: c Barley_Stubble_Revenue = (stubble*Crop_area)*residue__price {Euro}
: f Barley_Revenue =
Barely_residue_revenue+barley_Grain_Revenue+Barley_Stubble_Revenue
: c Farm_preparation_cost = (Labour_needed*price_per_8_hr)*Crop_area {Euro/ha}
: c Harvesting_cost = (Labour_needed*price_per_8_hr)*Crop_area {Euro/ha}
: c Market_transport_cost = (Barley_Grain*Price_per_Km__per_kg*Crop_area)*Distance {Euro/kg}
: c Weeding_cost = (Labour_needed*price_per_8_hr)*Crop_area {Euro/ha}
: f Barley_Costs =
(farm_preparation_cost+harvesting_cost+market_transport_cost+weeding_cost)
: c Total_Barley_grossl_profit = (Barley_Revenue-Barley_Costs)/12
: c Barley_gross_profit_AMS = (Barley_revenu_AMS-Barley_cost_AMS)/12
: c Barley_gross_profit_lost_AMS = IF (TIME >= 1) THEN (Total_Barley_marginal_profit-Barley_gross_profit_AMS) ELSE 0
: f Costs =
Management_costs+feed_costs+Deaths+Vetch_cost+Barley_marginal__profit_lost_AMS
: c Befor_margiinal_profit = IF (TIME <120) THEN(Revenues-Costs) ELSE 0 {Euro}
: c Financial_efficiency = Revenues/Costs
: c RDP_supplied_by_Crop_residue =
((Residue_Actual_DMI_per_ha*1000)*Residue_CP*Residue_Digestablity) {g/month}
: c RDP_supplied_by_Natural_pasture =
((Pasture_Actual_DM_per_ha*1000)*Crude_protien_GF*DM_digestablity_of_GV) {g/month}
: c RDP_supplied_by_Vetch =
((Vetch_produced_pe_ha*1000)*CP_Vetch*DM_digestablity_Vetch) {g/month}
: c RDP_supplied_by_diet =
(RDP_supplied_by_Crop_residue+RDP_supplied_by_Natural_pasture+RDP_supplied_by_Vetch)
: c Gross_Profit = Revenues-Costs
: c Total_Herd_ME_Demand =
(dry_ewes_energy+Fatten_energy+Lactating_ewes_energy+Pregnant_energy+Ram_energy+YE_energy+Young_energy+YR_energy)*RIF {MJ/month}
: c Feed_Gap = ROUND(Total_Actual_DM_per_ha-Total_herd_DD_per_Ha)
: c Energy_Deficit = ME_Suppled_by_diet-ME_Demand_per_ha
: c Total_Vetch_Forage = Green_Vetch_Consumed*Forage_area {kg DM}
: c Total_Vetch_Frost = Vetch_Being_Frost*Forage_area {kg DM}

: c Young_Vetch_DMI_per_month =
(Actual_Lamb_LW*Lamb_Vetch_suppplemet_per_dy*Young)*30.4 {kg DM/month}
: c YE_Vetch_DMI_per_month =
(Young_ewe_LW*Vetch_supplement_per_day*Young_Ewe)*30.4 {kg DM/month}
: c YR_Vetch_DMI_per_month =
(Actual_YR_LW*Vetch_supplement_per_day*Young_Ram)*30.4 {kg DM/month}
: c Ram_Vetch_DMI_per_month =
(Actual_Ram_LW*Vetch_supplement_per_day*Breeding_ram)*30.4 {kg DM/month}
: c Ram_Fattening_Vetch_DMI_per_month =
(Ram_FattenLW*F_Vetch_supplemt_per_day*Fattening)*30.4 {kg DM/month}
: c Ewe_Vetch_DMI_per_month =
((Dry_ewes*Vetch_supplement_per_day*Ewe_LW)+(lactating_ewes*Vetch_supplement_per_day*Lactating_ewe_LW)+(pregnant_ewes*Vetch_supplement_per_day*Pregnant_ewe_LW))*30.4
: c Total_Vech_DMI =
(Ewe_Vetch_DMI_per_month+Ram_Fattening_Vetch_DMI__per_month+Ram_Vetch_DMI__per_month+YE_Vetch_DMI_per_month+Young_Vetch_DMI_per_month+YR_Vetch_DMI_per_month) {kg DM/month}
: c Vetch_production = Vetch_produced_pe_ha*Forage_area
: c Vetch_gap = Vetch_production-Total_Vech_DMI
: c Herd = IF (Vetch_gap>= 0) THEN (Total_herd) ELSE IF (Vetch_gap<0) THEN
(Total_herd-Young_Ewe) ELSE 0

Appendix 3: Equations used in expanding the simulation model to predict genetic gain arranged in order of execution.

{VERSION 9.0.2, INITIALIZATION EQUATIONS}

{TIME SPECS: STARTTIME=0, STOPTIME=240, DT=0.25, INTEGRATION=EULER, RUNMODE=NORMAL, PAUSEINTERVAL=INF}

: I Pregnant_1 = 80 {sheep}

TRANSIT TIME = Gestation_period

: I Party_1 = 22 {sheep}

TRANSIT TIME = Lactation_period

: I Dry_ewe_1 = 24 {sheep}

TRANSIT TIME = Dry_period

: I Parity_2 = 32 {sheep}

TRANSIT TIME = Lactation_period

: I Pregnant_2 = 70 {sheep}

TRANSIT TIME = Gestation_period

: I Dry_ewe_2 = 14 {sheep}

TRANSIT TIME = Dry_period

: I Parity_3 = 27 {sheep}

TRANSIT TIME = Lactation_period

: I Dry_ewe_3 = 34 {sheep}

TRANSIT TIME = Dry_period

: I Pregnant_4 = 60 {sheep}

TRANSIT TIME = Gestation_period

: I Parity_4 = 26 {sheep}

TRANSIT TIME = Lactation_period

: I Dry_ewes_4 = 26 {sheep}

TRANSIT TIME = Dry_period

: I Pregnant_3 = 42 {sheep}

TRANSIT TIME = Gestation_period

: I pregnant_5 = 33 {sheep}

TRANSIT TIME = Gestation_period

: I Parity_5 = 10 {sheep}

TRANSIT TIME = Lactation_period

: c Conceiption_rate = IF(months =1) THEN (0.75) ELSE IF (months = 2) THEN (0.75) ELSE IF(months =3) THEN (0.75) ELSE IF(months = 4) THEN (0.75) ELSE IF(months = 5) THEN(0.75) ELSE IF(months = 6) THEN (0.75) ELSE IF(months = 75) THEN (0.85) ELSE

IF(months = 8) THEN (0.85) ELSE IF(months = 9) THEN (0.85) ELSE IF(months = 10) THEN (0.75) ELSE IF(months =11) THEN(0.75) ELSE IF(months=12)THEN (0.75) ELSE 0
: S Young_Ewe = 0 {sheep}
: c Female_P% = IF (TIME >= 1) THEN (RANDOM(0.70,0.79)) ELSE 0
: f Female_selected = ROUND ((Young_Ewe*Female_P%)) {sheep/month}
: f Conceived = (Breeding_female__replacement*Conceiption_rate) {sheep/month}
: c BF_culling_rate = IF (TIME <= 30) THEN (0) ELSE (0.0430)
: f BF_culling = Breeding_female__replacement*BF_culling_rate
: c Tag_cost = 0.25/12 {Euro/month}
: c Taging_cost = 0.0035/12 {Euro/month}
: c Animal_identification_cost = (Tag_cost+Taging_cost) {Euro/month}
: c FR_measuring_cost = (0.0035)/12 {Euro/month}
: c Genetic_evaluation_cost = 0.076/12 {Euro/month}
: c PWS__measuring_cost = (0.0035)/12 {Euro/month}
: c Six_month_wt_measuring = (0.0035)/12 {Euro/month}
: c Weaning_Wt_heritablity = 0.2
: c Weaning_Wt_Accurcy__of_selection = SQRT(Weaning_Wt_heritablity)
DOCUMENT: Based on won performance
: c Male_P% = If (months= 3) THEN (RANDOM(0.20,0.29)) ELSE IF (months= 8) THEN (RANDOM(0.20,0.29)) ELSE IF (months= 11) THEN (RANDOM(0.20,0.29)) ELSE 0
: c M_i_infinites_3 = GRAPH(Male_P%)
(0.01, 2.67), (0.02, 2.42), (0.03, 2.27), (0.04, 2.15), (0.05, 2.06), (0.06, 1.99), (0.07, 1.92), (0.08, 1.86), (0.09, 1.80), (0.1, 1.75), (0.11, 1.71), (0.12, 1.67), (0.13, 1.63), (0.14, 1.59), (0.15, 1.55), (0.16, 1.52), (0.17, 1.49), (0.18, 1.46), (0.19, 1.43), (0.2, 1.40), (0.21, 1.37), (0.22, 1.35), (0.23, 1.32), (0.24, 1.29), (0.25, 1.27), (0.26, 1.25), (0.27, 1.23), (0.28, 1.20), (0.29, 1.18), (0.3, 1.16), (0.31, 1.14), (0.32, 1.12), (0.33, 1.10), (0.34, 1.08), (0.35, 1.06), (0.36, 1.04), (0.37, 1.02), (0.38, 1.00), (0.39, 0.984), (0.4, 0.966), (0.41, 0.948), (0.42, 0.931), (0.43, 0.913), (0.44, 0.896), (0.45, 0.88), (0.46, 0.863), (0.47, 0.846), (0.48, 0.83), (0.49, 0.814), (0.5, 0.798)
DOCUMENT: selection intensity from table (proportion of selection (1-50%)
: c M_i_infinites_4 = GRAPH(Male_P%)
(0.5, 0.789), (0.6, 0.664), (0.7, 0.497), (0.8, 0.35), (0.9, 0.195)
: c M_I_intensity = IF(Male_P% <= 0.5) THEN (M_i_infinites_3) ELSE IF(Male_P% < 0.9) THEN(M_i_infinites_4) ELSE 0
DOCUMENT: selection intensity from table (proportion of selection (50-90%)
: c Male_SI = M_I_intensity
: c F_i_infinites_3 = GRAPH(Female_P%)

(0.01, 2.67), (0.02, 2.42), (0.03, 2.27), (0.04, 2.15), (0.05, 2.06), (0.06, 1.99), (0.07, 1.92), (0.08, 1.86), (0.09, 1.80), (0.1, 1.75), (0.11, 1.71), (0.12, 1.67), (0.13, 1.63), (0.14, 1.59), (0.15, 1.55), (0.16, 1.52), (0.17, 1.49), (0.18, 1.46), (0.19, 1.43), (0.2, 1.40), (0.21, 1.37), (0.22, 1.35), (0.23, 1.32), (0.24, 1.29), (0.25, 1.27), (0.26, 1.25), (0.27, 1.23), (0.28, 1.20), (0.29, 1.18), (0.3, 1.16), (0.31, 1.14), (0.32, 1.12), (0.33, 1.10), (0.34, 1.08), (0.35, 1.06), (0.36, 1.04), (0.37, 1.02), (0.38, 1.00), (0.39, 0.984), (0.4, 0.966), (0.41, 0.948), (0.42, 0.931), (0.43, 0.913), (0.44, 0.896), (0.45, 0.88), (0.46, 0.863), (0.47, 0.846), (0.48, 0.83), (0.49, 0.814), (0.5, 0.798)

DOCUMENT: selection intensity from table (proportion of selection (0.01-0.5%)

: c F_i_infinites_4 = GRAPH(Female_P%)

(0.5, 0.789), (0.6, 0.664), (0.7, 0.497), (0.8, 0.35), (0.9, 0.195)

DOCUMENT: selection intensity from table (proportion of selection (0.5-0.9%)

: c F_I_intensity = IF(Female_P% <= 0.5) THEN (F_i_infinites_3) ELSE IF(Female_P% <= 0.9) THEN(F_i_infinites_4) ELSE 0

: c Female_SI = F_I_intensity

: c Allocation_22 = 0.5

: c Breeding_ewes__in_use = 60

: c Female_Replacement__rate = 1/Breeding_ewes__in_use

: c percentage_of_ewes_1 = Female_Replacement__rate

: c Product_22 = Allocation_22*percentage_of_ewes_1*0.5

: c Gene_%__age_class_2 = Product_22

: c Allocation_32 = 0.5

: c Product_32 = Allocation_32*percentage_of_ewes_1*0.5

: c Allocation_33 = 0.4

: c Survival_rate = 0.9

: c Percentage_of_ewes_2 = Female_Replacement__rate*Survival_rate

: c Product_33 = Allocation_33*Percentage_of_ewes_2*0.5

: c Gene_%_age_class_3 = Product_32+Product_33

: c Allocation_43 = 0.6

: c Product_43 = Allocation_43*Percentage_of_ewes_2*0.5

: c Allocation_44 = 0.3

: c Percentage_of_ewes_3 = Female_Replacement__rate*Survival_rate*Survival_rate

: c Product_44 = Allocation_44*Percentage_of_ewes_3*0.5

: c Gene_%_age_class_4 = Product_43+Product_44

: c Allocation_54 = 0.7

: c Product_54 = Allocation_54*Percentage_of_ewes_3*0.5

: c Allocation_55 = 0.2

: c Percentage_of_ewes_4 =
Female_Replacement__rate*Survival_rate*Survival_rate*Survival_rate
: c Product_55 = Allocation_55*Percentage_of_ewes_4*0.5
: c Gene_%_age_class_5 = Product_54+Product_55
: c Allocation_65 = 0.8
: c Product_65 = Allocation_65*Percentage_of_ewes_4*0.5
: c Allocation_66 = 0.1
: c Percentage_of_ewes_5 =
Female_Replacement__rate*Survival_rate*Survival_rate*Survival_rate*Survival_rate
: c Product_66 = Allocation_66*Percentage_of_ewes_5*0.5
: c Gene_%_age_class_6 = Product_65+Product_66
: c Allocation_76 = 0.9
: c Product_76 = Allocation_76*Percentage_of_ewes_5*0.5
: c Allocation_77 = 1
: c percentage_of_ewes_6 =
Female_Replacement__rate*Survival_rate*Survival_rate*Survival_rate*Survival_rate*Surviv
al_rate
: c Product_77 = Allocation_77*percentage_of_ewes_6*0.5
: c Gene_%_age_class_7 = Product_76+Product_77
: c Female_Generation_Interval =
(2*((Gene_%__age_class_2*2)+(Gene_%_age_class_3*3)+(Gene_%_age_class_4*4)+(Gen
e_%_age_class_5*5)+(Gene_%_age_class_6*6)+(Gene_%_age_class_7*7)))*9.5
: c Breeding_ram__in_use = 24 {Euro/month}
: c Male_Replacement__rate = 1/Breeding_ram__in_use
: c percentage_of_rams_1 = Male_Replacement__rate
: c Male_Product_22 = Allocation_22*percentage_of_rams_1*0.5
: c Ram_Gene_%__age_class_2 = Male_Product_22
: c Male_Product_32 = Allocation_32*percentage_of_rams_1*0.5
: c Percentage_of_rams_2 = Male_Replacement__rate*Survival_rate
: c Male_Product_33 = Allocation_33*Percentage_of_rams_2*0.5
: c Ram_Gene_%_age_class_3 = Male_Product_32+Male_Product_33
: c Male_Product_43 = Allocation_43*Percentage_of_rams_2*0.5
: c Ram_Gene_%_age_class_4 = Male_Product_43
: c Male_Generation_Interval =
((2*((Ram_Gene_%__age_class_2*2)+(Ram_Gene_%_age_class_3*3)+(Ram_Gene_%_ag
e_class_4*4))))
: c Weaning_Wt__PSD = 2.4

: c M_WWt_Phenotypic__variance = Weaning_Wt__PSD*Weaning_Wt__PSD
: c M_Weaning_additive_SD =
SQRT(Weaning_Wt_heritablity*M_WWt_Phenotypic__variance)
: c Six_month_weight_GG =
((((Weaning_Wt_Accurcy__of_selection*Male_SI)+(Weaning_Wt_Accurcy__of_selection*Female_SI))/(Female_Generation_Interval+Male_Generation_Interval))*M_Weaning_additive_SD)/12 { Place right hand side of equation here... }
: c Exchange_rate = 24
: c SMWt__EV = 16.93/Exchange_rate
: c PWS__heritablity = 0.1
: c PWS_Accurcy__of_selection = (SQRT(PWS__heritablity))*0.5
DOCUMENT: accuracy based on dam performance
: c M_PWS_SD = 11.486
: c M_PWS_Phenotypic_variance = M_PWS_SD*M_PWS_SD
: c PWS_additive_SD = SQRT(PWS__heritablity*M_PWS_Phenotypic_variance)
: c PWS_GG =
((((PWS_Accurcy__of_selection*Male_SI)+(PWS_Accurcy__of_selection*Female_SI))/(Female_Generation_Interval+Male_Generation_Interval))*PWS_additive_SD)/12
: c PWS_EV = 14.61/Exchange_rate
: c Fr_heritablity = 0.05
: c Fr_Accurcy__of_selection = (SQRT(Fr_heritablity))*0.5
: c M_Fr_SD = 5.686
: c M_Fr_Phenotypic_variance = M_Fr_SD*M_Fr_SD
: c M_Fr_additive_SD = SQRT(Fr_heritablity*M_Fr_Phenotypic_variance)
: c Fr_GG =
((((Fr_Accurcy__of_selection*Male_SI)+(Fr_Accurcy__of_selection*Female_SI))/(Female_Generation_Interval+Male_Generation_Interval))*M_Fr_additive_SD)/12 { Place right hand side of equation here... }
: c Fr_EV = 14.61/Exchange_rate
: f Revenue =
(Six_month_weight_GG*SMWt__EV)+(Six_month_weight_GG*SMWt__EV)+(PWS_GG*PWS_EV)+(Fr_GG*Fr_EV)
: f Costs =
(Animal_identification_cost+FR_measuring_cost+Genetic_evaluation_cost+PWS__measuring_cost+Six_month_wt_measuring+Six_month_wt_measuring) {Euro/month}
: c Service_period = 24 {months}
: f Births = Lambing_1+Lambing_2+Lambing_3+Lambing_4+Lambing_5 {sheep/month}

: c F_lamb__Maturation_age = 9 {months}
: f YE_recruited = (Young*0.5)/F_lamb__Maturation_age
: c M_lamb__maturation_age = 6 {months}
: f YR_recruited = (Young*0.5)/M_lamb__maturation_age
: f Male_selected = ROUND ((Young_Ram*Male_P%)) {sheep/month}
: f Culled = Young_Ram-Male_selected
: c M_i_infinites_1 = GRAPH(Male_P%)
(0.01, 3.96), (0.02, 3.79), (0.03, 3.69), (0.04, 3.61), (0.05, 3.55), (0.06, 3.51), (0.07, 3.46), (0.08, 3.43), (0.09, 3.40), (0.1, 3.37)
: c M_i_infinites_2 = GRAPH(Male_P%)
(0.12, 3.31), (0.14, 3.27), (0.16, 3.23), (0.18, 3.20), (0.2, 3.17), (0.22, 3.14), (0.24, 3.12), (0.26, 3.09), (0.28, 3.07), (0.3, 3.05), (0.32, 3.03), (0.34, 3.01), (0.36, 2.99), (0.38, 2.98), (0.4, 2.96), (0.42, 2.95), (0.44, 2.93), (0.46, 2.92), (0.48, 2.90), (0.5, 2.68)
: c F_i_infinites_5 = GRAPH(Female_P%)
(0.01, 3.96), (0.02, 3.79), (0.03, 3.69), (0.04, 3.61), (0.05, 3.55), (0.06, 3.51), (0.07, 3.46), (0.08, 3.43), (0.09, 3.40), (0.1, 3.37)
: c F_i_infinites_2 = GRAPH(Female_P%)
(0.12, 3.31), (0.14, 3.27), (0.16, 3.23), (0.18, 3.20), (0.2, 3.17), (0.22, 3.14), (0.24, 3.12), (0.26, 3.09), (0.28, 3.07), (0.3, 3.05), (0.32, 3.03), (0.34, 3.01), (0.36, 2.99), (0.38, 2.98), (0.4, 2.96), (0.42, 2.95), (0.44, 2.93), (0.46, 2.92), (0.48, 2.90), (0.5, 2.68)
: c Feed_Gap = Total_Actual__DMI_per_ha-Total_herd_DD_per_Ha
: c Ewe_year_7 = Breeding_ewes*percentage_of_ewes_6
: c Total_herd =
(Breeding_ram+Young_Ewe+Young+Young_Ram+Dry_ewes+lactating_ewes+pregnant_ewes+Fattening+Breeding_female__replacement) {sheep}
: c Optimum_herd = IF (Total_Actual__DMI_per_ha >= Total_herd_DD_per_Ha) THEN (Total_herd) ELSE (Total_herd - 70)
: c Lambing_interval = 8.5 {month}
: c age_ate_first_lambing = 18 {month}
: c age_at_lambing_1 = age_ate_first_lambing {month}
: c age_at_lambing_2 = age_at_lambing_1+Lambing_interval {month}
: c age_at_lambing_3 = age_at_lambing_2+Lambing_interval {month}
: c age_at_lambing_4 = age_at_lambing_3+Lambing_interval {month}
: c age_at_lambing_5 = age_at_lambing_4+Lambing_interval {month}
: c Ram_age_at_lambing_1 = age_ate_first_lambing {month}
: c Ram_age_at_lambing_2 = Ram_age_at_lambing_1+Lambing_interval
: c Ram_age_at_lambing_3 = Ram_age_at_lambing_2+Lambing_interval {month}

: c Ram_age_at_lambing_4 = Ram_age_at_lambing_3+Lambing_interval {month}
: c Ewe_year_2 = Breeding_ewes*percentage_of_ewes_1 {Sheep}
: c Ewe_year_3 = Breeding_ewes*Percentage_of_ewes_2 {Sheep}
: c Ewe_year_4 = Breeding_ewes*Percentage_of_ewes_3 {Sheep}
: c Ewe_year_5 = Breeding_ewes*Percentage_of_ewes_4 {Sheep}
: c Ewe_year_6 = Breeding_ewes*Percentage_of_ewes_5 {Sheep}
: c Male_year2 = Breeding_ram*percentage_of_rams_1 {Sheep}
: c Male_year_3 = Breeding_ram*Percentage_of_rams_2 {Sheep}
: c Male_total_Gene_% =
Ram_Gene_%_age_class_3+Ram_Gene_%_age_class_4+Ram_Gene_%__age_class_2
: c Female_total_Gene_% =
Gene_%_age_class_3+Gene_%_age_class_4+Gene_%_age_class_5+Gene_%_age_class_6+Gene_%_age_class_7+Gene_%__age_class_2
: c M_Fr_Data_1 = GRAPH(Male_P%)
(0.01, 88.0), (0.0719, 87.3), (0.134, 85.3), (0.196, 85.2), (0.258, 85.0), (0.319, 84.3), (0.381, 83.8), (0.443, 80.6), (0.505, 79.1), (0.567, 78.0), (0.629, 77.8), (0.691, 77.2), (0.753, 76.6), (0.814, 74.7), (0.876, 71.6), (0.938, 70.3), (1.00, 70.1)
: s Fertility_rate = M_Fr_Data_1+Fr_GG
: f Fr_Gain = Fr_GG
: c Ram_ewe_ratio = Breeding_ewes/Breeding_ram
: c Ne = (4*(Breeding_ewes*Breeding_ram))/(Breeding_ewes+Breeding_ram)
DOCUMENT: Effective population size, based on the number of breeding ewes and breeding rams
: c Mean_L = (Female_Generation_Interval+Male_Generation_Interval)/2
: c F_WWt_Phenotypic_variance = Weaning_Wt__PSD*Weaning_Wt__PSD
: c Six_month_wt_Data = GRAPH(Male_P%)
(1.00, 18.4), (2.00, 18.0), (3.00, 17.6), (4.00, 17.6), (5.00, 17.1), (6.00, 16.9), (7.00, 16.8), (8.00, 16.5), (9.00, 16.4), (10.0, 16.2), (11.0, 16.1), (12.0, 16.0), (13.0, 15.9), (14.0, 15.9), (15.0, 15.7), (16.0, 15.6), (17.0, 15.5), (18.0, 15.4), (19.0, 15.4), (20.0, 15.3), (21.0, 15.3), (22.0, 15.2), (23.0, 15.1), (24.0, 15.1), (25.0, 15.1), (26.0, 15.0), (27.0, 15.0), (28.0, 14.9), (29.0, 14.8), (30.0, 14.8), (31.0, 14.7), (32.0, 14.7), (33.0, 14.6), (34.0, 14.6), (35.0, 14.5), (36.0, 14.5), (37.0, 14.4), (38.0, 14.4), (39.0, 14.4), (40.0, 14.3), (41.0, 14.3), (42.0, 14.3), (43.0, 14.2), (44.0, 14.2), (45.0, 14.2), (46.0, 14.1), (47.0, 14.1), (48.0, 14.1), (49.0, 14.0), (50.0, 14.0), (51.0, 13.9), (52.0, 13.9), (53.0, 13.9), (54.0, 13.8), (55.0, 13.8), (56.0, 13.8), (57.0, 13.7), (58.0, 13.7), (59.0, 13.7), (60.0, 13.6), (61.0, 13.6), (62.0, 13.6), (63.0, 13.5), (64.0, 13.5), (65.0, 13.5), (66.0, 13.4), (67.0, 13.4), (68.0, 13.4), (69.0, 13.3), (70.0, 13.3), (71.0, 13.3), (72.0, 13.2), (73.0, 13.2), (74.0, 13.1), (75.0, 13.1), (76.0, 13.1), (77.0, 13.0),

(78.0, 13.0), (79.0, 12.9), (80.0, 12.9), (81.0, 12.9), (82.0, 12.8), (83.0, 12.8), (84.0, 12.7), (85.0, 12.7), (86.0, 12.7), (87.0, 12.6), (88.0, 12.6), (89.0, 12.5), (90.0, 12.5), (91.0, 12.4), (92.0, 12.4), (93.0, 12.3), (94.0, 12.3), (95.0, 12.3), (96.0, 12.2), (97.0, 12.2), (98.0, 12.1), (99.0, 12.1), (100, 12.0)

: c F_PWS_Phenotypic_variance = M_PWS_SD*M_PWS_SD

: c F_Fr_Phenotypic_variance = M_Fr_SD*M_Fr_SD

: s Six_month_weight_Wt = Six_month_wt_Data+Six_month_weight_GG

: c Female_WWt_Data_1 = GRAPH(Female_P%)

(0.01, 14.2), (0.02, 13.8), (0.03, 13.6), (0.04, 13.4), (0.05, 13.3), (0.06, 13.1), (0.07, 13.0), (0.08, 12.9), (0.09, 12.8), (0.1, 12.7), (0.11, 12.6), (0.12, 12.6), (0.13, 12.5), (0.14, 12.4), (0.15, 12.4), (0.16, 12.3), (0.17, 12.2), (0.18, 12.1), (0.19, 12.1), (0.2, 12.0), (0.21, 11.9), (0.22, 11.9), (0.23, 11.8), (0.24, 11.7), (0.25, 11.7), (0.26, 11.6), (0.27, 11.6), (0.28, 11.5), (0.29, 11.4), (0.3, 11.4), (0.31, 11.4), (0.32, 11.3), (0.33, 11.3), (0.34, 11.2), (0.35, 11.2), (0.36, 11.2), (0.37, 11.1), (0.38, 11.1), (0.39, 11.0), (0.4, 11.0), (0.41, 10.9), (0.42, 10.9), (0.43, 10.9), (0.44, 10.8), (0.45, 10.8), (0.46, 10.7), (0.47, 10.7), (0.48, 10.7), (0.49, 10.6), (0.5, 10.6), (0.51, 10.6), (0.52, 10.5), (0.53, 10.5), (0.54, 10.4), (0.55, 10.4), (0.56, 10.4), (0.57, 10.3), (0.58, 10.3), (0.59, 10.2), (0.6, 10.2), (0.61, 10.2), (0.62, 10.1), (0.63, 10.1), (0.64, 10.1), (0.65, 10.0), (0.66, 9.99), (0.67, 9.97), (0.68, 9.93), (0.69, 9.90), (0.7, 9.86), (0.71, 9.83), (0.72, 9.80), (0.73, 9.76), (0.74, 9.73), (0.75, 9.70), (0.76, 9.67), (0.77, 9.63), (0.78, 9.60), (0.79, 9.57), (0.8, 9.54), (0.81, 9.51), (0.82, 9.47), (0.83, 9.45), (0.84, 9.42), (0.85, 9.39), (0.86, 9.36), (0.87, 9.33), (0.88, 9.29), (0.89, 9.26), (0.9, 9.22), (0.91, 9.19), (0.92, 9.15), (0.93, 9.12), (0.94, 9.08), (0.95, 9.05), (0.96, 9.01), (0.97, 8.97), (0.98, 8.93), (0.99, 8.91), (1.00, 8.86)

: f SMwt_Gain = Six_month_weight_GG

: c M_PWS_Data_1 = GRAPH(Male_P%)

(0.01, 100), (0.0719, 100), (0.134, 97.1), (0.196, 96.5), (0.258, 96.2), (0.319, 95.0), (0.381, 94.7), (0.443, 92.9), (0.505, 91.1), (0.567, 90.5), (0.629, 88.5), (0.691, 84.2), (0.753, 79.6), (0.814, 72.8), (0.876, 65.5), (0.938, 59.2), (1.00, 33.3)

: c F_PWS_Data_1 = GRAPH(Female_P%)

(0.01, 100), (0.0807, 100), (0.151, 100), (0.222, 100), (0.293, 100), (0.364, 97.0), (0.434, 96.3), (0.505, 96.2), (0.576, 95.7), (0.646, 94.9), (0.717, 94.1), (0.788, 93.1), (0.859, 92.9), (0.929, 91.7), (1.00, 91.7)

: s PWS = F_PWS_Data_1+ PWS_GG

: f M_PWS_GG = PWS_GG

: c F_Fr_Data_1 = GRAPH(Female_P%)

(0.01, 88.7), (0.0807, 87.9), (0.151, 86.1), (0.222, 84.1), (0.293, 83.6), (0.364, 82.8), (0.434, 82.0), (0.505, 79.8), (0.576, 78.9), (0.646, 76.9), (0.717, 75.3), (0.788, 74.9), (0.859, 73.4), (0.929, 71.3), (1.00, 70.4)
: s Acumulated_profit = Revenue-Costs
: c Returns =
(Six_month_weight_GG*SMWt__EV)+(Six_month_weight_GG*SMWt__EV)+(PWS_GG*PWS_EV)+(Fr_GG*Fr_EV)
: c Cost =
(Animal_identification_cost+FR_measuring_cost+Genetic_evaluation_cost+PWS__measuring_cost+Six_month_wt_measuring+Six_month_wt_measuring)
: c Profit_per_ewe__per_year = Returns-Cost

{RUNTIME EQUATIONS}
: s Breeding_female__replacement(t) = Breeding_female__replacement(t - dt) + (Female_selected - Conceived - BF_culling) * dt {Sheep}
: s Breeding_ram(t) = Breeding_ram(t - dt) + (Male_selected - Ram_to_fattening - BR_mortality) * dt {Sheep}
: S Young(t) = Young(t - dt) + (Births - YE_recruited - YR_recruited - lamb__deaths) * dt {Sheep}
: s Young_Ram(t) = Young_Ram(t - dt) + (YR_recruited - Male_selected - Culled - YR_mortality) * dt {Sheep}
: s Fertility_rate(t) = Fertility_rate(t - dt) + (Fr_Gain) * dt
: s Six_month_weight_Wt(t) = Six_month_weight_Wt(t - dt) + (SMwt_Gain) * dt
: s PWS(t) = PWS(t - dt) + (M_PWS_GG) * dt
: s Acumulated_profit(t) = Acumulated_profit(t - dt) + (Revenue - Costs) * dt
: I Fattening(t) = Fattening(t - dt) + (Ram_to_fattening - Fatten_sold) * dt {Sheep}
: I Pregnant_1(t) = Pregnant_1(t - dt) + (Conceived - Lambing_1) * dt {Sheep}
: I Party_1(t) = Party_1(t - dt) + (Lambing_1 - Lactation_1 - P1_deaths) * dt {Sheep}
: I Dry_ewe_1(t) = Dry_ewe_1(t - dt) + (Lactation_1 - Concieved_2 - ewe_1_culled) * dt {Sheep}
: I Parity_2(t) = Parity_2(t - dt) + (Lambing_2 - Lactation_2 - P2_deaths) * dt {Sheep}
: I Pregnant_2(t) = Pregnant_2(t - dt) + (Concieved_2 - Lambing_2) * dt {Sheep}
: I Dry_ewe_2(t) = Dry_ewe_2(t - dt) + (Lactation_2 - Concieved_3 - ewe_2_culled) * dt {Sheep}
: I Parity_3(t) = Parity_3(t - dt) + (Lambing_3 - Lactation_3 - P3_deaths) * dt {Sheep}
: I Dry_ewe_3(t) = Dry_ewe_3(t - dt) + (Lactation_3 - Concieved_4 - ewe_3_culled) * dt {Sheep}
: I Pregnant_4(t) = Pregnant_4(t - dt) + (Concieved_4 - Lambing_4) * dt {Sheep}

: I Parity_4(t) = Parity_4(t - dt) + (Lambing_4 - Lactation_4 - P4_deaths) * dt {Sheep}
: I Dry_ewes_4(t) = Dry_ewes_4(t - dt) + (Lactation_4 - Concieved_5 - ewe_4_culled) * dt {Sheep}
: I Pregnant_3(t) = Pregnant_3(t - dt) + (Concieved_3 - Lambing_3) * dt {Sheep}
: I pregnant_5(t) = pregnant_5(t - dt) + (Concieved_5 - Lambing_5) * dt {Sheep}
: I Parity_5(t) = Parity_5(t - dt) + (Lambing_5 - P5_culled - P5_deaths) * dt {Sheep}
: c Conceiption_rate = IF(months =1) THEN (0.75) ELSE IF (months = 2) THEN (0.75) ELSE IF(months =3) THEN (0.75) ELSE IF(months = 4) THEN (0.75) ELSE IF(months = 5) THEN(0.75) ELSE IF(months = 6) THEN (0.75) ELSE IF(months = 75) THEN (0.85) ELSE IF(months = 8) THEN (0.85) ELSE IF(months = 9) THEN (0.85) ELSE IF(months = 10) THEN (0.75) ELSE IF(months =11) THEN(0.75) ELSE IF(months=12)THEN (0.75) ELSE 0
: c Female_P% = IF (TIME >= 1) THEN (RANDOM(0.70,0.79)) ELSE 0
: f Female_selected = ROUND ((Young_Ewe*Female_P%)) {sheep/month}
: f Conceived = (Breeding_female__replacement*Conceiption_rate) {sheep/month}
: c Animal_identification_cost = (Tag_cost+Taging_cost) {Euro}
: c Weaning_Wt_Accurcy__of_selection = SQRT(Weaning_Wt_heritablity)
: c Male_P% = If (months= 3) THEN (RANDOM(0.20,0.29)) ELSE IF (months= 8) THEN (RANDOM(0.20,0.29)) ELSE IF (months= 11) THEN (RANDOM(0.20,0.29)) ELSE 0
: c M_i_infinites_3 = GRAPH(Male_P%)
(0.01, 2.67), (0.02, 2.42), (0.03, 2.27), (0.04, 2.15), (0.05, 2.06), (0.06, 1.99), (0.07, 1.92), (0.08, 1.86), (0.09, 1.80), (0.1, 1.75), (0.11, 1.71), (0.12, 1.67), (0.13, 1.63), (0.14, 1.59), (0.15, 1.55), (0.16, 1.52), (0.17, 1.49), (0.18, 1.46), (0.19, 1.43), (0.2, 1.40), (0.21, 1.37), (0.22, 1.35), (0.23, 1.32), (0.24, 1.29), (0.25, 1.27), (0.26, 1.25), (0.27, 1.23), (0.28, 1.20), (0.29, 1.18), (0.3, 1.16), (0.31, 1.14), (0.32, 1.12), (0.33, 1.10), (0.34, 1.08), (0.35, 1.06), (0.36, 1.04), (0.37, 1.02), (0.38, 1.00), (0.39, 0.984), (0.4, 0.966), (0.41, 0.948), (0.42, 0.931), (0.43, 0.913), (0.44, 0.896), (0.45, 0.88), (0.46, 0.863), (0.47, 0.846), (0.48, 0.83), (0.49, 0.814), (0.5, 0.798)
: c M_i_infinites_4 = GRAPH(Male_P%)
(0.5, 0.789), (0.6, 0.664), (0.7, 0.497), (0.8, 0.35), (0.9, 0.195)
: c M_I_intensity = IF(Male_P% <= 0.5) THEN (M_i_infinites_3) ELSE IF(Male_P% < 0.9) THEN(M_i_infinites_4) ELSE 0
: c Male_SI = M_I_intensity
: c F_i_infinites_3 = GRAPH(Female_P%)
(0.01, 2.67), (0.02, 2.42), (0.03, 2.27), (0.04, 2.15), (0.05, 2.06), (0.06, 1.99), (0.07, 1.92), (0.08, 1.86), (0.09, 1.80), (0.1, 1.75), (0.11, 1.71), (0.12, 1.67), (0.13, 1.63), (0.14, 1.59), (0.15, 1.55), (0.16, 1.52), (0.17, 1.49), (0.18, 1.46), (0.19, 1.43), (0.2, 1.40), (0.21, 1.37), (0.22, 1.35), (0.23, 1.32), (0.24, 1.29), (0.25, 1.27), (0.26, 1.25), (0.27, 1.23), (0.28, 1.20),

(0.29, 1.18), (0.3, 1.16), (0.31, 1.14), (0.32, 1.12), (0.33, 1.10), (0.34, 1.08), (0.35, 1.06), (0.36, 1.04), (0.37, 1.02), (0.38, 1.00), (0.39, 0.984), (0.4, 0.966), (0.41, 0.948), (0.42, 0.931), (0.43, 0.913), (0.44, 0.896), (0.45, 0.88), (0.46, 0.863), (0.47, 0.846), (0.48, 0.83), (0.49, 0.814), (0.5, 0.798)

: c F_i_infinites_4 = GRAPH(Female_P%)

(0.5, 0.789), (0.6, 0.664), (0.7, 0.497), (0.8, 0.35), (0.9, 0.195)

: c F_I_intensity = IF(Female_P% <= 0.5) THEN (F_i_infinites_3) ELSE IF(Female_P% <= 0.9) THEN(F_i_infinites_4) ELSE 0

: c Female_SI = F_I_intensity

: c Female_Replacement__rate = 1/Breeding_ewes__in_use

: c percentage_of_ewes_1 = Female_Replacement__rate

: c Product_22 = Allocation_22*percentage_of_ewes_1*0.5

: c Gene_%__age_class_2 = Product_22

: c Product_32 = Allocation_32*percentage_of_ewes_1*0.5

: c Percentage_of_ewes_2 = Female_Replacement__rate*Survival_rate

: c Product_33 = Allocation_33*Percentage_of_ewes_2*0.5

: c Gene_%_age_class_3 = Product_32+Product_33

: c Product_43 = Allocation_43*Percentage_of_ewes_2*0.5

: c Percentage_of_ewes_3 = Female_Replacement__rate*Survival_rate*Survival_rate

: c Product_44 = Allocation_44*Percentage_of_ewes_3*0.5

: c Gene_%_age_class_4 = Product_43+Product_44

: c Product_54 = Allocation_54*Percentage_of_ewes_3*0.5

: c Percentage_of_ewes_4 = Female_Replacement__rate*Survival_rate*Survival_rate*Survival_rate

: c Product_55 = Allocation_55*Percentage_of_ewes_4*0.5

: c Gene_%_age_class_5 = Product_54+Product_55

: c Product_65 = Allocation_65*Percentage_of_ewes_4*0.5

: c Percentage_of_ewes_5 = Female_Replacement__rate*Survival_rate*Survival_rate*Survival_rate*Survival_rate

: c Product_66 = Allocation_66*Percentage_of_ewes_5*0.5

: c Gene_%_age_class_6 = Product_65+Product_66

: c Product_76 = Allocation_76*Percentage_of_ewes_5*0.5

: c percentage_of_ewes_6 = Female_Replacement__rate*Survival_rate*Survival_rate*Survival_rate*Survival_rate*Survival_rate

: c Product_77 = Allocation_77*percentage_of_ewes_6*0.5

: c Gene_%_age_class_7 = Product_76+Product_77

: c Female_Generation_Interval =
(2*((Gene_%__age_class_2*2)+(Gene_%_age_class_3*3)+(Gene_%_age_class_4*4)+(Gene_%_age_class_5*5)+(Gene_%_age_class_6*6)+(Gene_%_age_class_7*7)))*9.5
: c Male_Replacement__rate = 1/Breeding_ram__in_use
: c percentage_of_rams_1 = Male_Replacement__rate
: c Male_Product_22 = Allocation_22*percentage_of_rams_1*0.5
: c Ram_Gene_%__age_class_2 = Male_Product_22
: c Male_Product_32 = Allocation_32*percentage_of_rams_1*0.5
: c Percentage_of_rams_2 = Male_Replacement__rate*Survival_rate
: c Male_Product_33 = Allocation_33*Percentage_of_rams_2*0.5
: c Ram_Gene_%_age_class_3 = Male_Product_32+Male_Product_33
: c Male_Product_43 = Allocation_43*Percentage_of_rams_2*0.5
: c Ram_Gene_%_age_class_4 = Male_Product_43
: c Male_Generation_Interval =
((2*((Ram_Gene_%__age_class_2*2)+(Ram_Gene_%_age_class_3*3)+(Ram_Gene_%_age_class_4*4))))*11
: c M_WWt_Phenotypic__variance = Weaning_Wt__PSD*Weaning_Wt__PSD
: c M_Weaning_additive_SD =
SQRT(Weaning_Wt_heritablity*M_WWt_Phenotypic__variance)
: c Six_month_weight_GG =
((((Weaning_Wt_Accurcy__of_selection*Male_SI)+(Weaning_Wt_Accurcy__of_selection*Female_SI))/(Female_Generation_Interval+Male_Generation_Interval))*M_Weaning_additive_SD)/12 { Place right hand side of equation here... }
: c SMWt__EV = 16.93/Exchange_rate
: c PWS_Accurcy__of_selection = (SQRT(PWS__heritablity))*0.5
: c M_PWS_Phenotypic_variance = M_PWS_SD*M_PWS_SD
: c PWS_additive_SD = SQRT(PWS__heritablity*M_PWS_Phenotypic_variance)
: c PWS_GG =
((((PWS_Accurcy__of_selection*Male_SI)+(PWS_Accurcy__of_selection*Female_SI))/(Female_Generation_Interval+Male_Generation_Interval))*PWS_additive_SD)/12 { Place right hand side of equation here... }
: c PWS_EV = 14.61/Exchange_rate
: c Fr_Accurcy__of_selection = (SQRT(Fr_heritablity))*0.5
: c M_Fr_Phenotypic_variance = M_Fr_SD*M_Fr_SD
: c M_Fr_additive_SD = SQRT(Fr_heritablity*M_Fr_Phenotypic_variance)
: c Fr_GG =
((((Fr_Accurcy__of_selection*Male_SI)+(Fr_Accurcy__of_selection*Female_SI))/(Female_G

eneration_Interval+Male_Generation_Interval))*M_Fr_additive_SD)/12 { Place right hand side of equation here... }

: c Fr_EV = 14.61/Exchange_rate

: f Revenue = (Six_month_weight_GG*SMWt__EV)+(Six_month_weight_GG*SMWt__EV)+(PWS_GG*PWS_EV)+(Fr_GG*Fr_EV)

: f Costs = (Animal_identification_cost+FR_measuring_cost+Genetic_evaluation_cost+PWS__measuring_cost+Six_month_wt_measuring+Six_month_wt_measuring)

: f Culled = Young_Ram-Male_selected

: c M_i_infinites_1 = GRAPH(Male_P%)
(0.01, 3.96), (0.02, 3.79), (0.03, 3.69), (0.04, 3.61), (0.05, 3.55), (0.06, 3.51), (0.07, 3.46), (0.08, 3.43), (0.09, 3.40), (0.1, 3.37)

: c M_i_infinites_2 = GRAPH(Male_P%)
(0.12, 3.31), (0.14, 3.27), (0.16, 3.23), (0.18, 3.20), (0.2, 3.17), (0.22, 3.14), (0.24, 3.12), (0.26, 3.09), (0.28, 3.07), (0.3, 3.05), (0.32, 3.03), (0.34, 3.01), (0.36, 2.99), (0.38, 2.98), (0.4, 2.96), (0.42, 2.95), (0.44, 2.93), (0.46, 2.92), (0.48, 2.90), (0.5, 2.68)

: c F_i_infinites_5 = GRAPH(Female_P%)
(0.01, 3.96), (0.02, 3.79), (0.03, 3.69), (0.04, 3.61), (0.05, 3.55), (0.06, 3.51), (0.07, 3.46), (0.08, 3.43), (0.09, 3.40), (0.1, 3.37)

: c F_i_infinites_2 = GRAPH(Female_P%)
(0.12, 3.31), (0.14, 3.27), (0.16, 3.23), (0.18, 3.20), (0.2, 3.17), (0.22, 3.14), (0.24, 3.12), (0.26, 3.09), (0.28, 3.07), (0.3, 3.05), (0.32, 3.03), (0.34, 3.01), (0.36, 2.99), (0.38, 2.98), (0.4, 2.96), (0.42, 2.95), (0.44, 2.93), (0.46, 2.92), (0.48, 2.90), (0.5, 2.68)

: c Feed_Gap = Total_Actual__DMI_per_ha-Total_herd_DD_per_Ha

: c Ewe_year_7 = Breeding_ewes*percentage_of_ewes_6

: c Optimum_herd = IF (Total_Actual__DMI_per_ha >= Total_herd_DD_per_Ha) THEN (Total_herd) ELSE (Total_herd - 70)

: c age_at_lambing_1 = age_ate_first_lambing

: c age_at_lambing_2 = age_at_lambing_1+Lambing_interval

: c age_at_lambing_3 = age_at_lambing_2+Lambing_interval

: c age_at_lambing_4 = age_at_lambing_3+Lambing_interval

: c age_at_lambing_5 = age_at_lambing_4+Lambing_interval

: c Ram_age_at_lambing_1 = age_ate_first_lambing

: c Ram_age_at_lambing_2 = Ram_age_at_lambing_1+Lambing_interval

: c Ram_age_at_lambing_3 = Ram_age_at_lambing_2+Lambing_interval

: c Ram_age_at_lambing_4 = Ram_age_at_lambing_3+Lambing_interval

: c Ewe_year_2 = Breeding_ewes*percentage_of_ewes_1

: c Ewe_year_3 = Breeding_ewes*Percentage_of_ewes_2

: c Ewe_year_4 = Breeding_ewes*Percentage_of_ewes_3

: c Ewe_year_5 = Breeding_ewes*Percentage_of_ewes_4

: c Ewe_year_6 = Breeding_ewes*Percentage_of_ewes_5

: c Male_year2 = Breeding_ram*percentage_of_rams_1

: c Male_year_3 = Breeding_ram*Percentage_of_rams_2

: c Male_total_Gene_% =
Ram_Gene_%_age_class_3+Ram_Gene_%_age_class_4+Ram_Gene_%__age_class_2

: c Female_total_Gene_% =
Gene_%_age_class_3+Gene_%_age_class_4+Gene_%_age_class_5+Gene_%_age_class_6+Gene_%_age_class_7+Gene_%__age_class_2

: c M_Fr_Data_1 = GRAPH(Male_P%)
(0.01, 88.0), (0.0719, 87.3), (0.134, 85.3), (0.196, 85.2), (0.258, 85.0), (0.319, 84.3), (0.381, 83.8), (0.443, 80.6), (0.505, 79.1), (0.567, 78.0), (0.629, 77.8), (0.691, 77.2), (0.753, 76.6), (0.814, 74.7), (0.876, 71.6), (0.938, 70.3), (1.00, 70.1)

: f Fr_Gain = Fr_GG

: c F_WWt_Phenotypic_variance = Weaning_Wt__PSD*Weaning_Wt__PSD

: c Six_month_wt_Data = GRAPH(Male_P%)
(1.00, 18.4), (2.00, 18.0), (3.00, 17.6), (4.00, 17.6), (5.00, 17.1), (6.00, 16.9), (7.00, 16.8), (8.00, 16.5), (9.00, 16.4), (10.0, 16.2), (11.0, 16.1), (12.0, 16.0), (13.0, 15.9), (14.0, 15.9), (15.0, 15.7), (16.0, 15.6), (17.0, 15.5), (18.0, 15.4), (19.0, 15.4), (20.0, 15.3), (21.0, 15.3), (22.0, 15.2), (23.0, 15.1), (24.0, 15.1), (25.0, 15.1), (26.0, 15.0), (27.0, 15.0), (28.0, 14.9), (29.0, 14.8), (30.0, 14.8), (31.0, 14.7), (32.0, 14.7), (33.0, 14.6), (34.0, 14.6), (35.0, 14.5), (36.0, 14.5), (37.0, 14.4), (38.0, 14.4), (39.0, 14.4), (40.0, 14.3), (41.0, 14.3), (42.0, 14.3), (43.0, 14.2), (44.0, 14.2), (45.0, 14.2), (46.0, 14.1), (47.0, 14.1), (48.0, 14.1), (49.0, 14.0), (50.0, 14.0), (51.0, 13.9), (52.0, 13.9), (53.0, 13.9), (54.0, 13.8), (55.0, 13.8), (56.0, 13.8), (57.0, 13.7), (58.0, 13.7), (59.0, 13.7), (60.0, 13.6), (61.0, 13.6), (62.0, 13.6), (63.0, 13.5), (64.0, 13.5), (65.0, 13.5), (66.0, 13.4), (67.0, 13.4), (68.0, 13.4), (69.0, 13.3), (70.0, 13.3), (71.0, 13.3), (72.0, 13.2), (73.0, 13.2), (74.0, 13.1), (75.0, 13.1), (76.0, 13.1), (77.0, 13.0), (78.0, 13.0), (79.0, 12.9), (80.0, 12.9), (81.0, 12.9), (82.0, 12.8), (83.0, 12.8), (84.0, 12.7), (85.0, 12.7), (86.0, 12.7), (87.0, 12.6), (88.0, 12.6), (89.0, 12.5), (90.0, 12.5), (91.0, 12.4), (92.0, 12.4), (93.0, 12.3), (94.0, 12.3), (95.0, 12.3), (96.0, 12.2), (97.0, 12.2), (98.0, 12.1), (99.0, 12.1), (100, 12.0)

: c F_PWS_Phenotypic_variance = M_PWS_SD*M_PWS_SD

: c F_Fr_Phenotypic_variance = M_Fr_SD*M_Fr_SD

: c Female_WWt_Data_1 = GRAPH(Female_P%)

(0.01, 14.2), (0.02, 13.8), (0.03, 13.6), (0.04, 13.4), (0.05, 13.3), (0.06, 13.1), (0.07, 13.0), (0.08, 12.9), (0.09, 12.8), (0.1, 12.7), (0.11, 12.6), (0.12, 12.6), (0.13, 12.5), (0.14, 12.4), (0.15, 12.4), (0.16, 12.3), (0.17, 12.2), (0.18, 12.1), (0.19, 12.1), (0.2, 12.0), (0.21, 11.9), (0.22, 11.9), (0.23, 11.8), (0.24, 11.7), (0.25, 11.7), (0.26, 11.6), (0.27, 11.6), (0.28, 11.5), (0.29, 11.4), (0.3, 11.4), (0.31, 11.4), (0.32, 11.3), (0.33, 11.3), (0.34, 11.2), (0.35, 11.2), (0.36, 11.2), (0.37, 11.1), (0.38, 11.1), (0.39, 11.0), (0.4, 11.0), (0.41, 10.9), (0.42, 10.9), (0.43, 10.9), (0.44, 10.8), (0.45, 10.8), (0.46, 10.7), (0.47, 10.7), (0.48, 10.7), (0.49, 10.6), (0.5, 10.6), (0.51, 10.6), (0.52, 10.5), (0.53, 10.5), (0.54, 10.4), (0.55, 10.4), (0.56, 10.4), (0.57, 10.3), (0.58, 10.3), (0.59, 10.2), (0.6, 10.2), (0.61, 10.2), (0.62, 10.1), (0.63, 10.1), (0.64, 10.1), (0.65, 10.0), (0.66, 9.99), (0.67, 9.97), (0.68, 9.93), (0.69, 9.90), (0.7, 9.86), (0.71, 9.83), (0.72, 9.80), (0.73, 9.76), (0.74, 9.73), (0.75, 9.70), (0.76, 9.67), (0.77, 9.63), (0.78, 9.60), (0.79, 9.57), (0.8, 9.54), (0.81, 9.51), (0.82, 9.47), (0.83, 9.45), (0.84, 9.42), (0.85, 9.39), (0.86, 9.36), (0.87, 9.33), (0.88, 9.29), (0.89, 9.26), (0.9, 9.22), (0.91, 9.19), (0.92, 9.15), (0.93, 9.12), (0.94, 9.08), (0.95, 9.05), (0.96, 9.01), (0.97, 8.97), (0.98, 8.93), (0.99, 8.91), (1.00, 8.86)

: f SMwt_Gain = Six_month_weight_GG

: c M_PWS_Data_1 = GRAPH(Male_P%)

(0.01, 100), (0.0719, 100), (0.134, 97.1), (0.196, 96.5), (0.258, 96.2), (0.319, 95.0), (0.381, 94.7), (0.443, 92.9), (0.505, 91.1), (0.567, 90.5), (0.629, 88.5), (0.691, 84.2), (0.753, 79.6), (0.814, 72.8), (0.876, 65.5), (0.938, 59.2), (1.00, 33.3)

: c F_PWS_Data_1 = GRAPH(Female_P%)

(0.01, 100), (0.0807, 100), (0.151, 100), (0.222, 100), (0.293, 100), (0.364, 97.0), (0.434, 96.3), (0.505, 96.2), (0.576, 95.7), (0.646, 94.9), (0.717, 94.1), (0.788, 93.1), (0.859, 92.9), (0.929, 91.7), (1.00, 91.7)

: f M_PWS_GG = PWS_GG

: c F_Fr_Data_1 = GRAPH(Female_P%)

(0.01, 88.7), (0.0807, 87.9), (0.151, 86.1), (0.222, 84.1), (0.293, 83.6), (0.364, 82.8), (0.434, 82.0), (0.505, 79.8), (0.576, 78.9), (0.646, 76.9), (0.717, 75.3), (0.788, 74.9), (0.859, 73.4), (0.929, 71.3), (1.00, 70.4)

: c Returns =

(Six_month_weight_GG*SMWt__EV)+(Six_month_weight_GG*SMWt__EV)+(PWS_GG*PWS_EV)+(Fr_GG*Fr_EV)

: c Cost =

(Animal_identification_cost+FR_measuring_cost+Genetic_evaluation_cost+PWS__measuring_cost+Six_month_wt_measuring+Six_month_wt_measuring)

: c Profit_per_ewe__per_year = Returns-Cost

Appendix 4: Pictures from Workshops in the research sites.