Tropentag 2016, Vienna, Austria
September 18-21, 2016

Conference on International Research on Food Security, Natural Resource Management and Rural Development
organised by the University of Natural Resources and Life Sciences (BOKU Vienna), Austria

The use of system dynamics modelling methodologies in sheep breeding programs and management systems

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Abstract

System dynamics modelling approach has been widely used in the agricultural sector to describe livestock production systems, livestock health and natural resource management. However, its application in modelling livestock breeding programs and systems is limited. Therefore, this study explores the utility of system dynamics modelling in evaluation of sheep breeding programs and management systems in the Ethiopian highlands. A community-based sheep breeding program was modeled using STELLA software. A weather and resource driven stochastic herd model was developed to evaluate the effect of genetic improvement and change in management system on herd dynamics and profitability. The baseline model was developed using historical rainfall and temperature data. Performance data was extracted from the herd-book of the breeding program and additional input data were obtained from various sources. The model accounts for pasture growth, nutrient requirement and seasonal variation in animal performance, physiological status and aging chain of the herd. Economic analysis was also done considering the returns and costs of the system. The baseline model was further expanded to account for genetic selection of body size, fattening strategies and alternative management systems to evaluate their effect on herd dynamics and profitability. Technical evaluation and extensive logic testing during the building phases was conducted. The model results were compared to independent calculations to determine whether the model was matching expectations, and to help clarify the relationships between variables. The model demonstrates that balancing the feed supply and demand is crucial. Genetic selection for large body size has resulted in decrease of herd size and higher income. Fattening of young animals has increased the farm income. Increase feed supply by producing improved forage plants increased herd size and farm income. For more economic benefit genetic improvement programs should be coincide with appropriate fattening strategies and resource availability. Overall, system dynamics modelling tools is useful to describe breeding programs and management systems by building a simple, flexible and usage driven simulation models.

Keywords: System dynamics, Breeding programs, STELLA, Sheep, Ethiopia

Introduction

System dynamics is a methodology and mathematical modelling technique for learning, understanding, and discussing complex issues and problems. It is a concept that considers dynamic interaction between the elements of the studied system and can help to understand their behaviour over time. System dynamics modelling approach has been widely used in the agricultural sector to describe livestock production systems, livestock health and natural resource management interventions. It has also been used in production system modelling, studying herd dynamics and herd structure and evaluation of profitability of management interventions (Kassa et al., 2002; Guimaraes et al., 2009; Parsons et al., 2011). However, so far it has not been applied in modelling livestock breeding programs and systems. Therefore, the objective of this study was to explore the utility of system dynamics modelling in evaluation of sheep breeding programs and management systems in the Ethiopian highlands.

Material and Methods

The study was conducted in the Menz highland area in the central northern part of Ethiopia. Historical data of monthly rainfall and temperature data were used. Sheep performance data were available from the herd-book of the local community-based sheep breeding program. Additional input data were sourced from questionnaires, observation, literature and expert knowledge. The simulation model was developed in STELLA software (STELLA 9.0.2., 2007). The length of the time horizon was 20 years (240 months).

The simulation model was resource and weather driven. Feed availability and feeding practices were described. The simulation model represented the herd as a group of individuals and simulated the dynamics of different age groups (from birth to herd exit). It allowed the tracking of both sexes through their respective life classes. It furthermore predicted the number of sheep in different age classes (Figure 1). The model determined the changes taking place in each animal's status during the month of the simulation, using endogenous biological processes regulated by exogenous management decisions. Thus, biological production parameters as length of gestation and lactation period, conception rate, open period and live weight of different sheep groups were considered. Economic analysis was also done considering the returns and costs of the system. The baseline model was further expanded to account for genetic selection of body size, fattening strategies (young or culled breeding rams) and alternative management systems (production of improved forage crop) to evaluate their effect on herd dynamics and profitability.

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.

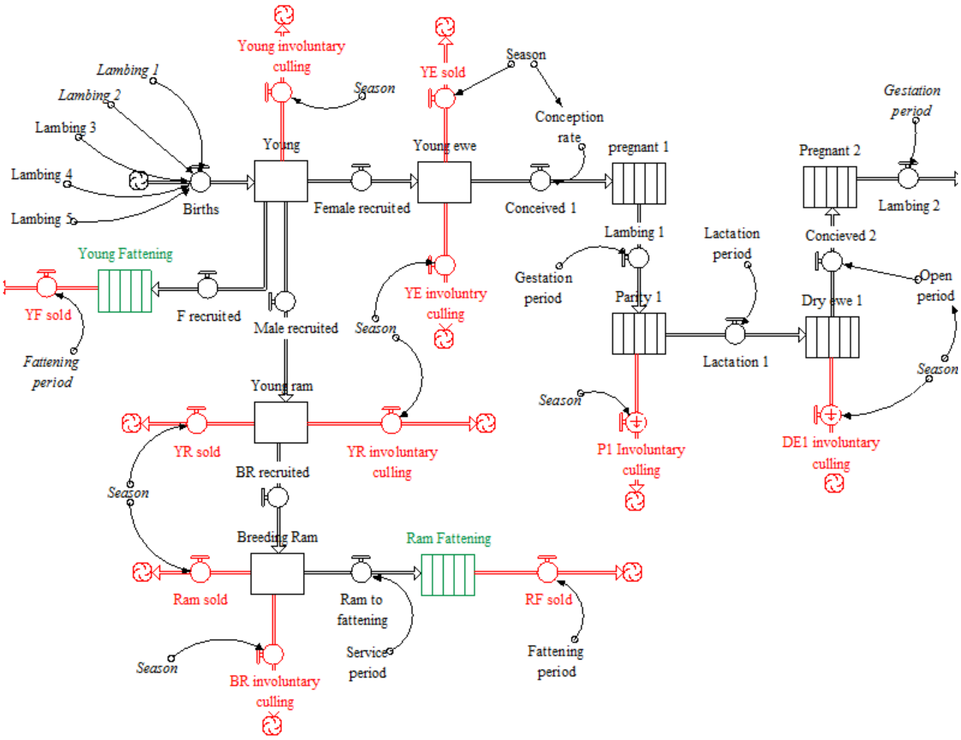

Figure 1: The aging-chain process of the sheep herd. Young fattened (YF), young ewe (YE), young ram (YR), breeding ram (BR), ram fattened (RF), parities (P1), dry ewes (DE). Red colour represents individuals leaving the herd and green colour represents the two scenarios (young fattening and ram fattening) tested while genetic selection was considered.

Results and Discussion

The comprehensive simulation model simulated the herd size at equilibrium in each time unit by balancing dry matter supply and demand. The model accounted for seasonal variation in feed resources which directly affected the size and productivity of the herd. The herd size was decreased in the dry season due to the shortage of dry matter supply, which resulted in a higher mortality and disposal rate of animals. Lambing occurred throughout the year, thus, there was higher loss of lambs which were 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. Higher profit was obtained when the feed supply is higher and appropriate sheep fattening strategy was introduced.
Based on the selection, genetic, biological and economic variables used, the model predicted annual genetic gain for six month weight (kg). A reasonable annual genetic gain was predicted varying from 0.213 to 0.214 kg. The breeding population showed a trend to decrease throughout the simulation period (Figure 2). This is because the predicted annual genetic gain for six month weight was additive to the initial values of body weight given prior simulation start. This resulted in an accumulated increase of body weight as well as dry matter intake (Gebre et al., 2014). Therefore, whenever the dry matter demand exceeded the dry matter supply young ewes were discarded from the system, to establish the herd at equilibrium. Considering the available resources and management systems a reasonable change in average performance of a sheep herd due to genetic selection could be achieved in community-based sheep breeding schemes under smallholder circumstance. Therefore, system dynamics modelling approach is valuable in demonstrating the dynamic smallholders' decisions in breeding, feeding and animal disposals.

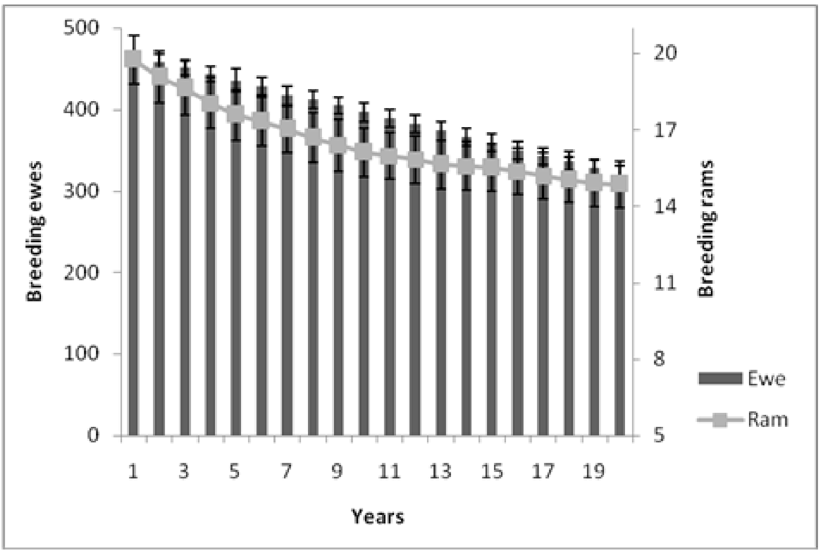

Figure 2: Simulated breeding ewe and breeding ram population throughout the simulation period.

The model revealed that alternative management systems such as production of improved forage crops need to be combined with appropriate finishing technology to increase farm income. This can also lead to regular income generation which might alleviate the disposal of animals with lower price. This result of the model was supported by Abegaz et al. (2004), where the authors recommend introduction of appropriate finishing technology and selling animals after attaining optimum desired market weight to enhance the economic benefit of sheep production. It has to be noted that introduction of improved forages to the community is quite dependent on other input services which are lacking now.

Conclusions and Outlook

A dynamic 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 developed 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 breeding programs and evaluating alternative management systems.

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