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SYSTEM DYNAMICS MODELLING APPROACH TO DETERMINE SUSTAINABLE STOCKING RATE FOR A SHEEP POPULATION IN THE ETHIOPIAN HIGHLANDS

Kahsa Tadel GEBRE [1, 2], Maria WURZINGER [3], Solomon GIZAW [4], Aynalem HAILE [5], Barbara RISCHKOWSKY [4], Johann SÖLKNER [2]

ABSTRACT

A system dynamics approach was used to determine the sustainable stocking rate of the Menz sheep population in the Ethiopian highland. A model was developed to simulate stocking rate based on communal grazing land. The model is weather and resource (feed supply) driven. Pasture growth and dynamics was modeled using rainfall and temperature data. Herd dynamics was based on age groups of male and female animals from birth to herd exit, taking production and reproduction parameters into account. To simulate sustainable stocking rate, a common unit (Tropical Livestock Unit, TLU) was used to represent the various classes of sheep. A higher stocking rate was observed in the long rainy season when the green pasture supply is higher. However, stocking rate was decreased with decrease in green and dry standing pasture in the long and short dry seasons. Application of the sustainable stocking rate in reality can be challenging since farmers keep large flocks and the pasture land is owned by groups of farmers. More awareness creation, including practical show-cases of the benefits of variation of stocking rate based on available resources, is needed to convince farmers in this and many other regions of Ethiopia.

Key words: system dynamics, simulation model, stocking rate, sheep, Ethiopia

1 INTRODUCTION

Ethiopia harbours a huge and diverse sheep population. Majority of the sheep population are found in the highland areas (CSA, 2011). In most of the highland areas, the production system is characterized by erratic rainfall, recurrent drought, high livestock density and feed scarcity. 90 % of the ruminant livestock feed on natural pastures, which vary in composition depending on the agro-ecology (Alemayehu, 2005). However, 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). Sustainable stocking rate is required to bring the number of animals down to the carrying capacity of the grazing area. Therefore, the main objective of this study is to determine sustainable stocking rate of sheep populations in the Ethiopian highlands, adopting system a dynamic modelling approach.

2 MATERIALS AND METHODS

2.1 STUDY AREA AND SHEEP POPULATION DESCRIPTION

The study was conducted in Mehal-Meda, Menz area in Ethiopia. This area is characterized as a low-input sheep-barley production system with a bi-modal rain-

1 Mekelle University, College of Dryland Agriculture and Natural Resources, Department of Animal, Rangeland and Wildlife Sciences. P.O. Box 231 Mekelle, Ethiopia.
2 Corresponding author: e-mail: kahsatadel06@yahoo.com or kasolet2006@gmail.com
3 University of Natural Resources and Life Sciences Vienna, Gregor Mendel-Strasse 33, A-1180 Vienna, Austria, e-mail: johann.soelkner@boku.ac.at and maria.wurzinger@boku.ac.at
4 Debre-Berhan Agricultural Research Center, P.O. Box 112, Debre-Berhan, Ethiopia, e-mail: s_gizaw@yahoo.com
5 International Center for Agricultural Research in the Dry Areas (ICARDA), P. O. Box 5466, Tel Hadya Aleppo, Syria, e-mail: A.Haile@cgiar.org and B.Rischkowsky@cgiar.org

fall 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 °C and 6.8 °C respectively, and frost is common from October to November.

Menz area is the main breeding tract of Menz sheep breed. Menz sheep is of small body size with a short-fat-tail and coarse wool used for weaving traditional blankets and carpets. The breed is adapted to high altitude ranges from 2600–3200 m.a.s.l 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. However, inadequate feed supply has resulted in overstocking and poor productivity.

2.2 SIMULATION MODEL DESCRIPTION

The simulation model developed by Gebre *et al.* (2014) was used and expanded to determine sustainable stocking rate for Menz sheep population. The 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 only feed source was set to be a communal pasture land for the simulation purpose. The pasture component is dynamic and depends on the monthly distribution of rainfall, which affects vegetation availability and quality, indirectly animal performance. The pasture growth and dynamics was developed based on a model by Diaz -Solis *et al.* (2003). Since frost is common from October to November in the Menz highland areas, pasture loss due to frost was taken into account.

The simulation model is weather and resource driven. Rainfall and temperature were considered the main driving variables for vegetation supply which can therefore affect the sheep performance. The model has a goal-seeking archetype and resource (feed) supply was important factor for determining the optimum herd size by balancing the dry matter supply and demand. Whenever there was feed shortage, the model discarded some sheep from the population. In case of excess dry matter supply, it was stored to be consumed when demanded. The model simulates the dynamics of green and dry pasture classes, grazing selection and animal production using equations provided by Diaz -Solis *et al.* (2003). The concept of rain use efficiency (RUE) proposed by Le Houreou (1984) was used to connect pasture growth and rainfall. RUE is the amount of pasture produced per unit of rainfall (kg DM/mm/ha). In order to simulate the seasonal variation in pasture production, monthly rainfall was generated randomly from a relative cumulative frequency distribution as explained by Grant *et al.* (1997).

The herd structure and dynamics represents 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 sheep in different categories, culled and dead sheep given the seasonal dry matter supply. The model determines the changes taking place in each animal's status during the months of the simulation, using endogenous biological processes regulated by exogenous management policies. Thus, biological production/reproduction parameters and live weight of different sheep groups were considered. The periodic variations in sheep performance and flock size were furthermore captured by the model. The length of the time horizon was 120 months (10 years).

The model uses the measure of livestock input on the range known as the tropical livestock unit (TLU) to calculate stocking rate. Following FAO (1991) stocking rate was determined as the actual number of livestock on a specific area at a specific time, usually described in terms of TLUs ha^{-1}. All sheep age groups were converted to Tropical Livestock Units (TLU) to bring all sheep classes under a common denominator (using conversion factors: 0.025 TLU for lambs, 0.075 TLU for young sheep and 0.1 TLU for mature sheep). Total TLU = Sheep Number * TLU factor and the Live Weight.

3 RESULT AND DISCUSSION

The simulated rainfall was compared with the observed 10 years rainfall data and the results are considered to be satisfactory (Fig. 1). The simulated annual mean rainfall was 1015 mm which is comparable to the observed annual mean of 950 mm for the study area. Annual rainfall was obtained by summing up the monthly rainfall for individual months. The model managed to capture monthly rainfall variability but showed less variation in the annual rainfall.

The mean annual pasture production was estimated to be 2015.50 Kg DM ha^{-1} with minimum of 1797 Kg DM ha^{-1} and maximum of 2165 Kg DM ha^{-1}. This was comparable with an experimental report by Tadesse and Peden (2003) which was 0.84–2.25 t ha^{-1} on comparable grazing land. Forage availability from natural pasture is dependent on the season. In this study season is related to rainfall and temperature condition which determines the growth and loss of the natural pasture. The model estimates optimum stocking rate by matching the dry mat-

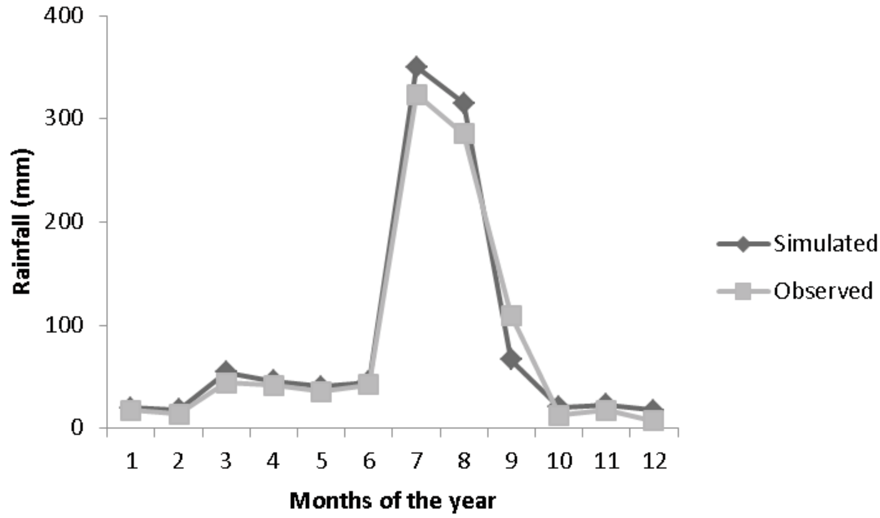

Figure 1: *Comparison of simulated and observed monthly rainfall in 10 years of period*

ter supply and demand of the herd (in live weights). The stocking rate is dynamic and heavily dependent on the season of the year. In the long rainy season (June to September) higher stocking rate was obtained since the plenty supply of green forage (Fig. 2.). However, the stocking rate decreased in the long and short dry seasons (October to January and April to May) due to decrease in green forage due to grazing, senescence and frost. In the early dry seasons the herd demand was supported by supply of dry standing pasture. The increase in stocking rate in the short rainy season is due to the increase in growth of green pasture due to the small rainfall availability.

The mean annual stocking rate varies from 0.51 TLU ha^{-1} to 0.62 TLU ha^{-1} (Fig. 3.) in the simulation period. According to the model results, smallholder farmers need to adjust their stocking rate. However, this can be a challenge since farmers keep large herd size even in the dry seasons. Since the pasture land is communal and accessed by group of farmers, organizational set up is required to introduce sustainable stocking rate. Overall, awareness creation and support from governmental and non-governmental organizations is demanded in training farmers on communal resource use and management.

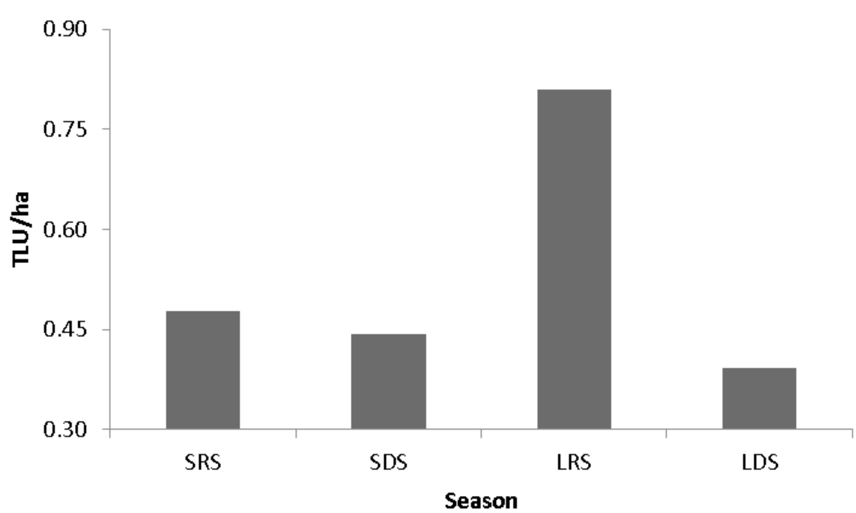

Figure 2: *The pattern of stocking rate in different seasons of the year*
SRS: short rainy season (February to March), SDS: short dry season (April to May), LRS: Long rainy season (June to September), LDS: Long dry season (October to January)

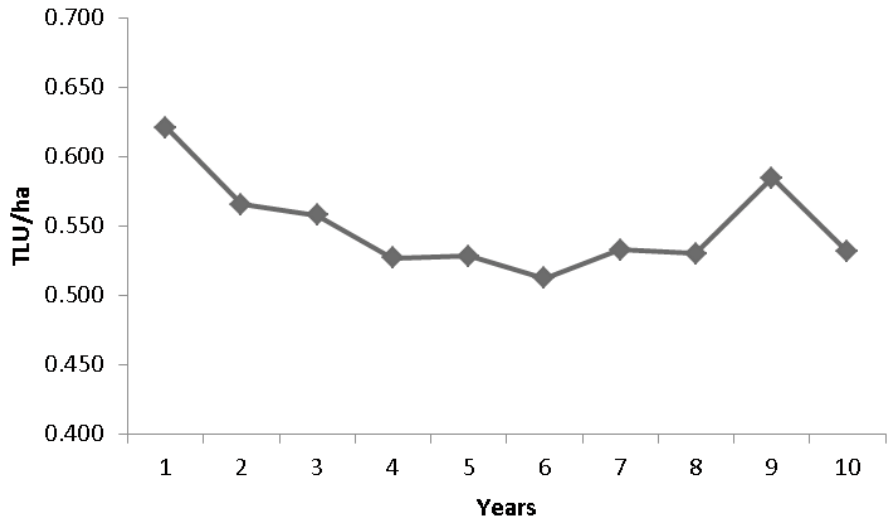

Figure 3: *Simulated mean annual stocking rate in 10 years of period*

4 CONCLUSIONS

The model demonstrates that stocking rate is dynamic and highly varied within a year rather than between years. The model has a goal-seeking archetype that balances the dry matter supply and demand which used to determine optimum stocking rate that a communal grazing land can support at a given time. Smallholder farmers have to adjust their stocking rate according to the season of the year. More awareness creation, including practical show-cases of the benefits of variation of stocking rate based on available resources, is needed to convince farmers in this and many other regions of Ethiopia.

5 REFERENCES

Alemayehu M. (2005). *Rangelands: biodiversity conservation and management and inventory and monitoring*. Addis Ababa, Ethiopia: Addis Ababa University, Faculty of Science.

CSA (Central Statistical Agency). (2011). *Agricultural sample survey 2010/11. Vol. II. Report on livestock and livestock characteristics (private peasant holdings).* Addis Ababa, Ethiopia: Central Statistical Agency, 114 pp.

Dejene, A. (2003). *Integrated natural resources management to enhance food security: the case for community-based approaches in Ethiopia*. Environment and natural resources, Working paper No. 16. Rome, Italy: Food and agriculture organization of the United Nations.

Diaz-Solis, H., Kothmann, M. M., Hamilton, W. T., Grant, W. E. (2003). A simple ecological sustainability simulator (SESS) for stocking rate management on semi-arid grazing lands. *Agricultural Systems*, *76*, 655–680.

FAO. (1991). *Guidelines: land evaluation for extensive grazing*. FAO Soils Bulletin 58. Rome: FAO.

Gebre, K. T., Wurzinger, M., Gizaw, S., Haile, A., Rischkowsky, B., Sölkner, J. (2014). Effect of genetic improvement of body weight on herd dynamics and profitability of Ethiopian meat sheep: A dynamic simulation model. *Small Ruminant Research*, *117*, 15–24.

Grant, W. E., Pedersen, E. L., Marín, S. L. (1997). *Ecology and natural resource management: systems analysis and simulation*. New York: John Wiley & Sons, 373 pp.

Getachew, T., Haile, A., Tibbo, M., Sharma, A. K., Sölkner, J., Wurzinger, M. (2010). Herd management and breeding practices of sheep owners in a mixed crop–livestock and a pastoral system of Ethiopia. *African Journal of Agricultural Researches*, *5*, 685–691.

Le Houreou, H. N. (1984). Rain use efficiency: a unifying concept in arid-land ecology. *Journal of Arid Environment*, *7*, 213–247.

STELLA 9.0.2. (2007). *Technical documentation for Ithink & Stella software*. Hannover, New Hampshire: HPS Inc.

Taddese, G. (2001). Land degradation: a challenge to Ethiopia. *Environmental Management*, *27*, 815–824.

Tadesse, G., Peden, D. (2003). Livestock grazing impact on vegetation, soil and hydrology in a tropical highland watershed. In McCornick P. G., Kamara A. B., Tadesse G. (Eds.), *Integrated water and land management research and capacity building priorities for Ethiopia*. Proceedings of a MoWR/EARO/IWMI/ILRI international workshop held at ILRI, Addis Ababa, Ethiopia 2–4 December 2002 (pp. 87–97). Colombo: IWMI; Nairobi: ILRI.