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Development of a mathematical model to study the impacts of production and management policies on the herd dynamics and profitability of dairy goats

Vinícius Pereira Guimarães [a,b], Luis Orlindo Tedeschi [a,*], Marcelo Teixeira Rodrigues [b]

[a] Department of Animal Science, Texas A&M University, 230 Kleberg Center, 2471 TAMU, College Station, TX 77843-2471, United States

[b] Departamento de Zootecnia, Universidade Federal de Viçosa, 36571-000 Viçosa, Minas Gerais, Brazil

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ABSTRACT

The reduction in goat milk production and the competitiveness of more profitable activities have increased the adoption of measures to enhance goat milk and meat around the world. A simulation model was built to evaluate the dynamics of a dairy goat herd under different scenarios of production. A System Dynamics approach was used to identify management policies that could affect the behaviour of the herd over 10 years of simulation using data from a dairy goat herd in Brazil. The impact of reproductive and mortality rates, one or two annual reproductive cycles on production, and economic health of dairy goats on changes in the herd dynamics were evaluated. Simulations indicated that small changes in reproduction and mortality rates and milk price can considerably affect the dynamics of the herd as well as the financial health of the production system. The interferences created to visualize the effects were not immediately realized because of intrinsic delays in the system. The comparison of models with one or two breeding seasons indicated that the latter was considerably more profitable and had a faster turnover. It was also found that the two breeding season had a greater capacity to support reduction in milk price that could generate financial instability in the production system. It was concluded that mathematical models can be used to predict impacts in management policies on herd dynamics and sensitivity to support the dairy goat activity showing its viability as an agricultural activity that can contribute to the production and incomes in small farms.

1. Introduction

Among all animals, goats were the first to be domesticated for production purposes, specifically for milk, thousands of years ago (Fan et al., 2007; Konarzewski and Werner Klinth, 2004; Wani and Hubert, 2002). Over the years, however, the economic importance of goats had declined compared with other domesticated animal species because of increased competitiveness of more profitable activities (de Rancourt et al., 2006; NASS, 2006). Currently, more efforts are being made to increase milk and meat productions from goats mainly because of their adaptability to lands not suitable for other agricultural activities (Santos et al., 2005) and the high prolificacy of the animals (Casey and Van Niekerk, 1988; Mellado et al., 1991).

The advancement of new technologies in animal production and the increased competition among products (e.g. milk and meat) from different animal species have been extremely important to enhance production efficiency, to reduce production costs, and to increase profitability in agricultural systems. This situation creates production scenarios that are highly competitive and requires a greater awareness by producers in order to adapt to different environments and productive cycles.

Nonetheless, understanding changes associated with competitiveness is not an easy task because of the complexity of production systems, which are comprised of enormous number of variables and their associated interactions (Salinas et al., 1999). For this reason, tools and methodologies that can assist producers in identifying strengths and weakness of their production systems are needed. Systems analysis methodologies and mathematical modelling can be used to predict responses of production systems caused by managerial, technological, and structural changes (Aguilar et al., 2006).

The reproductive cycle plays an important role in determining herd dynamics and milk production, which in turn dictates the success of the activity. However, because of the seasonal characteristics of goat reproduction (in the southeast of Brazil), their reproductive cycle occurs, naturally, at the end of the summer when daylight declines (Galina et al., 1995; Guimarães et al., 2006). Without major intervention, animals have only one chance during each year to kid, meaning the herd would have a specific period of milk production (Guimarães, 2007). This seasonal characteristic establishes the production behaviour of the herd and farm income when milk production is the main activity. Simulation

* Corresponding author. Tel.: +1 979 845 5065; fax: +1 979 845 5292.
E-mail address: luis.tedeschi@tamu.edu (L.O. Tedeschi).

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models can be used to quickly analyze behavioural changes in a dairy goat farm (Roberts et al., 1983) that otherwise would take years to be observed in practice.

Therefore, the main objective of this study was to use the System Dynamics methodology to develop a dynamic model to analyze key biological aspects that interfere in management practices that may affect the dynamics of a herd in a dairy goat farm. Other objectives included the evaluation of the impact of one or two annual reproductive cycles on the production and economic health of dairy goats and the identification of differences of production costs and revenues associated with changes in the herd dynamics.

2. Methodology

2.1. Model development

A dairy goat model was built using the System Dynamics approach to study long-term changes in the dynamics of the herd (Guimarães, 2007). System Dynamics allows for a holistic viewpoint, focusing on behavioural trends of the system and their relationships with managerial strategies (Sonawane, 2004). The model was developed using the main components of a System Dynamics simulation, including stocks, flows, feedbacks, delays, and decisions rules (Senge et al., 1994). Stocks are accumulations within the system. Flows are the movement of contents throughout the system. Feedback loops represent a chain of causality. They are responses created by the system that will change the current pattern. Delays are sources of dynamics in almost all systems creating instability and oscillations. There is always a stock in the system framework that accumulates the difference between input and output. Decision rules or policies represent the criteria used to regulate flows in attempts to drive the system to a desired state (Sterman, 2000).

Fig. 1 illustrates a system flow diagram in which the stocks are the boxes, arrows represents the flow of animals, valves are the restrictions or rules that interfere in the flow, and the gestation time and lactation time are auxiliary variables to build the model. Mathematically, Fig. 1 can be written as

$$\text{GestatingAnimals}(t) = \int_{t0}^{t} [\text{breeding}(t_i) - \text{kidding}(t_i)]ds + \text{GestatingAnimals}(t_0),$$

$$\text{LactatingAnimals}(t) = \int_{t0}^{t} [\text{kidding}(t_i) - \text{drying}(t_i)]ds + \text{LactatingAnimals}(t_0),$$

$$\text{Animals in the herd}(t) = \int_{t_0}^{t} [\text{births}(t_i) - \text{deaths}(t_i)]ds + \text{Animals in the herd}(t_0).$$

The goat model was setup to simulate a free-stall facility in which animals were grouped in pens by their milk production potential. All parameters considered in this study assumed values from an intensive production system in the Southeast region of Brazil, obtained by the extension service of the Federal University of Viçosa. The values are in agreement with the ranges found in the literature (Amarantidis et al., 2004; Bagnicka et al., 2006; Bosman et al., 1997; Mourad, 1994). We used the minimum, average, and maximum values of key variables (reproduction rates, mortality rates and milk production) to allow for stochasticity in the system. Upon the execution of the model, random values were generated based on the interval defined by minimum and maximum values. Costs and prices were expressed in US dollars. The inputs for the production system were feeds (i.e. concentrate and forage), labour, and fixed costs (Kosgey et al., 2003). The outputs of the system were the revenues from milk sales and sales of animals from all categories in the herd. Seasonal variation in animal performance and prices was not included in the model (Kosgey et al., 2003).

Despite all differences between animals such as productive potential and lactation length, the dynamic simulation considered a group of animals instead of individual animals (Myrtveit, 2005). In System Dynamics, state variables change continuously over time (Law and Kelton, 2000); and the program does not simulate each animal, but rather it aggregates similar animals (e.g. stage of lactation) and represents them as a single, continuous animal flow with the same properties. The purpose of the animal aggregation is to focus on the feedback effects of policy structure and dynamic behaviour of the group rather than on individual animals in the search for a broad view (Lane, 2000). This approach does not require extensive data, making it easy for simulation development.

The dairy goat production system consists of a group of animals that passes through various physiological and growth stages during their productive life (Singh, 1986); animals move from one stage to another as they grow, mature, gestate, kid, and milk.

2.2. Biological production parameters and animal flows

The length of gestation, fertility rate, litter size, kid mortality rate, number of growing kids and does, average production by categories, nursing time, and time to achieve the adult phase were considered as biological production parameters and their initial values are listed in Table 1. Animal categories used in this model were: lactating and non-lactating does, pregnant and non-pregnant does, female and male kids, and young animals for meat and reproduction purposes.

Each category was considered a stock of animals (i.e. state or level variables) that can increase or decrease depending on the inflow and outflow rates. The simulation started with a stock of 100 young does (nuliparous) entering for the first time in the

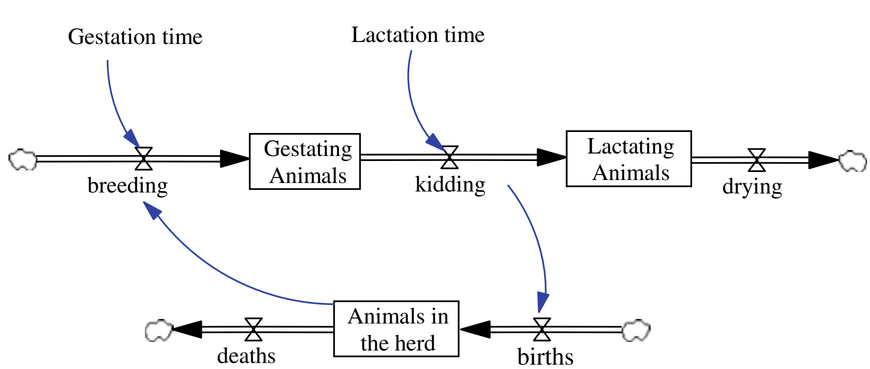

Fig. 1. Example of a system flow diagram for flow of animals.