Sustainability of Colombian Livestock Systems: the Stocking Rate Submodel

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1. ABSTRACT

This study is included in a broader PhD project of the National University of Colombia on socio-economic sustainability of countryside areas in Colombia. Especially the study focused important aspects for development of the Department of the Valle del Cauca. The general study focuses cattle farms and land use, their relationships with rural development (socio-economic aspects) and with environmental impacts (effects on water and ecological footprint). This paper will firstly show the casual loop diagram of the general project and then will focus the presentation of the developed stock and flow diagram of animal categories and biomass availability from land. In particular in this work a submodel of the stoking rate of raised cattle in a given farm was developed and presented. The model was able to describe the equilibrium of the herd consistency when constant precipitations lead to constant biomass production from the owned land. Drops in rainfall were also simulated and the model was used to investigate the most convenient farm strategy of animal selling in order to adjust the stocking rate of the farm to the stocking rate capacity of the land.

2. PREMISES

Globally, livestock, according to FAO, has grown at an average annual rate of 1.48%, reaching a cattle inventory of 1,558 million head in 2008. Of this total, Colombia holds a 1.73% and occupying the 13^{th} position globally (Gómez and Rueda, 2011).

The Colombian cattle were raised in five major biogeographic regions (Andean, Amazon, Caribbean, Orinoco and Pacific) and consists of about 23 million head raised in 39.2 million hectares, with a stocking rate of 0.6 head/ha. This number has not changed significantly in the last twenty years, which reveals the poor technological transformation of the livestock sector. From this cattle inventory, 6% is classified as specialized dairy, 35% is dedicated to dual purpose and the remaining 59% is destinated to fattening and breeding activities, extensively. The country reports a production of 6,300 million liters of milk/year, produced in 395,000 herds, exhibiting a low national average productivity of 4.1 liters/day per cow (Osorio, 2012). The low stoking rate, makes this activity classified as extended-extractive in the country. This form of livestock farming could be considered a national problem that affects the possibilities of human and rural development, in terms of generating employment, income, conservation and proper management of the environment and natural resources. It also critically affects the sustainability (environmental, economic and social) and accelerates the degradation of natural resources, the population growth and the rural poverty (PNUD, 2011). The efficiency of livestock systems in developing countries depends largely on the interaction between ecological, economic, social and technical factors (Figure 1). In this contest, production systems should undertake methodological and organizational changes to survive and grow in a dynamic equilibrium of sustainability and competitiveness (Rios, 2010).

This paper encourages the use of systems dynamics in the management of Colombian agricultural sector stimulating the improvement of decision process in agriculture and livestock sectors in order to meet important targets of food security and climate change for a sustainable development of the same country in the globalized economic contest.

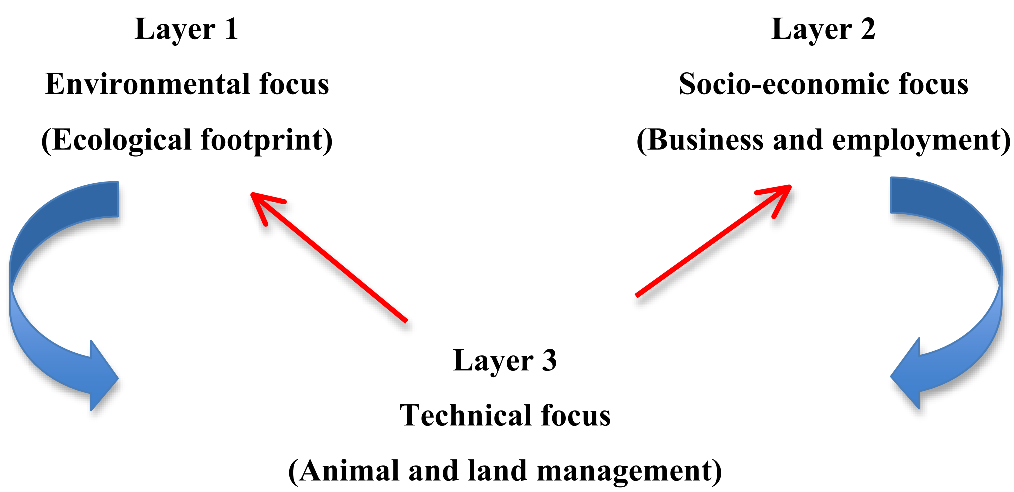

Figure 1. Interaction among ecological, economic, social and technical factors in dairy farms. Red arrows represent direct effects whereas blue arrows represent the strategy and policy effects within the system boundaries.

3. A SYSTEM DYNAMICS APPROACH TO LIVESTOCK SUSTAINABILITY

This study is included in a broader PhD project of the National University of Colombia on socio-economic sustainability of rural areas in Colombia. The study focused important aspects for the the development of Department of the Valle del Cauca - Colombia (N 03°27'09"; W 076°12'04"). The conceptual map of the modeling approach considers 4 main areas: animal production, soil-forage consumption, economics and ecological footprint. Each one of them is associated with the sustainability of the studied rural area. This paper will firstly show the casual loop diagram of the general project and will focus specifically the development of the stock and flow diagram of animal production, soil-forage consumption submodels. All presented diagrams were built using Vensim® version 5.9PLE (Ventana System, Inc.).

In Figure 2 is presented the causal loop diagram of the considered Colombian livestock system in order to test if the improvement of the management efficiency in the dairy farms can have positives effects on the social component of the system and on the environment. Causal loops R1 (production incomes), B2 and B3 (costs), and R4 (farm competitiveness) are related to the production - economic component. On the other side, loops B5 and B6 (grazing technique), B7 and B8 (environmental impact) were related with the environmental component whereas loops B9 and B10 (farm hiring) are related with the social component. Farm goal is to increase profit (net income = revenue - costs) and investment success. Incomes depend mainly on herd size and milk production (R1). Usually farmers tend to increase the number of animals to increase revenues from milk sold, but at the same time it does not reduce production costs because of the high maintenance cost of the herd (B2 and B3); thus the increase of animals cannot change the net income margin.

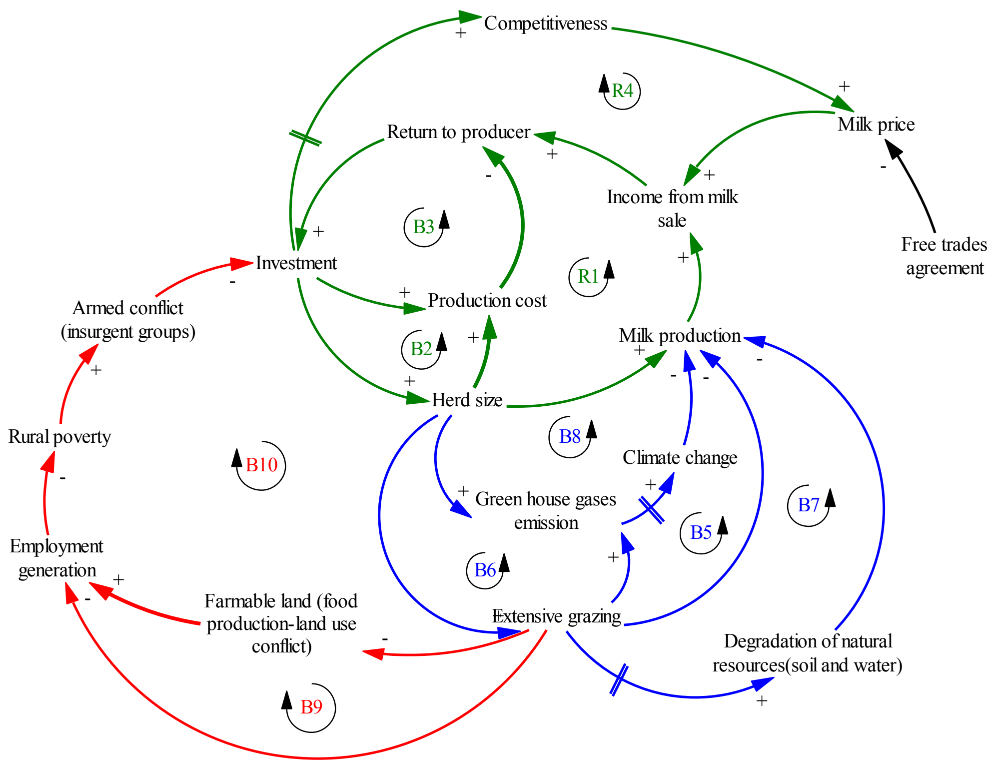

Figure 2. Causal loop diagram of Colombian rural system. The green arrows represent animal and economic variables; the blue arrows represent the land and environmental variables; the red arrows represent the social component.

In addition the increase in the herd size is often managed increasing the extensive grazing that in turn has negative impact on biomass availability, on milk production and increase the degradation of soil quality and productivity (fertility, water, biomass production, etc; B5, B6, B7). Due to this type of management practices, those negative feedback loops dominates the system reducing the land carrying capacity and limiting the farm profitability.

Furthermore, the traditional practices of extensive grazing cause an involvement of rural social component that is adversely affected by the low economic capacity of the system. In fact, increasing extensive grazing reduces hiring directly for herd management (B9) and indirectly for crop cultivation reduction (B10); it increase poverty of rural populations which in turn stimulates potential workers to join the ranks of the insurgents. These groups, generating the armed conflict in the country, also limit investments of money in improvement of livestock production systems and rural development (Arias and Ibáñez, 2012) and enhancing B10.

Most part of the farm in Colombia is based on extensive grazing as the main nutritional source for raised livestock. Native and naturalized species of low nutritional value allow low stocking rates, expressed as conventional livestock unit (LU; 1 LU = 450 kg of live weight). This is associated with extensive use of grasslands, minimal animal management and usually low production efficiency. Consequently, system changes are very limited by little investments and changes in expertise.

A system thinking approach on this causal map showed that, a policy of farm support by technical assistance that could help them to switching the investments from the increase of the herd size to the improvement of farm management and switch the land use from extensive grazing to rotational grazing it is possible to turn 4 balancing loops in to 4 reinforcing loops that can increase farm profitability with social and economical benefits (Molina et al. 2014). Policy makers can help to enable the switching of investment focus by providing initial resources for technical assistance capacity building. Some initial public effort should work like the starter of the system change.

4. CAUSAL MAP OF STOCKING RATE

Considering the main objective of this paper a smaller causal loop diagram is shown in Figure 3 to describe the relationship among forage availability, forage consumption and livestock consistency. The system is characterized by two renewable sources as main state variables: herd size and forage biomass. Rainfall regulated the biomass production that is positively related with stocking rate capacity, actually the carrying capacity of the system. Stocking rate capacity also negatively depends on the estimated forage consumption, which is function of the herd size. Herd size is positively related with production. Changes in meteorological parameters can cause variation of land carrying capacity while adjustments in herd size are needed to regulate the actual stocking rate to the stocking rate capacity of the available land.

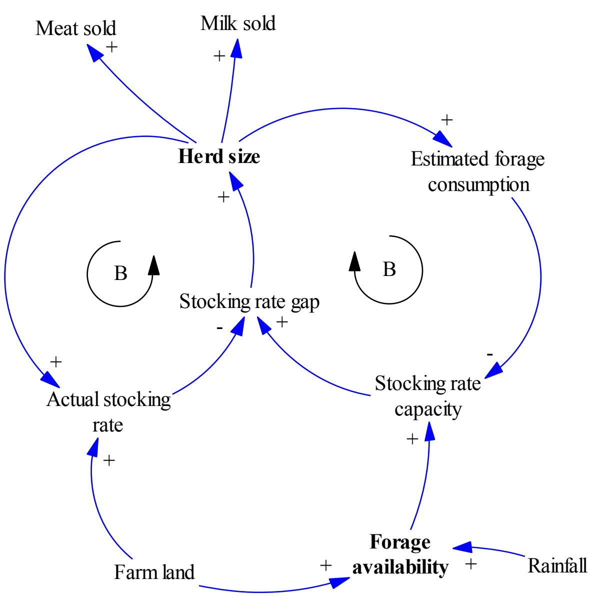

Figure 3. Causal loop diagram of the stocking rate capacity and stocking rate adjustment.

5. STOCK AND FLOW DIAGRAM OF STOCKING RATE SUBMODEL

In order to perform quantitative simulations on the modeled system, the causal loop diagram was translated in stock and flow diagrams. The 2 main state variables of Figure 3 are presented separately as Animal Inventory and Biomass Production and Consumption.

- Animal Inventory

This submodel is presented in Figure 4. The herd size variable was decomposed in 7 different stocks representing the physiological stages of raised cattle:

- Newborn calves from raised cows, splitted in two stocks of male and female calves; since the system is dedicated to milk production, male calves leave the farm in few days (<30).
- Suckling female calves are kept until weaning in order to select replacement heifers;
- Weaned calves needed for replacement are kept on farm, whereas excess of female calves were sold; the residence time in this stock depends on the time of weaning decided within farm; sales and annual rate of replacement heifers compensate the culling rate that is established as function of the productive life of the cows; the farmer decision an also change the culling rate;
- Replacement young heifers; animals remain in this stock until reach the age of mating and conception;
- Pregnant heifers; cattle remains in this stock during the entire length of gestation;
- Lactating cows, the enter the stock after their first calving. During the productive life, from first calving to culling, each cow pass through various cycles of lactation-dry periods;
- Dry cows; mature cows not in lactation.

Each stock has its detailed mortality rate. Cattle sales are supposed to be based on forage availability; when estimated forage consumption exceeds the available biomass in the farm land, the producer can sell part of the animals in order to adjust the stacking rate gap to forage availability; cattle to sell can replacement heifer, pregnancy heifers and cows.

Monthly milk production appears as an auxiliary variable not included in the model, positively influenced by the number of lactating cows and average daily milk production per cow.

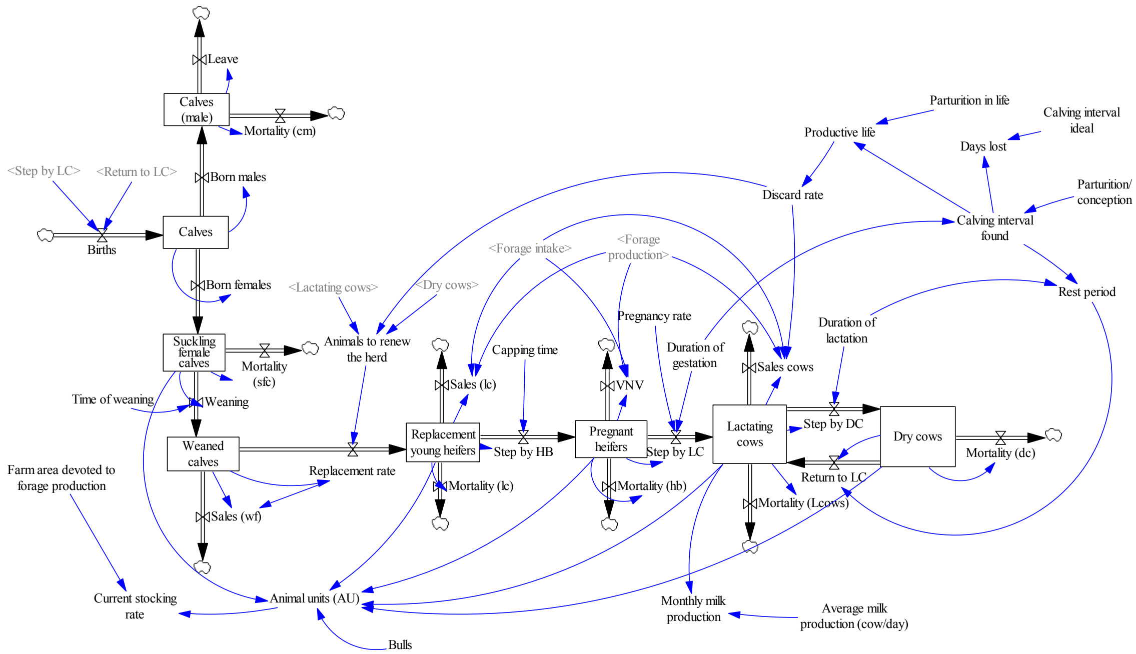

Figure 4. Stock and flow diagram of the raised cattle categories in the animal submodel.

- Biomass Production and Consumption

Forage production and consumption is shown in Figure 5. The main stock is the available biomass dry matter in pastures. It mainly depends on the available land for grazing (ha) and the production of forage per area unit (m^2), which is, in turn, function of rainfall in a homogeneous soil quality condition. Average precipitation in the model was set on 87 mm per month (average data recorded from 1996 to 2011 in the studied area; Cenicaña, 2012); the precipitation changes in the studied area can be considered equal to ±15%, mainly for positive and negative effects of traditional phenomenos named "*el Niño*" and "*la Niña*" (Gómez, 2006).

The inflow of available biomass depends on the relationship between precipitation and forage production per square meter, it was included in the model by using, as a lookup function of Vensim, the following equation:

$$biomass\ production\ (kg/ha\ per\ month) = 9exp^{-05x2} - 0.009\ x\ rainfall\ (mm/month) + 1.113$$

The outflow of available biomass was set up on forage intake, which mainly depends on the number of animals on the farm and their estimated DMI. Estimated DMI of the herd as determined on dietary fiber (NDF). In fact, NDF is the chemical and physical component of the diet that mainly influence the animal intake (Mertens, 1994). This stock and flow submodel for the production and consumption of forage was built following the structure proposed by McRoberts et al. (2013).

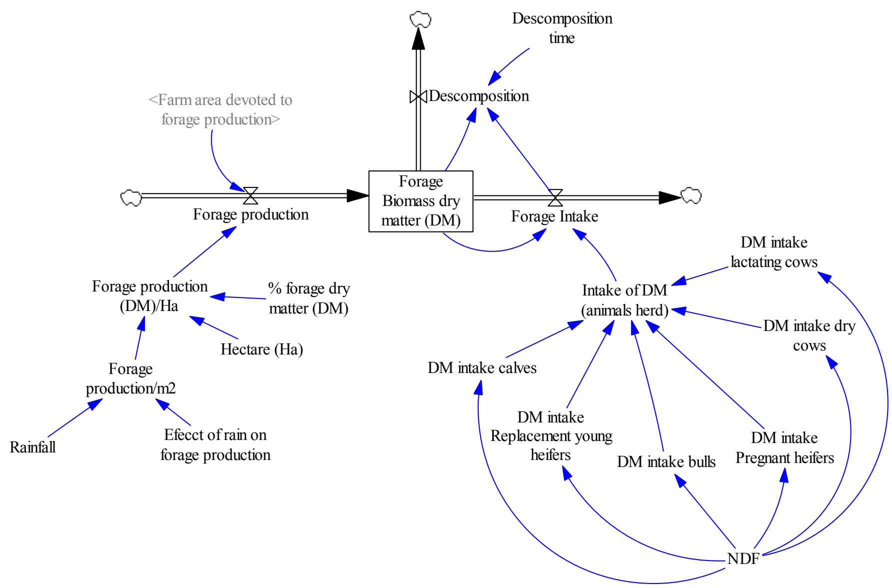

Figure 5. Stock and flow diagram of forage production and consumption in the land submodel.

6. SIMULATION SCENARIO

Three different scenarios of stocking rate adjustment were assumed in order to simulate the behavior of the cattle stock categories and milk sold when forage availability changes affected by precipitation. The horizon time was set on 20 years for a given farm area of 120 ha,.

A constant rainfall of 87 mm/month was assumed for the first 30 months, then rainfall dropped at 65 mm/month (simulating the effect of the "*Niño*") on the following four months (months 31 to 34). It was repeated after 120 months (months 145 to 148). Precipitation and biomass production are shown in Figures 6 and 7.

The simulated scenarios considered a sale of animals proportional to the reduction of available forage biomass and to the estimated dry matter consumption of each cattle category. Three ratios of heifer sales were set in the model in order to reduce herd size when biomass availability decreases:

A) 50% sales of replacement heifer and 50 % of pregnant heifers;

B) 60% sales of replacement heifer and 40 % of pregnant heifers;

C) 40% sales of replacement heifer and 60 % of pregnant heifers.

For all scenarios, non-producing animals were preferred for sells since cows produce milk and farm revenues.

On the other hand, when available forage is higher than estimated consumption, the culling rate is reduced in order to keep producing cows.

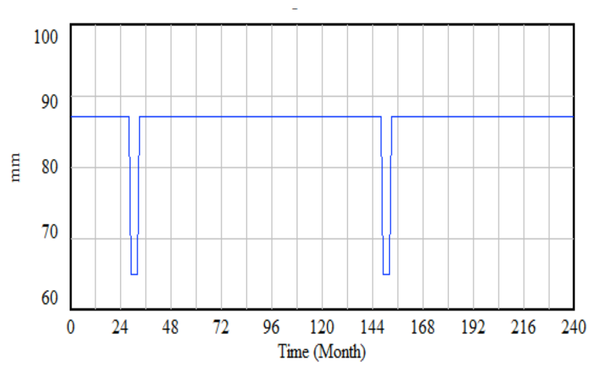

Figure 6. Precipitation (mm/month)

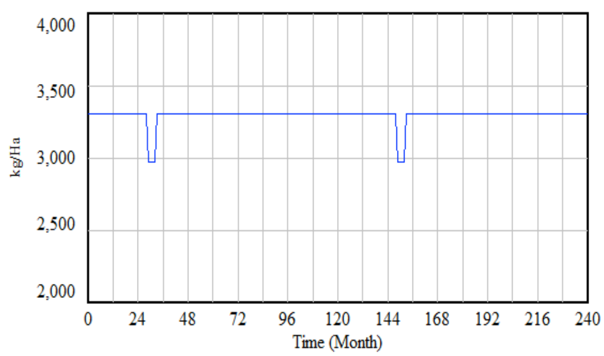

Figure 7. Forage production (DM/ha).

7. RESULTS

Considering a given typical farm, the average rainfall and biomass production the system tend to stabilize a dynamic equilibrium of the stocking rate in about 15 replacement heifers, 10 pregnant heifers, and 66 lactating cows, as shown in figures 8, 9 and 10 respectively. It corresponded to a potential milk sold of about 8,000 liters/month. When forage production decreases, proportionally to rainfall, the biomass production is reduced (Figure 7).

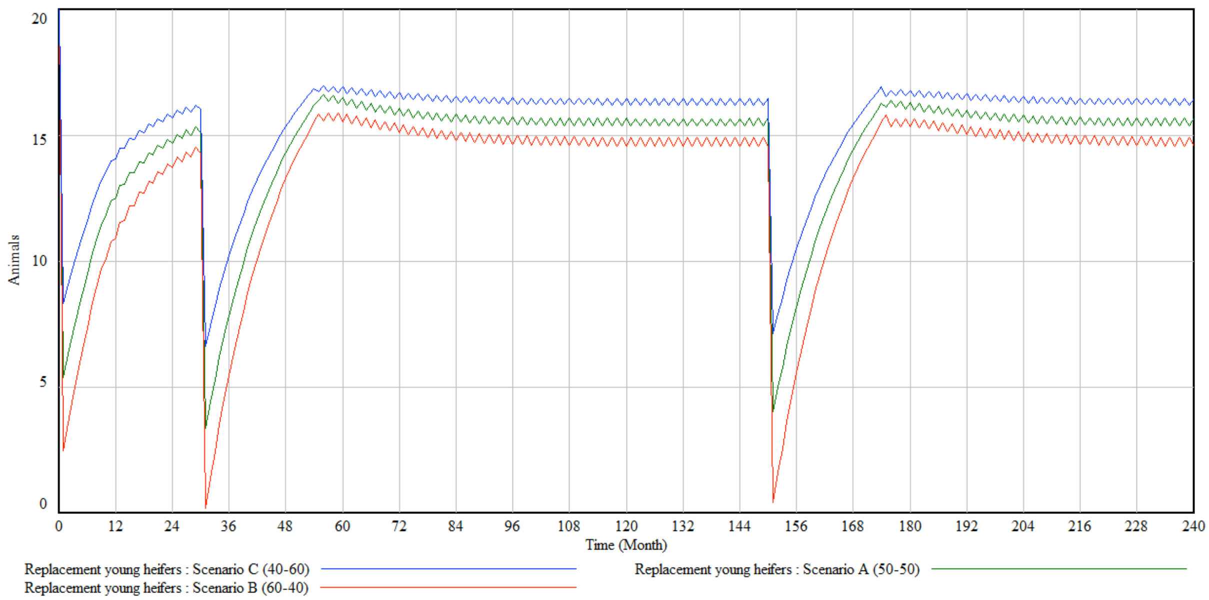

Figure 8. Stock dynamics of replacement young heifers.

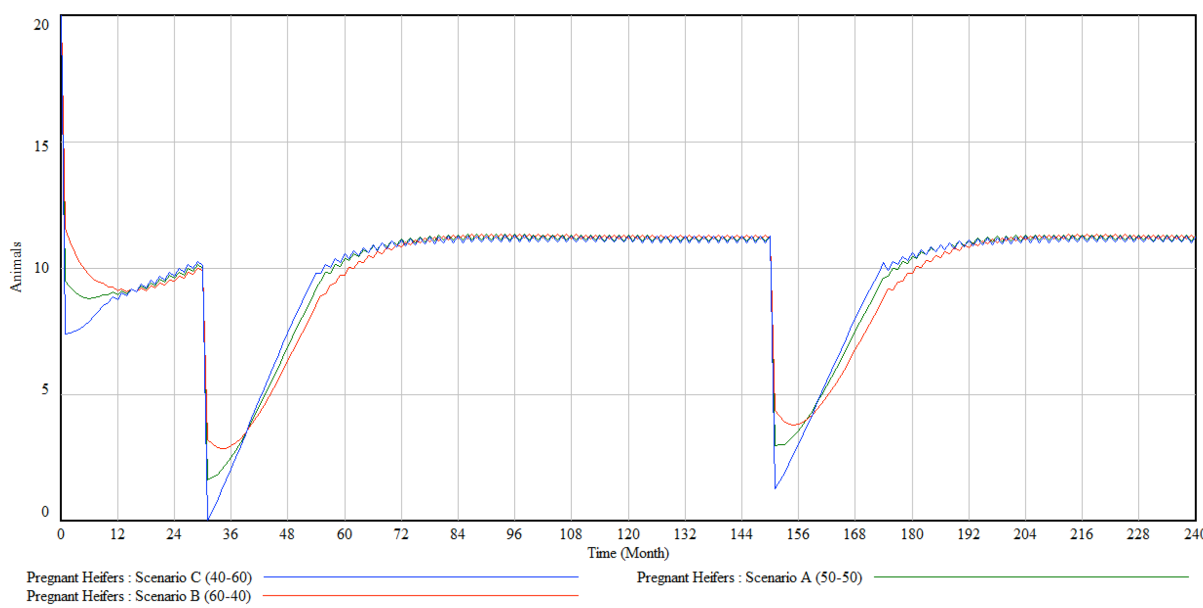

Figure 9. Pregnant heifers stock dynamics.

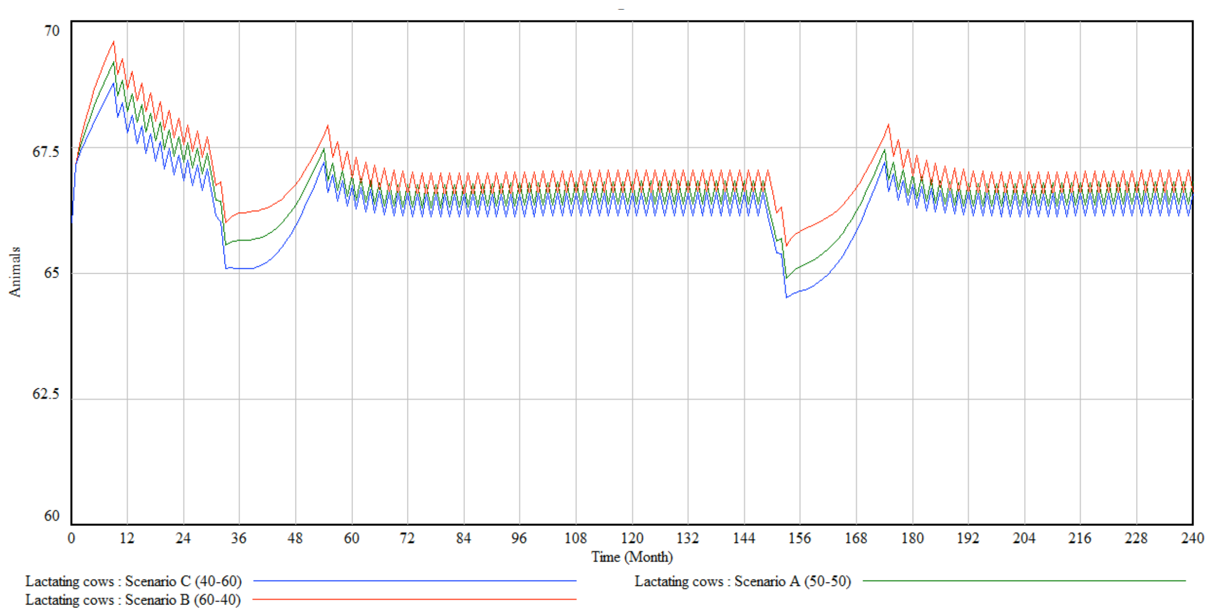

Figure 10. Lactating cows stock dynamics.

The effect of forage availability reduction in the 2 seasons of simulated rainfall drop oblige the farmer to sell their non producing animals in order to avoid overgrazing and low cow performances for starvation.

Considering the three scenarios, the ratio 60-40 for replacement and pregnant heifers, respectively, in comparison with the two others scenarios allowed to sell more replacement young heifers, to keep more pregnancy heifers and to maintain a higher number of lactating cows (Figures 8, 9, and 10). It also resulted in a higher amount of milk sold (Figure 11).

Considering the delay needed to go back to equilibrium after a drop in rainfall, noticeable differences were not observed between replacement young heifers (21 months; Figure 8) and cows (35 months; Figure 10); whereas a longer time to renew the pregnant heifers was observed for 60-40 than for other scenarios (21 vs 26; Figure 9). The behavior of the equilibrium phases was slightly oscillating, it was slightly higher in term of cattle number and was caused by the structure used to model the system; in fact a structure similar to two renewable stock resources was used which remember the prey-predator structure often replicated for similar approaches (Ford, 2009). Similar observations were done by McRoberts et al. (2013).

The lactating cows stock is slightly affected by the sales of heifers (about 2 cows; Figure 10). It was explained by the fact that culling rate is adjustable in a shorter period of time than heifers sale; from this point of view the cows stock behave like a buffer in the herd size system, reducing losses in milk production. The sale of more young animals (60-40) allows to the aging chain to renew the replacement stock quickly than other scenario, to keep more cows and to produce more milk (Figures 8, 9, 10, and 11). On the other hand (40-60), because of the direct relation between sales of pregnant heifers and lactating cows, when the sales of pregnant heifers were greater than sales of calves, the impact on the stock of lactating cows was higher.

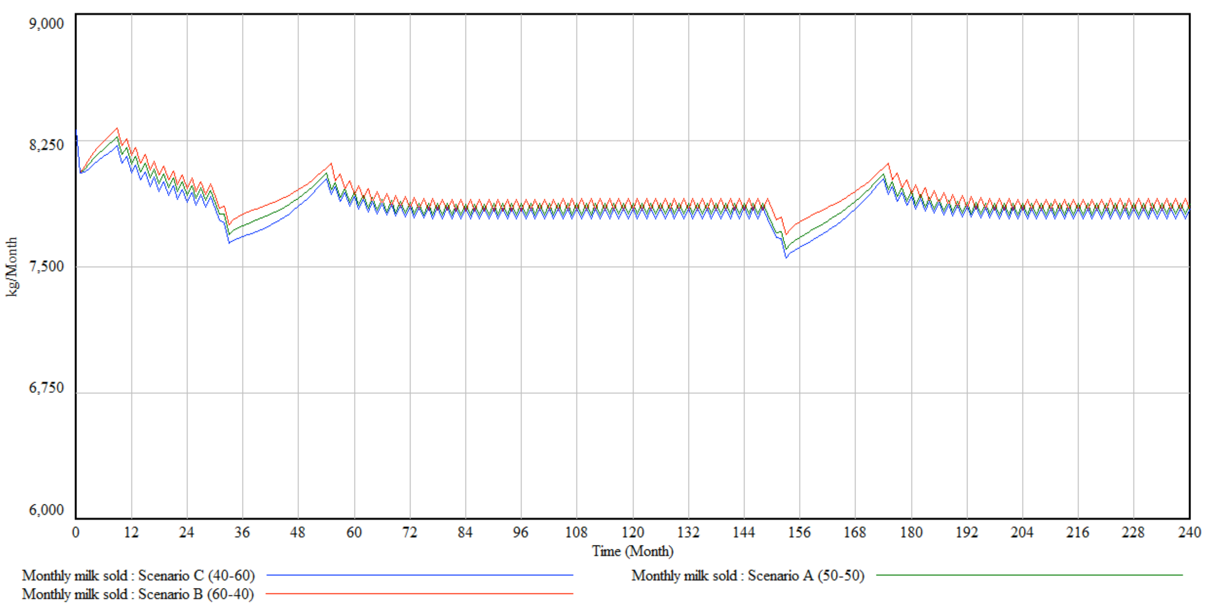

Figure 11. Milk sold, stock dynamics.

The dynamic equilibrium of the system was strongly sought by the modeled variables. It indicated that balancing loop structure intensely dominated the system behavior. The main balancing loop dominating the system can be identified in the replacement flow that is affected by mature animal performances, and directly proportional to the cows culling rate. On the other hand from a management point of view a sustainable equilibrium level depended on the farm capacity to adjust the stocking rate gap. When the animal productivity is sustained by the availability of forage, which in turn is a function of precipitation, it is imperative to achieve a good management of stocking rate. The equilibrium of these components is what can ensure the sustainability of the system (Pérez, 2010). Since stocking rate is the variable that the farmer can manage to control the equilibrium it is very important to correctly predict the forage availability in the next month and too correctly estimate animal requirements of DMI. Bad estimations of forage availability or animal needs might lead to overgrazing, decreased productivity and mandatory decisions of animal selling. Other hypothesis of feed purchasing was not taken into account in this partial model that focused a closed system for feed availability.

8. CONCLUSION

The behavior of complex systems can be analyzed using systems approach to understand the structure of the problem and its consequences. The presented submodel is included in a broader project aimed to study sustainability of Colombian rural areas. As previously demonstrated for the studied system, efficient management actions and investments in the farms, might help to switch from negative loops to reinforcing loops that promote sustainable development.

In this work a submodel of the stoking rate of raised cattle in the farm was developed and presented. The model was able to describe the equilibrium of the herd consistency when constant precipitations lead to constant biomass production. When drop in rainfall were simulated the model was helpful to identify a practical strategy of animal selling in order to adjust the stocking rate of the farm to the capacity of stocking rate of the land.

Using a system dynamics approach to support decision making can improve the identification of actions that result in greater technical efficiency and competitiveness of Colombian productive livestock systems.

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