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An integrated model of forage, meat and emission in a beef cattle production system

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ABSTRACT

The beef cattle production system is a complex system as it includes biological, economic and social factors which are also individually intricate in nature. In this approach a simplified relationship and interactions between various factors that control the system have been presumed to develop the integrated model of meat production, use and storage of forage, manure excretion and emission. Three major subsystems namely meat production, forage management and emissions were described separately and finally combined into a single system to simulate the system output. A dynamic Monte Carlo simulation software (GoldSim) has been used to simulate the system. Various management scenarios are considered to see the model performance and uncertainty.

Key Words: *Beef Cattle, Forage, Simulation, Biological systems and GoldSim*

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I. Introduction

In many countries, cattle production are based on widespread technology where animals graze on natural or cultivated pastures rather than being intensively fed with supplements. In such type of system, cattle productivity is strongly affected by forage production and management, which in turn depends generally on other natural factors (Kobayashi *et al.*, 2003). Raising beef cattle is a well-established profitable industry throughout the world. However, the profit and success of each beef producing industry depends on several management skills that each beef producer should chase. After

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choosing the perfect breed, land, labor and feed are the most important resources for this industry. To raise beef cattle profitably, these resources has to be managed properly to increase efficiency, reduce the uncertainty and control the variations. Unfortunately, this beef production systems is inherently complex and uncertain since this involve many variables and component parts that are interrelated (León-Velarde and Quiroz, 2001). The variables and components interact in complex ways with numerous feedback mechanisms, and in many cases, the systems are poorly characterized. In addition, such biological system is often controlled by stochastic variables such as transpiration and temperature and involve uncertain processes, parameters and events. For example, Pasture NDVI, a vegetation index that get depressed by grazing events which is a great indicator of canopy transpiration and ultimately the pasture growth rate (Alam *et al.*, 2018).

Using the mathematical modelling methods can makes it possible to separately describe the components, identify and analyze the cattle systems. Therefore, a cattle system is often symbolized by mathematical models, which are a representation of the realism. It has been assumed that the set of management policies categorized as optimal for the model will similarly prove to be the best when applied to real-world systems (Mayer *et al.*, 1999). Theoretical system models to describe such complex production systems is possible to construct that can be used educational, training and extension purposes (Hirooka, 2010).

A number of mathematical models have been reported to provide comprehensive descriptions of the biological characteristics of a herd or other specific components of the systems, such as forage (Rotz *et al.*, 1989; Rotz and Muck, 1994), nutrition (Bywater and Dent, 1976), reproduction (Boneschanscher *et al.*, 1982; Oltenacu *et al.*, 1980). Other models emphasize management or production replacement and prices (James, 1977), genetics (Groen, 1988), strategies (Congleton Jr, 1984; Dijkhuizen *et al.*, 1986; Sørensen, 1989) or decisions (Gartner, 1982; Herrero and Berry, 1982). These features play a significant role for assessing the biological sensitivity of the cattle production system to various production aspects. However, use of these mathematical models at farm level has limitations and problems associated with the implications of management changes in specific sites and ideal conditions.

Sanders and Cartwright (1979) reported a deterministic model that simulated beef cattle production under a wide range of management structures and environments with cattle differing widely in genotypes for size, growth and milk production is described where the genotypes are identified as production potentials. León-Velarde and Quiroz (2001) analyzed the main components considered to build subroutines to simulate intensive or grazing cattle production systems and suggested that the mathematical relationships explaining the interactions among and within components can be written in different programming languages (FORTRAN, C++, and spreadsheets,among others).

When analyzing the interaction between the growing pasture and grazing animals, it is often important to know the amount of forage eaten or the need for the rest of the season. Minson and McDonald (1987) developed an equation for predicting the forage intake by beef cattle from there liveweight and growth. The quantity of the forage selectively grazed was estimated solely from the growth rate and weight of the cattle therefore no laboratory analysis was done. This sort of equations are the stepping stone for modelling the system following the approach we used in this current study.

Beef cattle have varying feed and nutrient requirements depending on their age and stage of production. Calves will need a higher level of nutrition to allow for their growth, while mature cows will need a relatively low level of nutrition. However, for beef cows a nutritional balance should be maintained for maximize the meat production in a cost effective way. Therefore, regardless of some nutritional supplement, the major portion of the meal for a matured beef cow comprises of forage. In many areas of the world, the climate is just not suitable for forage growth during most of the year. In those regions forage has to be preserved through the management of harvest and storage to feed animals during the months when fresh forage is not available (Rotz and Muck, 1994). Proper estimation of exact need and consumption is therefore needed for better management of available forage resources.

Agriculture is the source of three key Green House Gas (GHG), being CO_2, CH_4 and N_2O have been considered to be responsible for 10–12% of global estimated GHG productions and ~50% of CH_4 and ~60% of N_2O from anthropogenic sources (Smith *et al.*, 2007). One of the main components of agricultural emissions is CH_4 from livestock enteric fermentation and CH_4 and N_2O from manure management (38%) (West and Marland, 2002). Therefore, estimation of the production of manure is indispensable component of the whole farm system modelling.

The boundaries of the system are determined by the environment of the whole subsystems and its relationship. This study has a net of complex subsystems that would be evaluated one by one. For the present study, we developed the system of the beef cow production as simple as possible starting with defining the inputs (feeding supplies and the animals settled) and outputs (meat, manure and gas emissions). We used some established mathematical equations to establish relationship between variables and the GoldSim modelling platform to simulate the whole beef cattle production system. The specific objectives of this study are to introduce the GoldSim modelling software for the purpose of simulating a complex system like beef cow production and to see the usability of the methods for further precise modelling of the system.

II. Materials and Methods

Model conceptualization

For the beef cows we considered a standard farm (400 ha) with a fixed ratio between young and mature cows. The feed uptake and weight increment for both groups are almost constant over the year with a slight seasonal variation. Similar assumptions are made for the manure production and the composition of manure. Besides the accumulation of animal weight, the model has also accumulation functions for manure and the amount of grass and corn in stock. The model was developed to be able to predict the feed stock, the increase of weight, the slaughtering moments and also the manure production.

An imaginary structure of a standard beef cow production system comprising three subsystems of meat production, feed stock and emission were constructed. The basic constrained variable was considered as the available land resources. The initial input into the system as young cows was then determined considering the capacity and profitability of the system with a fixed ratio between young and matured cows. Figure 01 shows the block diagram of the whole system comprising meat, feed and manure excretion subsystems whereas, **Table 01** shows the important input and output variables in different subsystems.

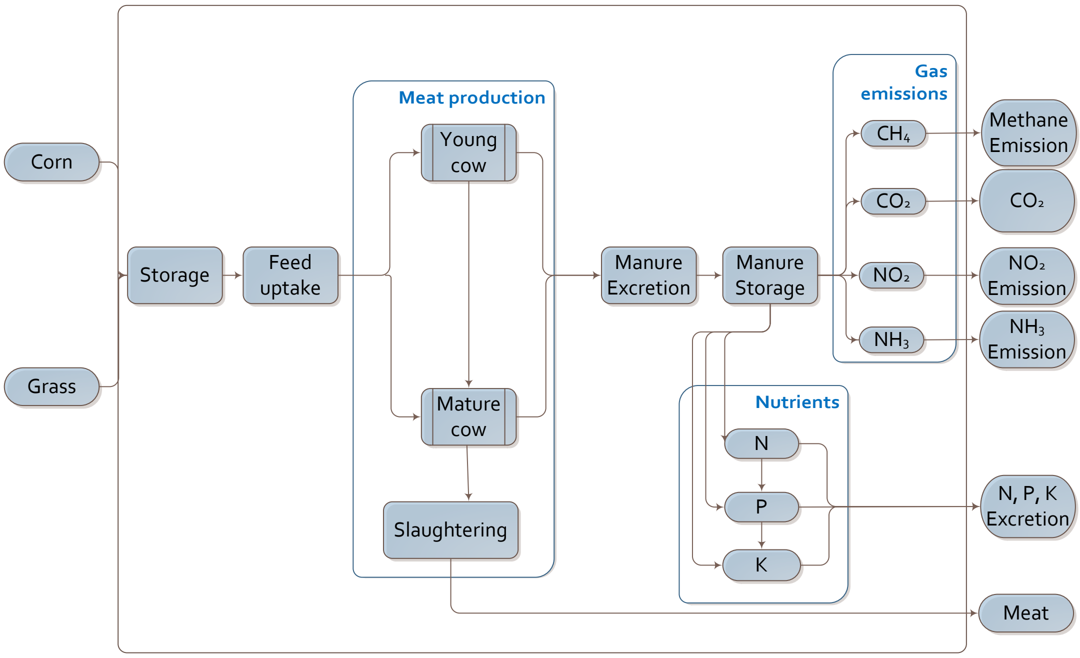

Figure 01. Block diagram of the beef cow production system.

Table 01. Input and output variables of the different subsystems

Subsystems	Input		Output	
	Variables	Units	Variables	Units
Meat subsystem	Grass & Corn Young cows	Kg/cow/day Item	Meat	Kg/day
Feed stock subsystem	Water Fertilizer Seed	mm/ha kg/ha kg/ha	Grass and Corn	Kg/ha
Manure subsystem	Matured and Young cows	Item	Manure	Kg/cow

Making assumptions are one of the important steps in model building. In this study following assumptions are made to construct the model:

- Only beef cows are in the system and there is no variation of growth and feed uptake of same weight cows.
- Cows are only fed with grass and corn.
- Similar assumptions for production and composition of manure.
- Off-farm activities including Nitrogen fertilizer production, transport and application are not included in the model.
- No loss of animal or crop due to unexpected reason.

A mathematical model let us demonstrate the interactions between the elements of the system. With this information an optimal productivity of the system would be guaranteed. Simulations of the system with different quantity variables are going to be presented in order to let the decision makers, choose the best option for the system that now we are analyzing.

Energy requirement for beef cattle

In animal production, the energy for maintenance is higher than the energy for growth. For that reason net energy values must be separated on two kinds, energy for physiological functions and energy for gaining weight.According to Lofgreen and Garrett (1968), for measuring the energy for maintenance, it is important to know the amount of energy required for heating a fasting animal. Heat production in animals depends on the basal metabolism, the heat increment and the heat produced by the activity.

On the other hand, the net energy required for growth is considered as the energy used to gain weight. There are different values to be considered on heifers and steers because of the body and metabolism conditions. The net energy requirement for maintenance and the net energy requirement for gaining weight can be calculated with the following equations (Lofgreen and Garrett, 1968).

The equation to estimate Net energy requirement for maintenance is:

$$NE_m = 0.077W^{0.75} \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where,
NE_m=Net energy for maintenance [Mcal/day]
W=Body weight [Kg]
And the equation for estimating the Net energy requirement for gaining weight is:

$$NE_g = (52.72g + 6.84g)W^{0.75} \ldots\ldots\ldots (2)$$

Where,
NE_m=Net energy requirement for growth [Kcal/day]
g =Daily weight gain [Kg/day]
W = Body weight [Kg]

Feed uptake

The determination of the requirements of the animals is the most important task for establishing a diet. The energy requirement can be found from equation (1) and (2) whereas the feed requirement can be found with the help of Table 02 (Lofgreen and Garrett, 1968) which shows the available energy that can be obtained from different types of feed.

Table 02. Available energy for growth and maintenance from the supplied feed

Feed	NE for Maintenance (Mcal/kg)	NE for Production (Mcal/kg)
Corn	1.27	0.75
Grass	0.83	0.4

To calculate the feed uptake by a cow the following equation was derived from equation (1) and (2) and from Table 02.

$$FU = (NE_m + NE_g)/(NE_f) \ldots\ldots\ldots\ldots\ (3)$$

Where,

FU=Feed uptake [Kg/day]
NE_m=Net energy for maintenance [Mcal/day]
NE_g=Net energy for growth [Mcal/day]
NE_f=Net energy from feed [Mcal/Kg]

Cow population

We had many options to select the number of cows and their age of entering into the system. We did some scenario study taking into account the number of cows and their ages and periodic input of different ages of cows throughout the year. As we have a limitation of area, we assumed that the maximum number of total cow population never exceed 350 (Items). The number of young cows and matured cows can be adjusted for maximizing the profit in different situations and according to the availability of grass and corn and the requirements of the market.

Feed storage

In the model, we assumed only grass and corn produced in the farm are used as feed. The grass is harvested twice in a year and the corn just once. “Grass and Corn” is a different subsystem and we incorporated the result of that subsystem into our model. The necessary amounts of grass and corn are stored so that cows can be continuously feed up until the next harvesting time. We assumed 50% of the area is used to produce grass and the other 50% is to produce corn. The grass and corn are used in bio refinery and for feeding the cows. There is no fixed ratio but depends on our model prediction that how much grass and corn we need to store to feed the cows. After harvesting, the grass and corn are needed to be stored to feed the cows throughout the season. The percentage of total production of grass and corn needed to be stored at the time of harvesting depends on the number of cows and their stage of growth. The model simulates the amount of grass and corn to be stored during the first and second harvest. Initially we need such an amount of grass and corn in the storage so that it becomes to zero at the next harvesting time. We stored the amount of grass and corn in order that after the season we can have the same amount of storage as it was during the beginning of the season.

Manure production

The annual manure production by grazing animals is difficult to determine, therefore the amounts are based entirely on estimations and consulting with experts. The quantities of manure excretions for the cattle subsystem are proportional to the number of cows and its weights. For that reason we considered the two different stages of animals that are part of the subsystem (young and matured animals) as two

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parameters for manure. In the case of young cows we assumed the amount of 6 kg of manure per day, for a range of animals between 100kg and 250kg. Also, it is considered 21kg of manure per day for animals between 300kg and 450kg.

Steps for the modelling

GoldSim modelling software has been used to construct the model. To reach the objective, we took into account values we obtained from the calculations using equations. In some cases we used conversion factors, used some parameter values from literature study and from the consultation with the experts. After constructing the main model we studied the scenario analysis by changing important variables and in some cases we calibrated the model by trial and error method. Figure 02 shows the combined model with the relationship of each major subsystem.

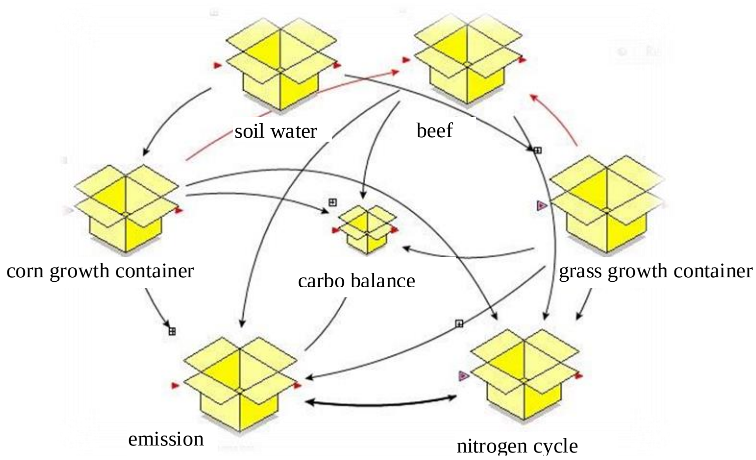

Figure 02. GoldSim model of the total system.

III. Results and Discussion

Simulation results

After joining three subsystems and all the necessary modifications in the model, it was run and the results were analyzed in order to ensure its proper operation at every level. However, only the most representative results are discussed, which from the point of view of productivity and sustainability are important.

Initially 150 young cows and 100 matured cows of different body weight within a range were considered (body weight with geometric mean 212kg/item and 350kg/item for young and matured cows respectively having a standard deviation of 0.7kg/item for both). First batch of young cows get matured after 140 days but at the same time we made same amount of young cow input into the system so the young cow population remains the same as before (150 item) till 280 days. After 280 days, second batch of young cows get matured and the number of young cows became zero as there is no further input of young cows into the system. On the other hand, we have 100 matured cows initially and from the beginning some matured cows were slaughtered every day. When the number of matured cows became 50, we made an input of another 50 matured cows to get continuous production and not to reduce the number of animals below a certain limit, considering the economic profitability of the farm (so the number of matured cows fluctuate between 50 and 100). After 190 days the young cows in the system get matured, so the matured cow population increase suddenly at that time. At the end of the season, when the second batch of young cows gets matured, the number of matured cows increases again.

Beef production results

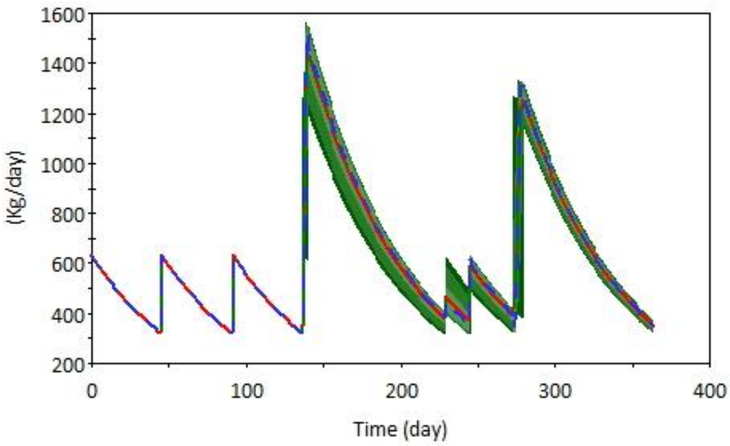

Figure 03. Beef production per day (kg/day).

Initial beef production begins with 150 young cows and 100 mature cows. The Figure 03 shows that the beef production starts at the rate of 600kg per day and it gradually reduces to the lowest value of 300kg per day. At that point 50 mature cows were added into the system. So the meat production increased to 600 Kg per day again. These events repeat until all the young cows from the system become mature. That happens around 140th day of the year. At this day, the beef production is reached into a peak of about 1600kg/day because the total amount of mature cow in the system reaches into the highest number. After that, meat production reduces gradually again up to the number of mature cows becomes fifty and the cycle repeats as before. At the end of the year, the second shift of young cows again becomes mature and the system gets into another big production up to the last day of the season.

Manure excretion

Figure 04 shows the manure production throughout the season. In this model, we assumed that all young cows produce an average 6 kg of manure and all mature cows 21 kg. So the manure production change suddenly when the phase shift occurs, that is all young cows get matured. After 140 days, at the time of first change in phase, also 150 new young animals put into the system so the cow population increase suddenly which also increase the manure production.

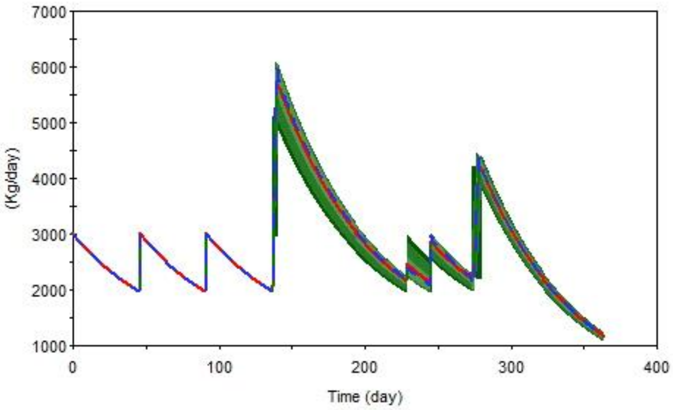

Figure 04. Manure production per day (kg/day).

The production of manure is 3000 kg per day at the beginning and it reduces as some cows go out of the system because of slaughtering but after some days it increases as some mature cows is imported into the system. When the young cows grows up and the weight exceed 350 kg they turned into mature, at that time we put 150 more young cows into the system, so the manure production increase suddenly after 140 days. Even though, the production is not as high as the previous, the same process happens at the end of the season but this is only because of manure production increase per cow due to phase shift.

Feed uptake

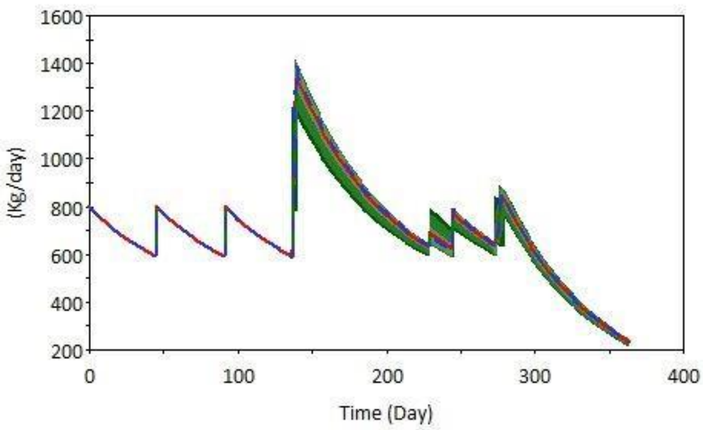

Figure 05. Feed uptake per day (kg/day).

The Figure 05 shows the total feed uptake per day by all the cows in system. Corn and Grass are used in a relation 1:1 for feeding the cows. The initial amount of feed uptake is 800kg per day which reduces and increase periodically up to the young cows become mature. When young cows have grown, another batch of calves is given input to the system, that's why at that time the feed consumption reach to the peak. The value of peak feed consumption is around 1500kg per day. The feed consumption is slightly uncertain after this point because all cows are not with same weight to assume that the whole group shifts to the next phase.

Grass storage

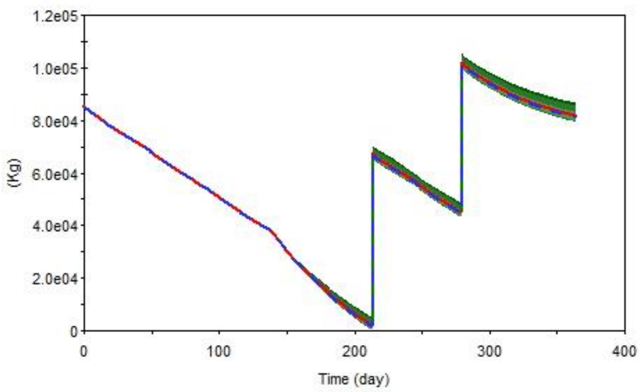

Figure 06. Status of Grass storage (kg).

The Figure 06 illustrate the flow of grass from storage. Initially we need a feeding stock of about 8.3e04kg of grass to feed the cows up to the first harvesting. During harvesting we stored 45% (the amount that is sufficient to feed the animals up to the next harvesting time and at that time storage will be zero, that is also simulated in the graph)of the total production of grass for feeding and the storage becomes 6.5e04kg after the first yield and about 1.1e05kg after the second. Once the first year has finished, the sum of grass that remains in the storage is the same as the obtained at the beginning (for the next season).

Corn storage:

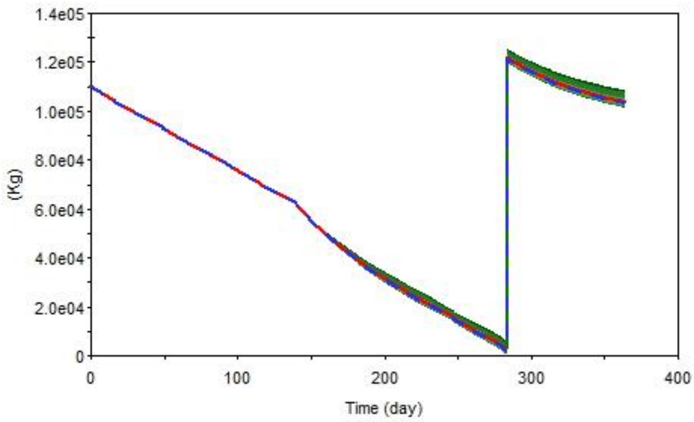

Figure 07. Status of Corn storage (kg).

The Figure 07 shows the flow of corn from storage. Initially we require about 1.1e05kg of corn to feed the cows up to the first harvesting of corn. During harvesting we store 31% of the total production of corn for feeding and the storage become 1.25e04kg. After the season same amount of grass remains in the feeding stock as we get at the beginning of the year for the next season.

Uncertainty

Developing uncertainties will help the subsystem to gain more confidence. The use of independent data input would lead the model to an important progress. The changes on the data management will allow us to see real effects of parameters and conditions established previously on the mathematical information process. Goldsim software package has a Montecarlo Uncertainty Propagation tool that allows the system to have different uncertainties (Indicated by the thickness of the line in the graphs). Uncertainties would be accumulative during the time through the elements used for modelling. For our model, the number of repetitions established was a total of one hundred times, for the standard values. Also, GoldSim consider storing state variables or outputs for some time instants by a determined number of repetitions. Goldsim warranties that the results would be affected day to day by new resamples with the use of the stochastic element.

In our model, we assumed a small uncertainty in the weight of the cows, so that it is also uncertain that exactly when the cows become matured and when they gain the weight that is selected for slaughtering. As cows are the main input in our system, all other production like meat, manure and gas become a little bit uncertain for this input.

Discussion

The model produced satisfactory result in predicting the daily meat production, manure production as well as making accurate decision for storage and production of grass and corn. However, the model were simplified in many ways and only few important variables were taken into account. Including these variable, lots of other variables can also affect the production and for a precise model in real life decision making purpose major modification in the model is necessary which should include the uncertainty of determining the values of variables. On the whole, the study demonstrate the suitability of using the software to be used in simulating complex systems like this. The sustainability of the system does not depend only on technical issues but on some managerial decisions and other socio-economic conditions of the society.

IV. Conclusion

To make a complete model it is very important to find the accurate data and equations. In this study we conquer our objective that was to learn the way to analyze a complex system using the Goldsim modelling tool. Only the most important variables were included in the model, therefore, the results

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obtained may not match perfectly with real life situation but according to the information described, we can analyze data results that demonstrate the development of a field. The objective has been obtained according to the tools and parameters established. Nevertheless, for a deeper exercise, is possible to go more in detail. Modelling with complete information allows the analyst to show reasonable results for the decision maker. This hypothetic case gives the experience to approach a system and optimize it with the correct use of mathematical equation. Recollecting the best information and determining correctly the assumptions would guarantee the best results to the process.

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APA (American Psychological Association)

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