LIFE - SIM: Livestock Feeding Strategies
Simulation Models

“... Make things as simple as possible, but not simpler than that”
A. Einstein

Dairy, Beef, Goat, Buffalo

Natural Resources Management Division
LIFE - SIM: Livestock Feeding Strategies
Simulation Models

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Comments are invited.

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Preface

The following document was prepared by a team of the Natural Resources Management Division of the International Potato Center (CIP), to describe the formulae of the models “Dairy,” “Beef,” “Goat” and “Buffalo, which integrate the Livestock Feeding Strategies Simulation Models, LIFE-SIM. The models were used in different workshops related to assess year-round feeding strategies in smallholder crop-livestock systems, on which sweetpotato can play an important role. Information utilized comprise different sources allowing an integration of the main components to estimate an animal performance under different feeding strategies.

Simulation models for “Dairy”, “Beef”, “Goat and ”Buffalo” production can be adapted to different local conditions. Considering the inputs for running the models it was possible to interact, during different workshops, with several participants who used their own data to validate the models. Several case studies were prepared and presented by workshop participants complementing the use of the LIFE-SIM models.

The development of LIFE-SIM models was sponsored by the International Potato Center (CIP), and the “System-wide Livestock Program” SLP/International Livestock Research Institute, ILRI. The SLP/ILRI contributions were channeled through the following projects executed by CIP: “Enhancing Crop - Livestock Productivity while Protecting Andean Ecosystem” and “Virtual Laboratory on Systems Analysis in Mixed Crop-Livestock Systems”. The Government of Perú (STC-CGIAR) also contributed in the development of the goat model and its validation through the project “Evaluación de producción y alternativas de manejo de cultivos promisorios en bosque seco y valles de la costa norte del Perú”, as well as the project supported by INIA-Spain “Reducción de la pobreza en los altos Andes a través de la producción, transformación y comercialización de productos agropecuarios”.
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The authors are indebted with the members of the NRM research team for their technical support. Several investors have contributed to the development of these tools and their validation; SLP/ILRI, The Ecoregional Fund, STC-CGIAR (Perù), and INIA-Spain. We are most grateful for their continued support. The models have been greatly enhanced with feedback received from the participants in the Workshops held in Latin America, Asia, and Africa.

Thanks to all.
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Introduction
Agricultural research traditionally aims to increase crop and livestock productivity. However, efficient food production is no longer enough, and additional external pressures have broadened traditional farming aims to include an array of objectives. The protection and sustainable management of natural resources is becoming an increasing necessity as natural resources diminish and farmers wish to successfully compete in new, more complex global markets. Recognizing this shift in priorities, it is imperative that agricultural researchers adjust their programs to meet the needs of farmers concurrently with improved natural resource management.

Research institutions have responded to new challenges; however, change has proven to be slower than expected. In the early 1960s, research institutes in Asia, Africa, and Latin America were already introducing the farming systems research (FSR) approach into their agendas, constituting an important step forward in agricultural research. Still, complete global adoption has been highly variable. While some research groups are only just currently implementing the tools and methods used by pioneers in the 1960s, other research groups have incorporated new pressures and externalities in farming system approaches to work within “more holistic paradigms.” One aspect that has not changed in FSR, however, is its emphasis on system description rather than predicting the outcomes of the introduction of technology alternatives.

The work that CIP’s Natural Resources Management Division and partners are conducting in the Andes can be considered as a Market Oriented Farming System Approach for Rural Development (MOFSA&RD). The goal is to search for the appropriate technology to improve a particular production program and to enhance the farm-market relationship, based on production-consumption chains for products with a comparative advantage in the market. Within the context of the document, the term market is defined as including the actual and potential markets for the good and services produced in the systems. As shown in Figure 1, the methodological steps are similar to the ones followed in the classic FSR&RD, however, in essence the important difference resides in the fact that the market is internalized in the analysis, and predictive tools like models and simulation are more extensively utilized in an effort to improve the management and productivity of natural resources.
Scientists and farmers alike realize the importance of approaches such as the MOFSA&RD as it requires a strong link between science (specifically the use of the scientific method) and technology. Conceptually, it is useful to recognize the link between science and technology (see Figure 2), and the value of the scientific method resides in its use of prior knowledge in order to generate new knowledge. However, the sole application of science is not sufficient to solve technological problems. Technology, on the other hand, uses knowledge to develop solutions or options, considering the milieu in which the system is embedded.
The value in knowledge generated through the scientific method resides in its formalized production and ability to predict future events. When this knowledge is used to both describe and predict, true science is practiced.

Systems Analysis – defined as the process of developing a model of an actual existing system through the means of a computer program – is one of the existing options to formalize the knowledge generated in science in a manner useful to design, test, and implement technology, (Shannon, 1975, 1982; Dent and Blackie, 1979).

Determining project objectives and then classifying a model function process by the hierarchy or scale of included elements is the most useful way to ensure that a model achieves its goals of improved and accurate knowledge development. For instance, understanding and predicting the atomic structure of the elements contained in sweet potato requires a sophisticated physical model with many input and state variables—a process that would be impossible to implement without a model. If, on the other hand, the objective is to understand and predict the production of sweetpotato by farmers, a model containing the variables and inputs describing the formation of roots and foliage is thus required. It should then be evident that if the purpose of a project is to predict sweet potato production as a function of varieties, a model based on variables describing fertilization, plant density and important nutritional and physiological processes is required. It is feasible to use the aggregation of atomic models to predict sweetpotato production in a farm, but the user will be required to have all the input variables at the atomic level and access to a super computer. In addition, given the level of refinement of the variables and parameters required in this model and the level of sensitivity, which is measured at the scale of sweetpotato production in the farm, would be too high and requires the input to be accurate. As a corollary, the objective determines the complexity of the model, and the simplest model is best for each hierarchy, i.e. the one with the least number of variables and parameters that would provide accurate outputs.

Because predictive models can be developed and used at different hierarchical levels, it can be concluded that system analysis is applicable in both the development (scientific method) and the application of knowledge to solve problems (technology development). One can then view the agricultural research for rural development as a continuum, spanning from basic research to the promotion and adoption of innovations. In that process, systems analysis constitutes a useful tool for most of the steps. Different and complementary skills in the art and science of modeling are thus required. In the first group we find model developers, in the second, model adapters, and finally the group that is directly involved with the farmers, the model users. This concept is better
understood with an analogy to the TV set industry. The TV makers condense all the science into the components of the apparatus and then assemble them into a unit. TV repairers diagnose and solve problems and adapt the sets to specific conditions by removing and replacing the required parts. Finally, TV users fine-tune in order to achieve better results.

The present document describes the information and processes of the computer models that comprise “Livestock Feeding Strategies Simulation Models”, LIFE – SIM. These models were used in workshops in LAC, SSA, and Asia to assess year-round feeding strategies, where SP constitutes an important component of the strategy. The models were successfully validated with experimental data provided by the participants in the workshops.

Livestock Feeding Strategies Simulation Models, LIFE-SIM

The software Livestock Feeding Strategies Simulation Models, LIFE-SIM was developed within the Natural Resources Management Division of the International Potato Center (CIP). The objective of the models is to evaluate the effects of different feeding strategies (scenario) on animal performance. Therefore, LIFE-SIM is comprised of four specific models for ruminant animals (Dairy, Beef, Buffalo, and Goat) and one for non-ruminants (Swine); only the general formulae for the ruminant models are described in this document. Each model is dynamic and probabilistic and runs on a daily basis. Consequently, it is necessary to run each feeding strategy or scenario several times to obtain the average response for an animal within a herd or region.

The components of each model include specific subroutines for pasture growth, voluntary intake, supplement availability, nutrient requirements, thermal regulation, milk – beef and meat production, manure production, methane emissions, and a bio-economic analysis. The graphic interfaces for all the models are similar and require the same inputs. Appropriate parameters were incorporated to the equations allowing the evaluation of the animal performance for each species considered.

Each model requires as inputs appropriate information on: livestock characteristics, pasture and forages, weather conditions, supplementation, and the prices of feeds and products. The information required for the animal component are: milk yield potential (the best average lactation curve in a farm or region), age, body condition and chemical composition of milk or meat, the stocking rate (number of animals per hectare), as well as the potential feed intake (as percent of the body weight) and the expected variation in feed intake. The models consider the month when calving occurs as the first month, and estimate outputs from those inputs for a year covering the whole lactation or fattening period. During the process, the model estimates forage
availability in relation to the changes in feeding practices during the year. Thus, it is important and necessary to define the average characteristics of the specific animal of the herd or groups of animals within the herd or region.

The outputs of the LIFE–SIM models are the expected milk yield during the lactation period, the changes in body weight during the same period, the weight gained during a fattening period, the amount of manure produced, and an estimate of methane emissions. Additionally, the model provides estimates of the total costs of production per animal per lactation/fattening period, and the average cost per kilogram of milk or meat.

The LIFE–SIM models contain six main input modules: animal, pasture and forage, supplementation, weather conditions, supplement strategy, and cost. The animal component inputs information considering the animal’s genetic potential, body condition, and response to the nutrients provided by pasture, forage, and supplements. Models predict responses due to energy or protein; thus, it uses the minimum value calculated to determine the “real” production of milk or meat. The pasture component is dynamic, and depends on the seasonal distribution of rainfall and temperature, which affects forage availability and quality, as well as animal performance. The supplement input module accounts for the additional feed provided to livestock and includes the nutritional characteristics of the supplements. Both modules have a sub-module that accounts for the order in which the food sources are consumed. The climate module determines the effects of temperature, relative humidity, and wind velocity on feed intake as they influence milk or meat production. The cost module inputs information necessary for a cost-benefit analysis based on the daily feed cost and its contribution to total costs in relation to milk production (León-Velarde, et al, 2003).

In summary, LIFE-SIM models constitute a practical tool for the evaluation of different feeding strategies in terms of their biophysical and economical performance. Output variables, like milk or meat production, economic gross margins, and methane emissions can be used with other models to calculate the function that best links a feeding strategy with economic gross margins, methane emissions and manure.

**Developing simulation models components to estimate meat and milk production in ruminant species**

Experimentation is vital for a continuous generation of the knowledge required to solve the diverse limiting factors faced by small farmers. However, in some circumstances, experimenting can be an expensive and time-consuming process, encountering severe difficulties in controlling
variables exogenous to the experiments. In such situations, computer-aided simulation models can substitute experimentation with an easy, cheap, and speedy task by the development of a suitable model.

In general, models are a simplified representation of reality. It is important to consider that a model is only an analytical tool and not an end in itself. Thus, models should be seen only as decision support tools. Nevertheless, the question to be asked is, what is a suitable (valid) model for virtual experimentation? A statistical test for model specification does not exist, which may not be a critical issue if the model can adequately predict real data. Models, as imperfect representations of reality, are effective in generating and testing hypotheses on how a component of a system or a whole system functions under a given set of simulated conditions. A comparison of trends of simulated and real responses is more meaningful than isolated statistical tests of model adequacy. A valid model is useful to evaluate scenarios that are difficult to test in the real world, especially valuable when assessing the long-term consequences of different management practices, considering the available resources or the possible impact of climate change. In such cases, comprehensive models are extremely helpful for evaluating and testing hypotheses that otherwise require many years of data gathering (Leon-Velarde, and Quiroz, 2001).

Considering the complexity of animal characteristics, management effects, available resources, and the climate affecting animal performance, (dairy cattle, beef cattle, buffalo, and swine) suitable models were developed to assess year-round feeding strategies in smallholder crop-livestock systems. Model outputs can be analyzed and used for decision making to enhance animal productivity and farm income. Developing components of simulation models to estimate meat and milk production from cattle in different ecoregions.

Simulation models constitute a tool of great value in the research process. Models make it possible to formalize existing knowledge about a system into mathematical equations, and the models are then used to test alternative futures or scenarios. In the process of building a model, the research group might determine research gaps—not a trivial issue, as research investment allocation is becoming more critical.

Research ideas can be screened using the model prior to testing them at the field level, thus saving time and money. By the same token, the technological options developed under a particular set of conditions can be included in the models and then used as a tool to predict how the technology would respond to a different situation. The process of developing a model can
vary according to research group. The following text correlates to the steps described in Figure 3 (Cañas, 1974).

**Objective**

The objective was to develop a computer simulation model based on relevant variables affecting cattle and goat production systems in order to evaluate how the target system would behave under different management conditions or scenarios.

**Analysis of the System**

This section describes the most relevant factors directly affecting the productive process:

- **Nutritional factors.** Each nutrient is important to animal production. However, in ruminants, energy and protein are the most important nutrient factors. For this reason, the models assess the quality of the feeds offered based on their energy and protein nutritional value. The energy is expressed in terms of metabolizable energy (ME) because this is the form of energy used in physiological processes. Protein, in contrast, is expressed...
in terms of total protein (N * 6.25), because neither gaining weight up to 1.2 kg/day nor producing milk in quantities equal or smaller than 15 kg/day requires bypass protein.

- **Environment factors.** The environment affects animal behavior. Temperature, humidity, and wind speed produce a thermo effect that varies feed intake. Changes in animal behavior also depend on the animal breed, fur thickness, and the level of feed intake. Animals with a high level of feed intake can reach a critical minimum temperature close to zero degrees without intake reduction. On the other hand, high temperatures and fibrous feed produce a high maximum critical temperature, for which the animal reduces its voluntary feed intake. The response to the combination of these two latter factors varies with the breed, but they constitute the key determinants for low milk production of dairy cows under tropical conditions.

- **Grazing.** Grazing has several effects on animals in the pasture, reflected among other changes in the:
  - Trampling effect, dependent on the grazing system, stocking rate, soil texture, and moisture levels.
  - Manure effect, dependent on the stocking rate, pasture digestibility, and animal size.

These effects are not directly entered as inputs nor are they produced as outputs by our models. Nevertheless, the user is required to input the percentage of the pasture used by the animal and thus very simply takes into account the effect the animal exerts on the sward. The model, however, contains functions that quantify the influence of the availability and digestibility of the pasture on the animal. These variables directly affect an animal’s feed selection, dry matter and nutrient intake, and the energy required for grazing.

- **Breed and animal type.** The breed and sex of an animal affect its body composition. In the model, a breed is characterized by variables such as feed intake, dairy potential, and milk and body composition. Breeds are grouped into three categories: pure, crossbreed, and native or Creole. The user defines the breed to be used through the input of specified parameters.

- **Health conditions.** It is evident that the health conditions of animals affect behavior. This effect is not evaluated in the models, since it is assumed that procedures such as vaccination, proper prophylaxis, and health management are provided.

- **Management conditions.** Management refers to the strategic use of resources. Therefore, supplementation during critical periods and the optimal months of parturition, fattening, and sales must be considered. These variables are included in the models, allowing for the evaluation of different management strategies or scenarios.
Summarizing the restrictions, the models:

- Do not include compensatory weight gain.
- Do not include the use of bypass protein, therefore, only work with animals with a weight gain less than or equal to 1.2 kg/day or production levels up to 15 kg/day of milk.
- Do not include the effect of the animal on the pasture.
- Assume adequate animal health.

Synthesis

Three components can be discerned at this stage: the algorithm, which is a description of how the parts of the model relate to each other; the equations, that quantify the relations explained in the algorithm; and the computer program, which creates a user-friendly interface allowing the user to interact with the algorithm and the equations to obtain responses.

The algorithm is the logical organization of the relevant elements of the model. It consists of flow charts representing a biological definition of relevant elements, which are important in the modeled system (Leon-Velarde, and Quiroz, 2001). These are used in the mathematical formulation to adequately represent the studied system. The proposed flow or algorithm chart for models is presented in Figure 4.
The algorithm chart (Figure 4) indicates that it is necessary to describe, in detail, the set of relationships for estimating forage intake under grazing conditions, as shown in Figure 5. The steps in the model are explained in detail, which ultimately estimate voluntary feed intake from the potential intake affected by variables of the pasture.

Three types of variables are considered in the mathematical relationships between the components:

Exogenous variables: These are independent variables of the system that constitute the data entry for the simulation process and act on the proposed calculation system.

Animal characteristics.
- Weight (kg)
- Breed
- Sex

Pasture characteristics.
- Forage availability (kgDM/ha)
- Pasture Digestibility (%)
- Pasture protein (%)
- Stocking rate (Number of animal units/ ha)
- Pasture growth rate (kg DM/day)
- Simulation starting date (day and month)
Feed supplementation.
- Quantity provided per day (kg)
- Concentration of metabolizable energy (Mcal/kg DM)
- Protein level (%)

Endogenous or state variables: These are variables generated by the interaction of input variables and parameters in the algorithm sequence. They are calculated during a simulation period. Among the important state variables are:
- Feed intake
- Total metabolizable energy intake
- Total crude protein intake energy, and
- Protein requirements for maintenance and production

Output variables: These are response variables calculated by the model:
- Milk production (kg/day)
- Weight gain (kg/day)
- Final weight after a simulation period (kg)
- Total milk production (kg/lactation)
- Feeding cost, total cost
- Average production cost per meat and milk produced ($/kg), including gross income, gross margin and income/cost ratio
- Forage final availability (kgDM/ha); forage budgeting across the year
- Manure, kg/day (Calculated from indigestible dry matter)
- Methane emission (l/day, kg/year). It is calculated from nutrients supplied and indigestible dry matter, (Blaxter, 1965)
- Nitrogen excreted (kg/day, kg/year). It is calculated by the sum of nitrogen not utilized during metabolism process.

Detailed description of Endogenous or State and output Variables

Dry matter intake
Dry matter intake is the most important variable in the production of meat and cow's milk. Potential voluntary feed intake can be calculated based on the weight of the animal. It is important to add some stochastic intake variability (7.5%) to account for the animal’s inherent variable attitudes over a period of days.
Potential dry matter intake
The potential dry matter intake is determined by the physical characteristics of the animal, represented by its maximum intake capacity when the characteristics of the diet are non-limiting factors (Allende, 2002). Potential intake is affected mainly by the rumen size, which is in turn a function of the animal size. For these models it was considered that potential consumption of the animal is a variable number (C) that ranges between 0.022 and 0.038 kg of DM/kg BW. This factor also depends on the breed.

\[ PDMI = W \times C \]

Where:
- \( PDMI \) : Potential dry matter intake (kg DM/day)
- \( C \) : Variation factor of potential intake (0.022-0.038)
- \( W \) : Animal weight (kg)

The feed volume and the residence time in the digestive tract are important in order to determine the intake rate. An increase in the intake of low degrading or indigestible feed causes a reduction in the rate of passage and the physical filling of the rumen, inducing a reduction of potential feed intake (Forbes, 1995).

In the case of lactating animals, potential intake increases in relation to milk production as per the additive formula for potential consumption:

\[ APDMI = b \times EMP \]

Where
- \( APDMI \) : Increase of potential intake due to lactation (kg)
- \( EMP \) : Expected milk production, according to genetic potential (kg/day);
- \( b \) : Coefficient for additional Kg of DM consumed per kg of milk produced (range 0.1 to 0.15)

Pasture effect on the animal
Forage availability and digestibility directly affect the potential dry matter intake of grazing animals (Zocal, 1984). Their quantification in the model is reviewed below:

Availability factor
Utilizing data from Abreu (1975) on the intake of young bulls grazing on temperate pastures, a correction factor for potential dry matter intake as affected by the availability was generated.
FCD = 1-e^{-0.001664*DD}

Where:
- **FCD**: Intake correction factor due to availability (0-1)
- **DD**: Instantaneous availability of pasture (kg MS ha⁻¹)
- -0.001664: Coefficient value for temperate pastures that can vary for other pasture types

**Digestibility factor**
The digestibility correction factor considers a linear relationship, in which the maximum value of voluntary intake is achieved with a forage digestibility of 80%, and it diminishes up to 1/3 of potential intake with 40% digestibility. The following relation was established:

FCG = (1.675 * DGC) – 0.34

Where:
- **FCG**: Correction factor due to digestibility (0-1)
- **DGC**: Digestibility of consumed DM (0-1)

**Digestibility of consumed dry matter (DGC)**
The model calculates a selectivity index that modifies the average digestibility of the pasture being grazed to estimate the digestibility of the consumed DM. The digestibility of the selected DM can be up to 25% higher than the average forage digestibility:

DGC = DGO * IS

Where:
- **DGC**: Digestibility of the consumed pasture (0-1)
- **DGO**: Digestibility of the offered pasture (0-1)
- **IS**: Selectivity index (1-1.25)

**Pasture selectivity index (IS)**
The estimated selectivity index takes into account the difference between the average digestibility of the pasture offered (DGO) and the digestibility of the forage consumed (DGC) caused by the opportunity of the animal to select from the diversity and availability of the pasture. There is at least a 25% difference between the digestibility of the offered pasture and that of the pasture actually consumed (Jamieson and Hodgson, 1979). Therefore, the IS in circumstances of low digestibility (40%) should have a multiplicative factor increasing by up to 25% of the observed value of digestibility (Zocal, 1984).
$$IS = 1 + SD \times SC$$

Where:
- **SD**: Correction factor due to pasture digestibility
- **SC**: Correction factor due to pasture availability

**Correction factor for selectivity due to forage digestibility (SD)**

When the digestibility of a pasture offered (DGO) is equal or greater than 80%, the selection is null, regardless of the availability of forage. A value of DGO equal to 40% is associated with a value of selectivity equivalent to 25%:

$$SD = 0.5 - (0.625 \times DGO)$$

Where:
- **SD**: Correction factor due to pasture digestibility = 0 when DGO $\geq$ 80%
- **DGO**: Digestibility of the pasture offered (Values between 0 – 1)

**Correction factor for selectivity due to forage availability (SC)**

The maximum selectivity of a pasture by the animal occurs when the pasture utilization factor is smaller than 10% and is at minimum (zero) when the pasture utilization is greater than 50%. The implication is a correction factor for availability, ranging from 10% to 50% of the pasture utilization:

$$SC = 1.25 - (2.5 \times PU)$$

Where:
- **SC**: Correction factor due to pasture availability
- **PU**: Percentage of pasture utilization (0.1 to 0.5)

For PU values less than 10% (0.1), the correction factor due to pasture availability is 1, and for PU values greater than 50% (0.5) it is 0.

**Percentage of pasture utilization (PU)**

$$PU = (PDMI \times FCD \times N) / DD$$

Where:
- **PU**: Percentage of pasture utilization (0-1)
- **PDMI**: Potential DM intake
- **FCD**: Intake correction factor for availability (0-1)
- **N**: Number of animals (stocking rate)
- **DD**: Instantaneous pasture availability
Instantaneous pasture availability (DD)
The instantaneous pasture availability is corrected daily by considering potential intake, the loss attributed to animal trampling, and the senescence of green material (Allende, 2002). A variable value should be considered which would depend on the number of animals, type of soil, pasture species, and climatic conditions. This value can range between 10% and 30%.

To estimate herbage senescence, an equation was developed considering that greater forage availability increases the level of dead plant material (Bircham, 1981). The correction is applied when forage availability ranges between 1500 and 3000 kg DM/ha. When the availability is lower, senescence takes a fixed value of 2% of available herbage, and at greater levels of availability it represents 5% of the dry matter. As a result, the equation is:

$$\text{SEN} = (0.00003 \times \text{DDi}) - 0.025$$
$$\text{DD} = [\text{DDi} - ((\text{CFREAL} \times \text{CA}) \times 1.2 - (\text{DDi} \times \text{SEN})) + \text{TA}]$$

Where:
- SEN : Senescence index
- DDi : Instantaneous forage availability at day i, (kg DM/ha/day)
- CA : Stocking rate (AU/ha)
- TA : Growth rate of the pasture (kg DM/ha/day)

Voluntary intake of forage under grazing
The predicted voluntary intake (CVO) is based on several factors that directly affect the potential dry matter intake (White et al., 1979).

$$\text{CVO} = \text{PDMI} \times \text{FCG} \times \text{FCD}$$

Where:
- CVO : Voluntary Dry Matter Intake (kg DM animal/day)
- PDMI : Potential Dry Matter Intake (kg DM animal/day)
- FCG : Correction factor due to forage digestibility (0–1)
- FCD : Correction factor due to forage availability (0–1)

ENERGY
Energy consumption
Energy consumption is determined by multiplying the gross energy (4.4 Mcal/kg DM) with the digestibility of the dry matter intake and the constant of conversion of ingested digestible energy into metabolizable energy (0.81).
CEM = (CVO * 4.4 * DGC * 0.81) + (CVS * 4.4 * DGS * 0.81)

Where:
- VO: Voluntary dry matter intake from pasture, kg DM/day
- CEM: Intake of metabolizable energy (Mcal EM/day)
- DGC: Digestibility of the ingested pasture (percentage)
- CVS: Supplement consumption (kg DM/day)
- DGS: Supplement digestibility (percentage)

Energy use

Maintenance requirement

The maintenance requirement includes two components: the first corresponds to the energy for maintenance, which is a function of the animal's weight; the second is the efficiency of utilization of the metabolizable energy ($K_m$), dependent on feed.

The basal metabolism or net maintenance energy ($EN_m$) is 77 kcal per unit metabolic weight ($W^{0.75}$) (Garret 1972). This equation is adequate to determine net energy of maintenance for cows with low and medium milk production levels and for young bulls. For high production cows, the net energy of maintenance depends on the feed intake. A logistical function is utilized, dependent on the intake of metabolizable energy per unit of metabolic weight (Cañas, 1974).

$$EN_m = \frac{126}{1 + 2.00262} \times e^{0.0036 \times CEM}$$

This equation was evaluated during the model construction and the result becomes in the following equation:

$$EN_m = \frac{77 \times W^{0.75}}{1000}$$

Where:
- $EN_m$: Net energy for maintenance (Mcal/day)
- $W$: Body weight of the animal (kg)

Efficiency of utilization of energy for maintenance

The efficiency of utilization of metabolizable energy for maintenance ($K_m$) is estimated by:

$$K_m = \frac{(54.6 + 6.818 \times CCD)}{100}$$

Where:
- $K_m$: Efficiency of utilization of metabolizable energy for maintenance
- CCD: Caloric concentration of the feed (Mcal/kgDM)
The $K_m$ of consumed energy for maintenance can range from 66%, when the CCD is 1.6 Mcal/kg DM, to 76% with a CCD of 3.2 Mcal/kg DM.

Consequently, the maintenance requirement for young bulls and cows with low and medium milk production levels is:

$$RM = \left(\frac{EN_m}{K_m}\right) \times W^{0.75}$$

Where:
- $RM$: Maintenance requirement (Mcal EM/animal/day)

Energy cost of harvesting feed

The energy cost of harvesting feed corresponds to the quantity of energy an animal needs to obtain its feed. The value depends on forage availability and the animal breed (Cañas, et. al. 2003). When forage availability is high, the estimated value of the harvest energy cost is equivalent to 10% to 15% of the maintenance requirement. The proposed equation is:

$$HC = (B + A \times e^{-K_0 \times e(K_1 \times X)}) \times \text{weight}$$

Where:
- $HC$: Harvesting cost
- $K_J$: Metabolizable energy/ kg of body weight
- $K_0 = 1.13 \times 10^{-2}$
- $K_1 = 3.8 \times 10^{-4}$
- $A = 108.78 \text{ KJ ME/kg BW}$
- $B = 33.47 \text{ KJ ME/kg BW}$

In the equation, the energy cost of harvesting feed can vary according to animal breed:

<table>
<thead>
<tr>
<th>Bovines</th>
<th>$A$</th>
<th>$B$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hereford</td>
<td>163.18</td>
<td>58.21</td>
</tr>
<tr>
<td>Yak</td>
<td>66.94</td>
<td>20.92</td>
</tr>
<tr>
<td>Zebu</td>
<td>76.15</td>
<td>27.16</td>
</tr>
</tbody>
</table>

However, if it is only necessary to account for locomotion, a percentage of the energy requirement for maintenance can be used. The value ranges from 0.05 to 0.30.
Temperature Regulation
The model determines the effect of high temperatures on the dry matter intake. To determine the effect of the thermal sensation, a factor that relates temperature with humidity is used. The index of temperature and humidity is:

\[
ITH = 1.8 \times \text{Temp} - (1 - \text{HR}) \times (\text{Temp} - 14.3) + 32
\]

Where:
- \(\text{Temp}\) : Daily mean temperature in degrees Celsius
- \(\text{HR}\) : Relative humidity (percentage)

The index to calculate the reduction of DM intake (DCMS) is calculated by this equation:

\[
\text{Temp CH} = \text{Stemp CH} \times ITH - \text{Temp CH}
\]

Where:
- \(\text{Temp CH}\) : daily temperature in °C corrected by humidity
- \(\text{Stemp CH}\) : slope of the equation of temperature corrected by humidity = 1.1831*\(e^{0.7984*\text{HR}}\)
- \(\text{Stemp CH}\) : Intercept of equation of temperature corrected by humidity = 55.307 * \(e^{-1.167*\text{HR}}\)

\[
\text{DM Heat} = 1.0331 - 0.0916 \times \log (\text{Temp CH} + 15.814)/(15814 + 24.8284 - \text{Temp CH})
\]

Where:
- \(\text{DM Heat}\) = correction factors of the voluntary intake by temperature

The equation indicates that a reduction of intake occurs due to temperature for which it is necessary to have an \(ITH\) of 73% or more. This is obtained with daily average temperatures of at least 23°C (Blaxter, 1977). When temperatures are low, the model assumes that the animal is equivalent to a black body that has a given heat production, which is dissipated depending on the area of the black body, its radius, the environmental temperature, the wind speed, and a constant conductance. For its calculation the model uses the following group of equations: The radius (R) of the animal is measured in mm and is a function of the animal weight, according to the equation:

\[
R (\text{mm}) = 80.756 \times \ln (W) - 97.631
\]

Where:
- \(\ln (W)\) corresponds to the natural logarithm of the weight expressed in kg.

Area of the animal (A) (m²) is a weight function assuming an animal shape similar to a cylinder. It is calculated as:
A = 0.09 * W^{0.667}

Where:

W : Weight in kg
A : Area of the animal in m²

Conductance is a constant (Kc) that corresponds to the degree of thermal insulation of a black body. Consequently, it is a function of the animal size and the insulation produced by the fur. This is given by the formula:

\[ Kc = 1 / ((R/R+Gr) * (1/0.115 + 0.099 * \sqrt{V/1.609})) + R * LN ((R+Gr)/R) + 0.46 - 0.09 * \sqrt{V / 1.609}) \]

Where:

R : Radius of the animal (mm)
V : Wind velocity (km/hour)
Gr : Fur thick
LN : Natural logarithm function

Based on this group of equations, the caloric exchange (DQ), expressed in Mcal, can be calculated by the equation:

\[ DQ \text{ (Mcal)} = Kc * (39 - Ta) \]

Where:

Kc : Constant of conductance
Ta : Environmental temperature in °C

Heat production (PC) corresponds to the total caloric increments (CI) of maintenance and production, the net energy of maintenance (ENm), and the energy cost for feed harvesting. This is expressed as:

\[ PC \text{ (Mcal)} = CI \text{ maintenance} + CI \text{ of Production} + ENm + HC \]

The energy destined to temperature regulation corresponds to the difference between the caloric exchange and heat production. If heat production is greater than the dissipated heat, the expenditure is equal to zero and the animal reacts by reducing intake.

**Maintenance Requirement (REM)**

Maintenance requirement corresponds to the total metabolizable energy produced by an animal within a particular environment. The value is maintenance energy plus energy required for...
harvesting, plus the necessary energy for temperature regulation (this is equal to zero if the animals are in a thermo neutrality zone).

\[
\text{REM(Mcal EM/animal/day)} = \text{RM} + \text{HC} + \text{RT}
\]

**Energy for Production (EP)**

The energy for production (EP) corresponds to the total metabolizable energy intake minus the maintenance requirement. This energy is prioritized as follows: gestation, milk production, and weight gain.

**Energy requirement for gestation**

During pregnancy, part of the metabolizable energy consumed is destined to net energy for gestation (NE\(_g\)), with its corresponding efficiency (K\(_{ges}\)).

The net energy for gestation (NE\(_g\)) is associated with the energy stored in the fetus, the associated membranes, and the tissues of the uterus. This stored energy increases exponentially daily throughout the pregnancy and is of considerable importance in the final stages. For cattle, the caloric value of the energy deposited in the uterus can be estimated with the following equation:

\[
\text{VC uterus} = 0.0072 e^{0.0174t}
\]

Where:

- VC uterus : Net energy deposited in the uterus, Mcal/day
- t : Days of gestation

The efficiency of the gestation (K\(_{ges}\)) is low and constant throughout the gestation period (between 12% and 13%). Thus, K\(_{ges}\) = 0.133

As a result, the requirement of metabolizable energy for gestation, regardless of the requirement of maintenance and weight change, can be calculated in the following way:

\[
\text{Emges} = 0.27 e^{0.0106t}
\]

Where:

- Emges : Requirement of energy for gestation (Mcal EM/day)

**Energy requirement for milk production**

The net energy for milk production (NE\(_{pl}\)) is equivalent to the energy contained in the milk produced. Consequently, the total net energy for milk production will depend on the quantity of milk produced and its energy value. Although milk composition varies, it basically contains fat and non-fat milk solids including Lactose (Lac) and Casein (Cas).

Therefore, the energy value of milk (VE\(_{milk}\)) can be calculated as follows:
\[ V_{\text{Emilk}} = \frac{(9.22 \times G + 4.1 \times L + 5.7 \times C)}{1000} \]

If it is assumed that the lactose-casein ratio is approximately 1:1, the VEmilk can also be calculated by the following formula:

\[ V_{\text{Emilk}} = \frac{(9.22 \times G + 4.85 \times S)}{1000} \]

Where:
- \( V_{\text{Emilk}} \): Energy value of milk (Mcal/ kg milk)
- \( G \): Milk fat (g/kg milk)
- \( L \): Milk lactose (g/kg milk)
- \( C \): Milk casein (g/kg milk)
- \( S \): Non-fat solids (g/kg milk)

The combustion value of the milk fat is 9.22 kcal/g. Proteins and carbohydrates have a combustion value of 5.7 and 4.1 kcal/g, respectively. Assuming that each component represents 50% of milk’s non-fat solids (SNG), the value of combustion of the SNG will be 4.85 kcal/g on the average. Table 2 shows the value of the net energy of milk from different breeds.

**Table 2.** Energy value (NE) of milk from different breeds of dairy cows.

<table>
<thead>
<tr>
<th>Breed</th>
<th>Fat (g/kg)</th>
<th>Non fat solids (g/kg)</th>
<th>Energy value (kcal/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shorthorn</td>
<td>36</td>
<td>87</td>
<td>753.87</td>
</tr>
<tr>
<td>Ayrshire</td>
<td>37</td>
<td>88</td>
<td>767.94</td>
</tr>
<tr>
<td>Friesian</td>
<td>35</td>
<td>86</td>
<td>739.80</td>
</tr>
<tr>
<td>Yak</td>
<td>95</td>
<td>189</td>
<td>1698.40</td>
</tr>
</tbody>
</table>

The efficiency of milk production (\( K_p \)) is correlated with the feed energy concentration (Blaxter 1977).

\[ K_p = \frac{(46.3 + 5.45 \times CCD)}{100} \]

Where:
- \( K_p \): Coefficient for milk production efficiency, percentage (0-1)
- \( CCD \): Average concentration by kg of dry matter intake (Mcal ME/ kg DM)

The variation obtained in \( K_p \) ranges between 58% and 65%, depending on the diet.

The metabolizable energy for the production of 1 kg of milk is the value of the net energy required for milk production divided by the \( K_p \):

\[ E_{\text{mpl}} = \frac{(V_{\text{Emilk}} \times K_p)}{PL} \]

Where:
- \( E_{\text{mpl}} \): Metabolizable energy for milk production (Mcal ME/day)
**Vemilk**: Net energy for producing 1 kg of milk (Mcal NE/kg)

**Kₚₗ**: Coefficient for milk production efficiency (0-1)

**PL**: Milk production (kg/day)

### Weight change in dairy cows

Changes in body weight during the lactation are affected by the amount of energy consumed in relation to the amount of milk produced. Thus, Holstein cows have a significant reduction of postpartum weight during the first three months of lactation. The weight loss is a function of the body condition and the milk production potential of the animal. The weight loss of an animal corresponds to the mobilized tissue utilized as energy in milk production. The net energy of the mobilized tissue is 4.8 Mcal/kg. The efficiency of milk production from this energy source is 82%. As a result, every kilogram of mobilized tissue produces 3.94 Mcal of net energy as milk (4.8 * 0.82). Taking into account that each kilogram of milk has a caloric value of 0.744 Mcal, 1 kg of mobilized tissue is converted into 5.3 kg of milk.

In the instance of a cow with a potential milk production of 4000 kg/lactation, a corporal condition of 3 (scale from 1 to 5), and weight of 400 kg, it is estimated that the animal is capable of mobilizing 4% of its weight. Thus, 16 kg of body weight are lost during the first third of the lactation period (90 to 100 days). This loss amounts to 160 grams of mobilized tissue per day, which are capable of producing 848 grams of milk per day during the first 100 days.

During the last two thirds of lactation, the animal needs to recover the weight lost (16 kg in the previous example), corresponding to a daily weight gain of 80 grams.

During this period (last two thirds of lactation), the efficiency of the recovery of weight is calculated by:

\[ K_{\text{wg}} = 19.7 \times \text{CCD} \]

### Weight change in young bulls

For a young bull, the expected metabolizable energy for production corresponds to a destined weight gain. The efficiency with which the metabolizable energy destined to weight gain is transferred to net energy of gained weight depends on the caloric concentration of the diet:

\[ K_{\text{wp}} = (3 + 18.4 \times \text{CCD})/100 \]

The value of the weight change ranges between 32%, when the CCD is 1.6 Mcal/kg DM, to 50%, where the CCD is 2.6 Mcal/ kg DM.
**Production as determined by energy**

**Milk production**

The potential milk production is calculated by the incomplete gamma model; \( y = at^b e^{-ct} \). Where “\( y \)” is the daily milk produced in relation to the coefficient “\( a \)”, “\( b \)”, and “\( c \)”, corresponding to initial, increment and decreasing milk production, respectively. (Wood, 1967). The daily milk production as determined by energy is expressed by:

\[
PLE = (EP - ME_{ges}) \cdot \frac{K_{pl}}{V_{Emilk}}
\]

Where:
- **PLE**: Milk production determined by energy (kg/day)
- **EP**: Energy utilized for production (Mcal ME/day)
- **\( K_{pl} \)**: Milk production efficiency (0.55–0.65)
- **V_{Emilk}**: Energy value of 1 kg of milk (Mcal NE/kg)
- **ME_{ges}**: Energy for gestation (Mcal ME/kg)

In the event that milk production is greater than the corresponding potential on a given day, the milk production will be equal to the potential and with the result that the surplus energy will be destined to weight gain.

**Weight gain**

The body weight gain is determined by:

\[
GPE = \frac{(EP \cdot K_{gp})}{V_{Egp}}
\]

Where:
- **GPE**: Weight gain determined by energy (kg/day)
- **EP**: Energy utilized for production (Mcal EM/day)
- **\( K_{gp} \)**: Coefficient for weight gain efficiency (0.35–0.51)
- **V_{Egp}**: Energy value of 1 kg of weight gain (Mcal NE/kg)

**Caloric value of the weight gain**

The caloric value of the weight gain is a function of the quantity of net energy destined to weight gain and the animal’s weight. For this reason, the weight gained by a small animal (\( \leq 100 \) kg) has less fat content than the same unit of weight gain of an adult animal.

\[
V_{Egp} = FR + (0.3 \cdot EN_{gp}) + (0.0045 \cdot W)
\]

Where:
- **FR**: Breed factor for correcting the caloric value for weight gain
Vegp : Energy value of 1 kg of weight gain (Mcal NE/kg)
Engp : Net energy utilized for weight gain.

For Holstein and Hereford, the breed factor is 1.5, while for less specialized animals the factor can reach up to 3.5.

**PROTEIN**

**Protein intake**

The protein intake from forage is calculated as:

\[
CP = CVO \times PD \times IS
\]

Where:
- CP : Protein intake (kg)
- CVO : Forage dry matter intake (kg MD/day)
- PD : Percentage of protein (0-1)
- IS : Selectivity index (1–1.25)

The total protein intake is the sum of the protein intake from forage and other protein sources.

**Requirement of metabolizable protein for maintenance**

**Fecal metabolic protein (PMF)**

The fecal metabolic protein corresponds to the N previously absorbed by the body. The value includes nitrogen from the secretions of the digestive system (enzymes) and lumen cells sloughed off from the ruminal epithelium and the intestinal mucous membrane. The fecal metabolic protein is estimated as follows (NRC, 2001):

\[
CMSI = CVO \times (1-DGC)
PMF = 0.068 \times CMSI / (PBV \times TO)
\]

Where:
- CVO : Voluntary dry matter intake (kg DM/ day)
- CMSI : Indigestible dry matter intake (kg DM/ day)
- PMF : Requirement of fecal metabolic protein (kg/day)
- PBV : 0.456 (coefficient for protein biological value)
- TO : Coefficient of turnover corresponding to the nitrogen recycling through saliva. (1.15-1.6)

The biological value of the protein (0.456) is an average of the biological value of the rumen microorganisms, which varies between 0.4 and 0.55 (Garcia, 1992).
TO signifies the “Turn Over” or recycling of nitrogen, which is indispensable in the diet and is re-utilized through recycling in saliva. The value depends on the previously consumed diet and fluctuates between 15% and 60%. Consequently, the TO is a correction factor of the protein biological value (PBV) that oscillates between 1.15 and 1.60.

**Endogenous urinary protein**

A minimum catabolism of amino acids is caused by the maintenance of the vital body processes and as the product of the catabolism of proteins from tissues. This value amounts to 146 milligrams of nitrogen per unit of metabolic weight, corrected by the protein biological value at a starvation state. It rises to 350 mg of nitrogen per unit of metabolic weight in well-fed animals.

\[
PUE = \frac{(0.350 \times 6.25 \times (W^{0.75}))/\text{PBV}/\text{TO}}{1000}
\]

Where:

- **PUE**: Endogenous urinary protein (kg)
- **PBV**: 0.456 (coefficient for protein biological value)
- **6.25**: Nitrogen conversion factor to protein
- **W**: Weight (kg)

Maintenance requirement includes the superficial protein losses caused by the replacement of hair, hooves, dermal epithelial desquamation, and sebaceous glands. The model establishes the following relationship:

\[
DW = \frac{(0.1125 \times W^{0.75})/\text{PBV}/\text{TO}}{1000}
\]

Where:

- **DW**: Requirement of superficial protein (kg/day)
- **PBV**: 0.456 (coefficient for biological protein value)
- **W**: Body weight (kg)

To estimate raw protein efficiency, the factor 0.45 is utilized to account for the requirements of urinary and superficial endogenous proteins. To estimate the fecal metabolic protein, a factor of 0.67 is applied.

Therefore total maintenance protein is the sum of the fecal metabolic protein, endogenous urinary protein, and superficial proteins.

\[
PTM = PMF + PUE + DW
\]
Metabolizable protein for production
The metabolizable protein for production value corresponds to the total protein intake minus the requirement of total protein for maintenance.

\[ PP = (CVO \times PD) - PTM \]

Where:
- \( PP \): Protein destined to production (kg/day)
- \( CVO \): Voluntary dry matter intake (kg DM/day)
- \( PD \): Protein percentage of the diet (0-1)
- \( PTM \): Total protein for maintenance (kg/day)

Milk production
The protein content of a kilogram of milk is variable and depends on the breed. For example, the Holstein breed has a protein content of 3.5%, which correspond to 35 grams of protein per each kilogram of milk. Also the percentage of milk casein ranges among breeds between 2.5% and 4.5%. Therefore, to analyze milk protein, it is necessary to know the milk's composition in each particular breed. The protein value of 1 kilogram of milk is:

\[ VPL = \frac{(Cas \times 10)}{(0.456 \times TO)} / 1000 \]

Where:
- \( VPL \): Quantity of protein required to produce a kg of milk (kg)
- \( Cas \): Percentage of casein in milk (2.5–4.5%)
- \( 0.456 \): Biological value of the microbial protein
- \( TO \): Nitrogen Turn Over (value between 1.15 and 1.6)

Weight gain
Weight gain depends on the breed and the weight of the animal. The percentage of protein in one kilogram of weight gain in young Holstein bulls (between one and five years old) is 16%. Consequently, in one kilogram of weight gain there are 160 grams of protein, thus:

\[ VPGP = \frac{(PPGP \times 10)}{(0.456 \times TO)} / 1000 \]

Where:
- \( VPGP \): Quantity of protein required to gain a kg of weight (kg)
- \( PPGP \): Percentage of protein in weight gain (15–18%)
- \( 0.456 \): Biological value of the microbial protein
- \( TO \): Nitrogen Turn Over. Value fluctuates between 1.15 and 1.6
Typically, an animal will recover weight lost during the first third of the lactation period at the end of this same lactation period. However, actual weight loss will depend on the cow’s productive potential and its body condition. The estimated protein recovery for lost weight during lactation is approximately 10% and corresponds to the mobilization of fatty tissue with connective tissue.

**Estimation of the production limited by protein**

**Milk production**

\[ \text{PLP} = \frac{\text{PDP}}{\text{VPL}} \]

Where:

- PLP : Milk production due to protein
- PDP : Protein available for production
- VPL : Milk protein value

**Weight gain**

\[ \text{PGP} = \frac{\text{PDP}}{\text{VPGP}} \]

Where:

- PGP : Weight gain due to protein
- PDP : Protein available for production
- VPGP : Protein value of the weight gain

The metabolizable protein can be transformed to total protein by dividing by a factor of 0.85.

**Modified production value**

The modified production value corresponds to the minimum of the estimates for milk (PLR) and for weight gain (GPR) due either to energy (PLE, GPE) or to protein (PLP, PGP).

\[ \text{PLR} = \min (\text{PLE}, \text{PLP}) \]
\[ \text{GPR} = \min (\text{GPE}, \text{PGP}) \]

**Verification**

This stage establishes the rationality of the results given by the model under various scenarios. The best way to confirm the results is to run the model mimicking real conditions (preferably experimental results) and to consult with farmers if the model produces a reasonable response, according to the given conditions. Upon consultation, various farmers and research scientists in South America, Central America, Asia, and Africa have considered the results provided by the models as reasonable.
Validation and model use

The validity and accuracy of a simulation model should be evaluated in relation to the original purpose for which it was developed (Shannon, 1982). The validation process tests the model's functionality based on statistical procedures that assume an acceptable level of confidence (Aguilar, 1997 and Baldwin, 1995).

For the validation of the models, data from different sources and agro-ecological conditions were used. The outputs for each breed under study were utilized to generate an average curve of production under different management conditions. Confidence intervals were calculated when at a level of significance higher or lower than 95%.

Feeding strategies

In general the models estimated experimental values with errors that ranged from 7-11%. Three examples analyzing different bio-economic scenarios of feeding strategies are presented. The use of a composite rotatable central design allows for a simultaneous comparison of a combination of the main factors considered in the models to design a particular strategy. Figure 6 shows the weight gain of steers under Panama conditions related to pasture availability, stocking rate and digestibility.

Figure 6. Response surface of weight gain of steers under typical conditions of tropical pastures, maintaining a digestibility of 52%, Panama.
Figure 7 shows the milk response of buffalos in The Philippines under grazing and different feeding strategy.

Figure 8 shows the combination of sweetpotato and maize used in an intensive dairy production of small farmers in the Peruvian coast. Levels ranging from 75-25 to 50/50 of maize and sweetpotato, allow an increment of milk production with a minimum use of concentrate.
Crop-livestock –environment

The importance of the methane routine in the models is that undernourished ruminants also contaminate the environment with the methane gas, which is more reactive than CO₂ for the environment. Supplementing with sources of high nutritive value, like sweetpotato could not only improve productivity but also decrease the contamination of the environment and these models can help in making this case with decision-makers.

By using “Dairy” simulation model, combined with a database of farms from the Altiplano of Bolivia several bio-economic scenarios were analyzed. Alfalfa was used to supplement either Creole/crossbred or crossbred cows. The objective was to determine how the change in the nutritional plane affected both methane emission and level of production. Figure 9 shows the evaluation of four scenarios including creole and crossbred grazing on pasture with 25% and 75% of alfalfa.

The scenarios analyzed were clustered into three groups. The first group includes scenarios A and B with low levels of gross income 0.055 $/kg and 0.065, respectively. The second group includes scenario C and part of D. The range of gross income goes from 0.08 to 0.14$/kg. The scenario D
present a gross income from 0.11 to 0.19 \$/kg. For both breeds it is advantageous to provide good quality feed. Even though creole animals did not improve income, the level of methane emitted was reduced in 28%. For animals with specialized dairy genes, the supplementation produced a decrease in methane emission of 13% and an increment in gross income of 40%.

The change of creole/crossbreed to crossbreed cattle under the same feeding regime increased milk production maintaining the same level of methane, however increasing the proportion of alfalfa increase level of production reducing methane per kilogram of milk produced. The model estimated correctly the levels of productions found in the field data and thus it was assumed that since the emission is estimated by the inefficiency of the same biochemical process, the estimation is also correct. A similar approach can be used to analyze the use of sweetpotato as part of feeding strategies in Asia or Africa.

**Conclusions**

The LIFE-SIM comprising the “Dairy”, “Beef”, “Buffalo”, and “Goat” models adequately simulated data from several production systems using a generic and specific model containing a common structure with the same components adding the parameters needed to differentiate among animal species. The good agreement between observed and simulated data shows the adequacy of the approach. The usefulness of the models described was evidenced when used as tools to analyze different feeding strategies.

**Implications**

The LIFE-SIM model developed by a team of the Natural Resources Management Division of the International Potato Center performed well when used for the purposes for which each sub model was designed. Specific models attempt to mimic reality, but are not reality themselves. The model should be a useful tool to address several feeding strategies and management questions relevant to dairy, beef, buffalo and goat production systems in different ecoregions. They facilitate the integration of scientific concepts and help scientists, teachers, and producers better understand the complex production systems that they study and/or manage. There are several farm-level problems in crop-livestock production systems that can only be studied through simulation because they are either too expensive or time consuming to address through traditional experiments. Simulation results should always be viewed with a favorable dose of skepticism and optimism. However, if such studies foster additional research or greater exchange among disciplines, then simulation has made a useful contribution.
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Annex

**Basic economic analysis**

In LIFE–SIM models the total gross income is calculated considering the milk sale price and the milk or meat produced. Since the feeding cost represents a high percentage of the total cost structure, the dairy, beef, buffalo, and goat model simplifies the estimation of milk or meat production cost as a function of feeding cost.

However, in a livestock-crop production system, the investment and production costs must be related to the available resources. To estimate the indexes of economic efficiency, it is necessary to consider:

A. **Investment**
   - Land
   - Pastures
   - Paddock installations
   - Fences
   - Drinkers, feed stall, salt feeders.
   - Replacement cows
   - Milking parlor
   - Equipment (dairy and field)
   - Equipment for insemination

B. **Annual fixed cost**
   - Administration
   - Opportunity cost (land rent)
   - Depreciation of equipment plus the annual interest of all investment (does not include animal’s value). If the farmer has a loan, it is necessary to include the amortization plus the annual interest.

C. **Annual variable cost**
   - Labor
   - Fertilizers
   - Feeds and supplements
   - Electricity
   - Artificial insemination (nitrogen, straw, semen)
   - Field equipment (ropes, bucket, shovel, others)
D. **Total annual income**

Sales of milk, cheese etc.
Sales of culled animals, heifers, steers and calves
Changes in the livestock inventory

E. **Unitary price of milk in the market (farm gate price)**

**Index of economic efficiency**

- The estimation of some indexes is necessary in order to analyze and plan the best use of the available resources:

\[
\text{Total Cost} = \text{Fixed Cost} + \text{Variable Cost}
\]

\[
\text{Total Income} = (\text{Total Production} \times \text{farm gate price}) + \text{others sales}
\]

\[
\text{Total Gross Income} = \text{Total Income} - (\text{Total Cost} + \text{Administration})
\]

\[
\text{Investment Return} = \frac{(\text{Total Income} - \text{Total Cost} + \text{Interest}) \times 100}{\text{Total Investment}}
\]

\[
\text{Production Cost} = \frac{\text{Total Costs} - \text{Sale of cows and calves}}{\text{Annual Total Milk Production}}
\]

Production cost by unit produced:

\[
\text{Gain or loss, by unit} = \text{Sales price} - \text{production cost}
\]

**Financial Analysis: The fattening case**

The beef, goat and buffalo model includes an estimation of the change of value of animals due to feeding strategy and prices, considering:

\[
T = \text{Fattening time}
\]

\[
C = \text{Livestock purchase cost}
\]

\[
R = \text{Return by sale}
\]

\[
p = \text{Price per kg live weight}
\]

\[
w = \text{Live weight, kg}
\]

\[
d = \text{Change in } C, R, p, \text{ or } w \text{ on the fattening period}
\]

\[
o = \text{Original price or live weight (beginning of the fattening)}
\]

\[
Fd = \text{Final price}
\]
\[ W_f = \text{Final live weight} \]

The interaction among those values is calculated as:

\[
I = \left[ \left( \frac{R-C}{C} \right) \times \frac{365}{T} \right] \times 100 \tag{1}
\]

The equations for \( C \), \( R \), and \( d(R) \) are:

\[
C = P_0 \times W_0 \tag{2}
\]

\[
R = F_p \times W_f \tag{3}
\]

\[
d(R) = R - C \tag{4}
\]

By definition,

\[
F_p = P_0 + d(p) \tag{5}
\]

\[
W_f = W_0 + d(w) \tag{6}
\]

Then substituting equations 2, 3, 5 & 6 into 4 and solving results in:

\[
d(R) = d(p) \times W_0 + d(w) \times P_0 + d(p) \times d(w) \tag{7}
\]

The proportion of each component is obtained by dividing equation (7) by \( d(R) \):

\[
100 = \% (d(p) \times W_0) + \% (d(w) \times P_0) + \% (d(p) \times d(w))
\]

Three components are estimated:

a) Price: equal to the product price change by the initial weight

b) Weight: equal to the product weight change by the initial price

c) The interaction: equal to the product weight change by change in weight

The price component is then the proportion of the return due to the change in price throughout the fattening period if the weight has not changed. If the component price is equal to 100%, the animal could not have gained weight during the fattening period. Any income earned by the product could be due to the price paid in the purchase.

- The weight component represents the proportion of the return explained by the change in weight if the price has not changed. If this component is equal to 100%, it means that all of the income is coming from the fattening process.
The interaction shows the returns resulting from the interaction between price and weight changes during the fattening period. By definition, it cannot be equal to 100%, since this would imply that both price and weight components are equal to zero.
The International Potato Center (CIP) seeks to reduce poverty and achieve food security on a sustained basis in developing countries through scientific research and related activities on potato, sweetpotato, and other root and tuber crops, and on the improved management of natural resources in the Andes and other mountain areas.

THE CIP VISION
The International Potato Center (CIP) will contribute to reducing poverty and hunger; improving human health; developing resilient, sustainable rural and urban livelihood systems; and improving access to the benefits of new and appropriate knowledge and technologies. CIP, a World Center, will address these challenges by convening and conducting research and supporting partnerships on root and tuber crops and on natural resources management in mountain systems and other less-favored areas where CIP can contribute to the achievement of healthy and sustainable human development.

CIP is a Future Harvest Alliance Center and receives its funding from a group of governments, private foundations, and international and regional organizations known as the Consultative Group on International Agricultural Research (CGIAR).

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