Using Mathematical Models in Ruminant Nutrition

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1. Introduction

Mathematical models can be used to improve performance, reduce cost of production, and reduce nutrient excretion by accounting for more of the variation in predicting requirements and feed utilization in each unique production situation. However, the use of models to assist in production decisions is limited by the information (model inputs) that is typically available on the farm. The purpose of this paper is to discuss the development of nutrition models for predicting requirements and feed utilization by cattle in formulating accurate rations and feeding systems in each production situation.

2. Using Models to Predict Requirements and Supply of Energy and Nutrients

Mathematical models can be used to integrate our knowledge of feed, intake, and digestion and passage rates upon feed energy values, escape of dietary protein, and microbial growth efficiency. They can be valuable tools for estimating animal requirements and nutrients derived from feeds in each unique farm production scenario, and thus can have an important role in providing information that can be used in the decision-making process to enhance the feeding system.

A cattle nutrition model is defined as an integrated set of equations and transfer coefficients that describe their various physiological functions (GILL et al., 1989). Included in cattle models are predictions of tissue requirements (maintenance, growth, pregnancy, lactation and tissue reserves) and supply of nutrients (dry matter intake, feed carbohydrate and protein fraction pool sizes and their characteristic digestion and passage rates, microbial growth, intestinal digestion and metabolism of absorbed nutrients). The purpose of a simulation model is to describe mathematically the response of each compartment or several connected compartments to a variable or combination of variables.

FRANCE; THORNLEY (1984) categorized mathematical models as follows:

- *Static* vs. *Dynamic*; dynamic models incorporate time explicitly whereas static models do not,
- *Empirical* vs. *Mechanistic*; empirical models provide a best fit to data obtained at the prediction level (e.g., body weight) whereas mechanistic models incorporate

concepts about the underlying biology and data from lower levels of aggregation (e.g. cellular function), and

- *Stochastic* vs. *Deterministic*; deterministic models always give the same solution to a given set of inputs whereas stochastic models include probabilistic element(s), giving a distribution of outputs to a given set of inputs.

HAEFNER (1996) suggested additional categories as follows:

- *Continuous* vs. *Discrete*; continuous models represent time continuously (time may take on any value) while in discrete models time is an integer only, and
- *Spatially Homogeneous* vs. *Heterogeneous*; spatially homogeneous models have an explicit representation of space (e.g. objects have a position in space) whereas in spatially heterogeneous models space is not essential (e.g. population dynamics, enzyme kinetics).

The mathematical representation and prediction of animal function has been a widespread endeavor in biology and a wide range of approaches has been proposed. Objectives in modeling animal performance may include:

- Description of past observations,
- Prediction of outcomes of different management strategies, and/or
- Explanation of mechanisms.

Each of these objectives requires a different approach. Descriptive and predictive models are usually static and empirical, whereas explanatory or mechanistic models require a dynamic approach. Dynamic models are usually represented by differential equations, which may be solved analytically or numerically.

A mathematical model is considered mechanistic when it simulates behavior of a function through elements at a lower level of aggregation. Completely mechanistic models do not exist (GILL et al., 1989). A limitation is the ability to account for the fact that most biological responses are integrated and nonlinear and change over time (dynamic) (SAUVANT, 1991). Dynamic models are rarely used for application in formulating rations on farms because of limitations in information over the whole range of possible conditions that is typically available to drive such mathematical models and the inability to evaluate all of the functions. In most ruminant feeding systems, the prediction of metabolism of nutrients is not as advanced as the prediction of ruminal fermentation, because of the complex metabolic pathways connecting the numerous tissue and metabolic compartments, the multiple nutrient interactions, and the sophisticated metabolic regulations (hormones, enzymes) which drive the partitioning of absorbed nutrients (homeorhesis and homeostasis) (SAUVANT, 1991). Therefore, most animal nutrition models used for formulating diets on farms use a combination of mechanistic and empirical approaches, are generally steady state and static, and use statistical representations of data that represent the aggregated response of whole compartments.

Determining the appropriate level of aggregation of equations (closeness to the cellular level) is a major problem in formulating models. The most critical step is to describe the objective of the model and then to determine the appropriate mix of empirical and mechanistic representations of physiological functions, given development and evaluation dataset availability, inputs typically available and the benefits versus the risks of use associated with increased sensitivity. Since many inputs cannot be absolutely quantified with information typically available on farms, these models must allow inputs from each situation to be adjusted in a logical way until predicted and observed performance (daily gain, milk amount and composition, and body condition score changes) agree (also known as *calibration*). Then, responses to changes in management and feeds can be more accurately predicted by accounting for effects on ruminal fermentation, intestinal digestion, metabolizability of energy and amino acids, and product amount and composition.

3. Metabolic and Dynamic Systems

There are several models that employ dynamic modeling at the metabolism level, such as enzyme-substrate relationships, to ultimately predict animal responses and performance to different substrates. Generally, these models have been developed in support of research rather than for application. As research tools, mechanistic, dynamic and deterministic models enable scientists to integrate existing information, identify research needs and evaluate alternative hypotheses at a lower level of aggregation. However, their complexity and lack of appropriate information at the farm level limits their usage by consultants and/or producers. Nonetheless, these models aggregate the basic scientific knowledge that is necessary to increase our ability to understand certain biological mechanisms and identify priorities for fundamental and applied research. Such models include MOLLY (BALDWIN, 1995, BALDWIN et al., 1987a, BALDWIN et al., 1987b), DIJKSTRA et al. (1992), DANFÆR (1990), SAINZ; WOLFF (1990a, 1990b), HANIGAN et al. (2004).

As an example of the differences in philosophy and approaches between research and application modeling, the models of BALDWIN et al. (BALDWIN et al., 1987a, BALDWIN et al., 1987b), DIJKSTRA et al. (1992), and DANFÆR (1990) are all derived from the analyses of FRANCE et al. (1982), and therefore share many common features, including:

- Model equations are based on saturation kinetics (i.e. Michaelis-Menten), so that the overall system is more stable than if linear mass-action equations were used,
- Inputs are based on detailed chemical and physical properties of the feeds, so that the models require information that often is lacking in field and even in many research situations; models differ as to the level of aggregation of feed components, and
- Different microbial pools with specific substrate preferences allow for variable fermentation patterns under different diets, and for interactions among structural and non-structural carbohydrate fermentation.

Since the main objective was to evaluate available data and concepts for adequacy, feed descriptions (input data) are limited to those characteristics that can be measured in the laboratory. For example, detailed chemical and physical properties of the feeds are required inputs, but not digestion and passage rate constants because these are considered to be animal-dependent. This constraint limits the applicability of the models for practical use, but enables researchers to focus on the identification of research priorities such as uptake and utilization of amino acids and peptides at cellular level.

Future developments in the modeling field must accompany improved understating of the underlying biology. In fact, modeling and research must go hand in hand. This fact, long understood by physical scientists, is only now being realized by biologists: "… based upon the past, mechanistic models of metabolic processes will continue to evolve as our knowledge of regulatory mechanisms improve and that modeling analyses will continue to be a valuable means of placing advances in our knowledge in context with overall aspects or ruminant digestion and metabolism and productive functions in growing and lactating animals" (BALDWIN, 2000).

4. Comparison of Mathematical Models

Comparison of mathematical models for adequacy and appropriateness is not an easy task since models require different set of inputs and sometimes a common input has a different connotation among models.

On the requirement computations, ARNOLD; BENNETT (1991a) evaluated the ability of four growth models (LOEWER et al., 1983, NOTTER, 1977, OLTJEN et al., 1986, SANDERS; CARTWRIGHT, 1979) to predict weight gain, body composition, and feed intake. As expected, predicted intake was the most influential measurement upon the relative differences in simulating growth and composition among the models; that's why actual intake is necessary to ascertain good accuracy and evaluation of models. The definition of mature weight was different among models and higher prediction performance was obtained when the mature weight of the simulated animal was relatively adjusted to the specific definition of each model. The authors concluded each model would perform differently upon the same production scenario regardless of the similarity of inputs used. Additionally, models were not able to accurately estimate body composition or intake (ARNOLD; BENNETT, 1991b). The authors concluded that more detailed and complex mechanistic models are needed to account for more of the variation.

BANNINK; VISSER (1997) reviewed the ability of three mechanistic rumen models (BALDWIN et al., 1987b, DANFÆR, 1990, DIJKSTRA et al., 1992) to predict the dynamics of ruminal fermentation and microbial growth. The authors found large differences in the microbial functions of substrate fermentation, substrate incorporation, and microbial synthesis among these models. They also differ in extramicrobial ruminal functions, and microbial mechanisms had important consequences for simulated nutrient outputs from the rumen.

CANNAS (2000) compared several feeding systems (AFRC, 1993, CSIRO, 1990, INRA, 1989, NRC, 2001 and CNCPS (FOX et al., 2004)) in predicting the energy and protein requirements of dairy cows. The requirements for ME for maintenance under thermoneutral conditions were higher in the CSIRO and CNCPS systems than in the INRA and AFRC systems, while NRC had intermediate values. Milk production requirements were similar among all systems. Total energy requirements differed by about 8% between the highest (CSIRO) and the lowest (AFRC) estimate. The energy requirements of cold stressed cows were similar in the CNCPS and CSIRO systems, the only two that accounted for these environmental variables. The MP requirements for maintenance were much higher in the NRC and CNCPS systems than in the CSIRO, INRA and AFRC systems. The MP requirements for milk production were slightly higher in the INRA and CNCPS systems than in the others. The ranking of total MP requirements differed by about 25% between the highest (CNCPS) and lowest (AFRC) estimates. The energy and protein requirements for pregnancy were very different among systems, both in the approach used and in the predicted requirements. Areas with great differences surfaced in the assessment of requirements for growth of heifers and for body reserves. The approaches used in the partitioning of nutrients between growth and reserves for heifers and the prediction of the energy, fat and protein content of reserves were very different between systems.

FOX et al. (2004) summarized the numerous evaluations that have been conducted to determine the accuracy of CNCPS submodels (e.g., growth, body reserves, and rumen). For a model to be useful on-farm, however, the combination of model equations must accurately predict animal responses. When the CNCPS reserves model was used to adjust supply of energy to account for changes in BCS, the model accounted for 90% of the variation in the milk production of individual Holstein cows with a mean bias of 1.3%. The model accounted for 89% of the variation in ADG of individual steers with mean bias of 90 g/d (7.4% underprediction bias).

Several papers have been published on the application of the CNCPS in warm climates. The CNCPS accounted for 72% of the variation in live weight gain of Nellore bulls and steers with a 2% bias and explained 71% of the variation in milk production of Zebu crossbred cows with a 10% bias (LANNA et al., 1996). The 10% bias for the lactating cows is believed to be due to difficulties in establishing the maintenance requirements of the animals because of the wide variation in their percentage of Holstein and Zebu. JUAREZ LAGUNES et al. (1999) conducted two experiments using the CNCPS to characterize the carbohydrate and protein fractions and corresponding rates of digestion of 15 tropical pasture grasses and to evaluate their ability to support milk production by dual purpose cows. LANNA et al. (1996) and JUAREZ-LAGUNES et al. (1999) concluded that the CNCPS was more accurate than the empirical, tabular NRC (1984, 1989) systems under tropical conditions when the feeds and cattle types could be characterized adequately to provide accurate inputs into the CNCPS.

RUEDA-MALDONATO et al. (2003) demonstrated the usefulness of using the CNCPS to predict performance of dual-purpose cows and Nellore steers in identifying the most profitable management system in the Western Amazon region of Brazil. REYNOSO-CAMPOS et al. (2004) demonstrated that a dynamic application of the CNCPS can facilitate more accurate monitoring and management of cyclic changes in energy and protein balances over the calving interval of dual-purpose cows, which can help producers to achieve productivity and profitability goals.

The CNCPS has been linked to a crop, soil, and manure nutrient management program (Cornell Cropware; RASMUSSEN et al., 2002) to evaluate its potential to improve environmental and economic sustainability of a 650 cow commercial dairy (TYLUTKI et al., 2004). A summary of a five-year study indicated that the precision nutrient management system developed resulted in a 26% increase in animal numbers, a 9% increase in milk/cow, a 45% increase in total milk, a 48% decrease in purchased feed, a 52% decrease in feed cost/kg of milk sold, and 17 and 28% decreases in total manure N and P, respectively. These improvements could be explained by better forage production due to quality (harvest timing), storage (38% increases in proportion of feeds grown on farm), and the ability of CNCPS to allocate these high forage diets more efficiently among groups of animals in the dairy herd.

Studies with pen-fed growing cattle consuming high-forage diets indicated that the NRC (2000) tabular system had an overprediction bias because intake effects on feed digestibility were not considered and the carbohydrate and protein fractions were not adequately described (TEDESCHI, 2001, Ch. 2). The mean square error were similar in all evaluations (tabular, and levels 1 and 2 of the CNCPS), but the CNCPS level 2 had the highest accuracy (lowest RMSPE) followed by level 1. Although it uses similar carbohydrate and protein fractions as CNCPS level 1, the CNCPS level 2 accounted for more of the variation in animal performance because variables such as digestion rates, effects of level of intake, microbial growth on cell wall and noncell wall carbohydrate fractions, rate of passage, rumen pH, and ruminal nitrogen deficiency, on feed ME and MP values were considered.

In recent years, mineral requirements have received a great deal of consideration because accurate prediction of mineral requirements may minimize mineral excretion and environmental pollution. TEDESCHI (2001, Ch 1) compared the prediction of mineral requirements of ARC (1980), CSIRO (1990), AFRC (1991), and NRC (2000, 2001) systems with equations developed for typical cattle production in Brazil (CASTRO et al., 1993, LANA et al., 1992, PIRES et al., 1993a, PIRES et al., 1993b, SILVA SOBRINHO et al., 1987). It was concluded the net requirements for growth estimated by LANA et al. (1992) and PIRES et al. (1993a) were very close to that recommended by both AFRC (1991) and NRC (2000, 2001) systems for Ca, but only LANA et al. (1992) estimates for P was closely related to AFRC (1991) and NRC (2000, 2001) recommendations. Although the ARC (1980), AFRC (1991), and NRC (2000) had similar net requirements, the absorption coefficients used by NRC (2000) and ARC (1980) are different, which lead to distinctly different dietary estimates. Also, the net requirement for maintenance is similar, but the absorption coefficient differs between NRC (2000), ARC (1980), and AFRC (1991). We conclude the lack of information for endogenous losses and absorption coefficients for major minerals in tropical conditions requires the use of values from experiments conducted in different conditions from those found in the tropics. Inconsistencies in these coefficients also were found between different nutrient requirement systems (AFRC, 1991, ARC, 1980, CSIRO, 1990, FOX et al., 2000b, NRC, 2000, 2001).

More recently, OFFNER; SAUVANT (2004) performed a comparison of three models (BALDWIN et al., 1987b, LESCOAT; SAUVANT, 1995, RUSSELL et al., 1992) on their ability to predict various ruminal parameters and digestive characteristics with observed experimental data covering a wide range of feeding situations. Results underlined the fairly good capacity of the LESCOAT; SAUVANT (1995) model to predict starch digestion in the rumen and ruminal pH. The duodenal flow of microbial N was best predicted by the CNCPS model (FOX et al., 2004). Unfortunately, the models did not accurately predict fiber digestion in the rumen or volatile fatty acids concentrations. The authors recommended that future improvements in rumen modeling could be considered by pooling the advantages of each model.

5. Considerations for Future Research

Priorities for research and routine feed analysis procedures that need to be implemented depend on the ratio of cost to benefit and the procedures available to measure sensitive variables. There is little value in developing more complex models for amino acid balancing until the first limiting factors can be accurately predicted. This was demonstrated when measured duodenal flows from 80 diets were not predicted as accurately with the dynamic, low level aggregation rumen model of BALDWIN et al. (1987a) as with the CNCPS (SAUVANT, 1991). The sensitivity analysis of FOX et al. (2004) indicated that the rumen model can be sensitive to all of the CHO and protein pools under certain conditions.

Similarly, ROBINSON et al. (2004) indicated that due to the lack of better description of feed samples, laboratorial methods that accurately and precisely predict the nutritive value of feeds used in ruminant diets are needed. Three key components that determine the energy value of a ruminant feed are fat (high energy density), non-fiber carbohydrates (high digestibility), and digestibility of fibrous carbohydrates. Nonetheless, the prediction of digestibility of the latter one has proven to be troublesome. ROBINSON et al. (2004) evaluated the accuracy and precision of six unified prediction approaches for ME: two from NRC (2001), two from the University of California at Davis (UCD) and two from ADAS (Stratford, UK). The authors concluded that there are differences among the six predictive approaches in the number of laboratorial assays, and their costs, as well as that the NRC approach (three empirical equations that require categorical description of feeds; therefore, inappropriate for mixed feeds). No procedure was able to consistently discriminate the ME values of individual feeds within feedstuffs determined *in vivo* among these approaches.

Preliminary sensitivity analysis based on Monte Carlo simulations have indicated that the current fractionation scheme of protein does not increase the variability in the RUP or MCP measurements, but has an impact on which inputs become more critical (*Cristina Lanzas*, personal communication). The following concerns have been raised regarding the current feed protein fractionation structure in the CNCPS.

1. The assigned digestion rates for protein B fractions are based on the number of pools and rates identified by curve-peeling technique of data based on protein *in vitro* degradation when incubated with protease from *Streptomyces griseus*. The low rates for the B3 protein fraction (0.1 to 1.5 %/h) are not supported by recent research data (COBLENTZ et al., 1999). If the B3 digestion rate was assigned wrongly to the B3 pool as the result of this approach, then one should be concerned about the assigned B2 rates;
2. The NDF and ADF systems (VAN SOEST et al., 1991) were developed to measure available cell wall and may not be appropriate for fractionating protein especially for protein concentrates, which have a large protein B2 pool, which is estimated by difference; thus it contains the accumulated analytical error. The protein B3 rate is based on the assumption that NDIN minus ADIN represents N

bound to the fiber that is potentially digestible. This implies that it may be released from the fiber matrix at a degradation rate similar to the available NDF. Nonetheless, the amount of protein associated with the cell wall is relatively small (2% of the N) and remains fairly constant (BUTLER; BAILEY, 1973), but the laboratory measurement of NDIN is 3 to 5 times larger and more variable;

3. The ADIN measure may not represent a totally unavailable pool. Lucas' tests (regression of digestible protein on protein content) have shown that for some feeds, ADIN does not behave as a completely indigestible entity (slope different than unity). The ADIN and N indigestibility in forages have almost a 1 to 1 relationship. NAKAMURA et al. (1994) found poor relationships between ADIN and N indigestibility for protein concentrates. The high levels of ADIN from distiller's grains have been associated with heat damage during processing (VAN SOEST, 1994); however, it may be possible that prolamin proteins (such as zein) may be recovered in the ADIN fraction; and
4. The lack of a reliable and feasible laboratory assay to estimate NPN in the soluble protein may affect the calculation of MCP. It is known that the protein A fraction is rapidly converted into ammonia and that peptides from this protein fraction do not contribute to the ruminal peptides pool, which is derived from the degraded protein. We have shown via simulation modeling that a failure in accounting for these solubilized peptides is one of the major factors that contributes to the underprediction of MP allowable milk (low MCP prediction) in diets based on high quality alfalfa silage, which affects NFC microbial protein production (AQUINO et al., 2003).

The ability to describe metabolic transactions, and their resultant affects on nutrient requirements, is critical to raise food-producing animals in efficient ways around the world. Complex models, ever grounded in validated research data, will continue to be enhanced. The only way to eventually define the true complexity of the organisms that we are dealing with is to have an ordered model approach which, in a planned iterative fashion, asks complex questions and increases our knowledge with the clear answers we receive (MCNAMARA, 2004).

There are several limitations in modeling the dynamics of metabolism as discussed by MCNAMARA (2004). The main one is the lack of detailed and accurate data. Similarly, the rapid dynamic changes in metabolic flux during lactation, especially in late pregnancy and early lactation pose another major limitation. It is likely that these limitations arise from the experimental focus and design. Another major restriction is the complexity of the system itself: "this might seem an incredibly obvious statement, but I think that proper experiments are often not done because too many scientists simply either do not appreciate the true complexity of the system, or they do but are unwilling or unable to actually study it" (MCNAMARA, 2004).

The development and deployment of sustainable agriculture concepts require an insightful knowledge of the dynamics of agricultural systems at both the farm and regional levels. At the farm level, management decisions affect soil fertility, food production, animal care, and ultimately income whereas at the region level, the interactions between agro-ecological and socio-economic aspects are important in the sustainability of the environment where the farm resides through nutrient flows, water supply, productivity, and longevity of the operation (BONTKES; VAN KEULEN, 2003).

The efficient use of nutrients in agriculture to improve profitability while protecting water and air quality relies on our ability to understand and manage the complex interactions and impacts of decisions made in developing animal-soil-crop-environmental system (**ASCES**) on farms. Concerns about N and P concentrations underscore the necessity of simulating nutrient flows and their environmental impacts (BERNTSEN et al., 2003). Nonetheless, few simulation models (KEBREAB et al., 2004, THORNLEY; VERBERNE, 1989) have been developed that are able to adequately explain the pattern of observed behavior of the integrated ASCES (such as DSSAT[1], SWAT[2]2, CENTURY[3]). A principal limitation of these models is they focus only on a specific subsystem (crop, water, and soil, respectively) and their lack of feedback relationships, that is, the manner in which the integrated system developed affects future outcomes.

Therefore, the development of a model to predict nutrient flows and fate on livestock farms, using systems dynamics modeling is necessary to understand the impact of the intrinsic nonlinear behavior of different subsystems on environment pollution as depicted in Figure 1.

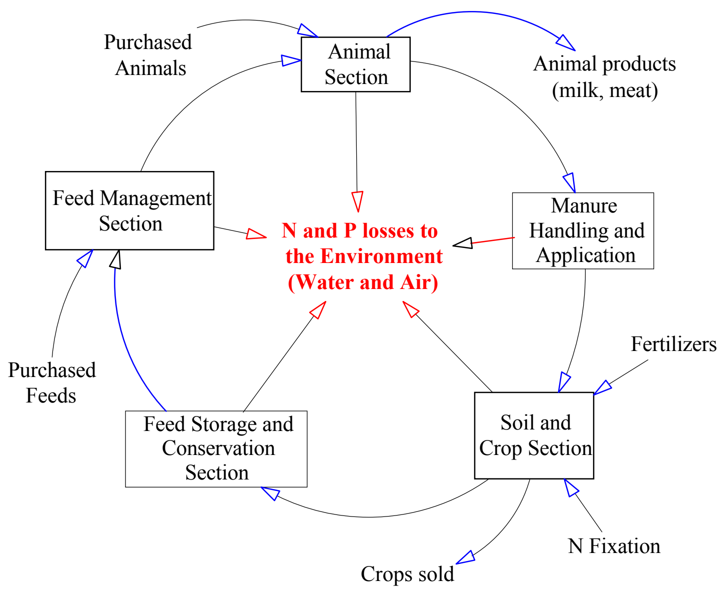

Figure 1. Integration of animal, soil, and crops with the environment on N and P flow dynamics

This type of model can be used to predict how alternative farm-level nutrient management strategies will influence N and P utilization and losses as well as farm financial performance over time. The great concern in NH_3 air emission is mainly caused

[1] http://www.icasa.net
[2] http://www.brc.tamus.edu/swat
[3] http://www.nrel.colostate.edu/projects/century

by the uncertainty in the NH_3 emission fractions from animal manure and the major concern in N_2O emission is due to the uncertainty in the fractions relating total nitrification and denitrification to NO_2 emissions (DE VRIES et al., 2003, KROEZE et al., 2003). Therefore, a dynamic model that simulates the flow and behavior of N compounds can assist in detecting the effects, extent, and prevention of N pollution into the environment.

The foremost goal of mathematical models is the ability to provide producers, consultants, and researchers with tools to assist in complex problem solving and decision-making. Such tools are known as decision support systems (DSS). The DSS integrates scientific knowledge to help people make better decisions. Some examples of DSS in agriculture are GRAZPLAN (DONNELLY et al., 1997, FREER et al., 1997, MOORE et al., 1997), DAIRYPRO (KERR et al., 1999a, KERR et al., 1999b, DECI (JENKINS; WILLIAMS, 1998), and the CuNMPS (FOX et al., 2002, FOX et al., 2000a).

Nonetheless, several problems have being identified that restrict the use of DSS, including is their complexity and the number of inputs and information needed to execute DSS models (MCCOWN, 2002). Data requirements for the CNCPS are already high, and future versions of the CNCPS will require additional inputs. These inputs are needed to more accurately determine carbohydrate and protein fraction digestibility in order to improve prediction accuracy of ruminal and post-ruminal N accounting (including rumen and whole tract recycled N), and absorbed amino acids derived from dietary and microbial sources. However, to offset the challenges of high data requirements and entry, there is a need to develop input structures that can be used to streamline inputs (including feed analysis, animal inputs, and environmental inputs).

Despite limitations in utilizing DSS at the farm level, there is still optimism about its future because computational modeling is used in everyday life and provides a cost-effective (and attractive) way to describe and predict biological relationships (NEWMAN et al., 2000). Furthermore, environmental regulations demand that producers make more accurate decisions regarding their production systems prior to implementing changes. Therefore, there is opportunity for use of DSS on farms, but care must be taken to build DSS that are user friendly, easy to understand, useful on the farm (how well it enhances decision-making), and are based on sound science.

6. Conclusions

Mathematical models integrate our scientific knowledge of feeds and feeding, intake, and digestion and passage rates upon feed energy values, escape of dietary protein, and microbial growth efficiency to estimate energy and nutrient supply and requirements and feed utilization in each unique farm production scenario. Therefore, they have an important role in assisting the improvement of feeding systems. These models can be used to further improve cattle and sheep production systems by accounting for more of the variation in predicting requirements and supply of nutrients while minimizing the environmental impacts through reduced nutrient excretion in an economically feasible fashion.

For the coming decades, producing meat and milk from cattle will become more efficient in the use of nutrients by using mathematical models to accurately predict requirements and feed utilization in each unique production setting. These mathematical models must allow inputs from each situation to be adjusted in a logical way until the cattle and feeds are accurately described. Then, when predicted and observed performance match, improved feeding programs can be developed for that unique situation where nutritional safety (excess supply) factors and nutrient excretion are minimized. The challenge will be to develop systems that are aggregated at a level that can reflect our understanding of the underlying biology; yet, be usable on farm considering information available, ability to monitor and quantify key input variables and animal responses, and knowledge and time available of the consultant using the models.

The CNCPS is a mechanistic, deterministic, and static mathematical model that was developed (and continues to be improved) from basic biological principles to assist producers, consultants, and researchers in evaluating diets and animal performance. Models such as the CNCPS enable nutritionists to identify sources of variation and can be used to formulate more economical and environmentally friendly rations. By more accurately formulating diets in each unique production situation, the need for expensive, and often environmentally detrimental, nutritional safety factors can be minimized

Animal models are used for a variety of purposes, including the simple description of observations, prediction of responses to management, and explanation of biological mechanisms. Depending upon the objectives, a number of different approaches may be used, including classical algebraic equations, predictive empirical relationships, and dynamic, mechanistic models. The latter offer the best opportunity to make full use of the growing body of knowledge regarding animal biology. Continuing development of these types of models and computer technology and software for their implementation holds great promise for improvements in the effectiveness with which fundamental knowledge of animal function can be applied to improve animal agriculture and reduce its impact on the environment.

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