The Utility of Applied Nutrition Models: A Brief History and Future Perspectives

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For approximately 55 years, computer models have been used as Decision Support Systems (**DSS**) to apply scientific knowledge to virtually every branch of science: from life sciences (e.g., development of the molecular structure of drugs and the management and planning for sustainable production of foods) to earth sciences (e.g., space exploration and global warming). Humankind has benefited tremendously by using DSS in specific areas for which experimentation is practically impossible or infeasible. Decision Support Systems (also referred to as Smart Decision Tools) can be broadly categorized into five classes: communication-driven, data-driven, document-driven, knowledge-driven, and model-driven (D. J. Powers[(1)]). In the late 1960s, data-driven and model-driven DSS were built based on scientific knowledge, theory development, and operational research concepts. However, it was not until the advancement of microcomputers and software in the mid-1980s that DSS became user friendly and started being applied practically. The development of DSS was tightly connected to the evolution of the architecture and processing power of microcomputers.

"One of the goals of energy metabolism research with ruminants always has been the development of an accurate means for evaluating feedstuffs and stating animal requirements" [1]

DSS have positively influenced several sectors in agriculture. The predictive power of DSS has contributed to improvements in the productivity and profitability of many agriculture-oriented companies. With DSS, users can evaluate many production alternatives and choose the best solution for each specific condition and desired outcome. For decades, animal scientists have taken advantage of DSS computer models. These systems allow users to appraise feed biological, nutritive, and substitution values; determine quantity and quality of feed required to support different animals' physiological needs; and estimate animal performance for given values of intake and feed quality.

Since 2006, the Ruminant Nutrition Laboratory of the Department of Animal Science at Texas A&M University has offered different computer models at http://nutritionmodels.tamu.edu. We designed these computer models to help producers, consultants, researchers, and students on issues related to the nutrition of large and small ruminants, help feedlot managers to achieve maximum profit, provide advanced modeling techniques, and deliver a complete system for assessing the quality of feeds for ruminants. Some of these models offer solutions for specific problems (e.g., Cattle Value Discovery System—**CVDS**, Large Ruminant Nutrition System—**LRNS**, Small Ruminant Nutrition System—**SRNS**) while others can be broadly used in many different areas of research (e.g., Model Evaluation System—**MES**). Figure 1 depicts the regions of the world that have visited our website and provides an initial assessment of where these models are being used.

Ruminant animals are widely utilized to convert human-inedible feedstuffs to nutritious food under widely varying conditions around the world. The goals of enhancing ruminant nutrition are to improve productivity, reduce resource use, and protect the environment. However, scientists

[(1)] http://dssresources.com/history/dsshistory.html

Figure 1. World map showing more than 26,000 visitors to the http://nutritionmodels.tamu.edu website since 2006. On March 2014, the countries that visited more were Vietnam (>7,900), United States (>5,200), and Brazil (>3,700).

often have to extrapolate nutrient requirements and feed values developed under standardized, controlled, laboratory research conditions to all combinations of cattle types, feeds, and environmental and management conditions. In these cases, DSS can be used as virtual simulators to predict nutritional requirements and feed utilization in a variety of production settings.

Modeling animal requirements and the availability of nutrients

Historically, nutritionists have formulated cattle rations to optimize production responses, as predicted by empirical equations that were developed under controlled research conditions. To account for real-world variations in types of cattle, feeds, and environmental and management conditions, these systems often produced nutritional recommendations that included significant "safety factors." These extra nutrients were meant to ensure that cattle received the required nutrients, but they often increased nutrient excretion and contributed to adverse effects on water and air quality [3].

Our Large Ruminant Nutrition System (**LRNS**; http://nutritionmodels.tamu.edu/lrns.html) is a computer model that estimates beef and dairy cattle nutrient requirements and supply under specific conditions of animal type, environment (climatic factors), management, and physicochemical composition of available feeds. Accounting for farm-specific management, environmental, and dietary characteristics has enabled more accurate prediction of cattle growth, milk production, and nutrient excretion in diverse production situations have been possible. The LRNS uses the basic computational engine of the Cornell Net Carbohydrate and Protein System (**CNCPS**) model, version 5, with additional modifications and implementations. CNCPS-based models were developed from mechanistic principles of rumen function, microbial growth, feed digestion and passage, and animal physiology. The CNCPS[(2)] was first published in 1992 and 1993 in a series of four papers [4-7] and it has since been continually refined and improved [3,8-10]. A comprehensive list of publications related to the LRNS model and other nutrition models from our research group is available at http://nutritionmodels.tamu.edu/publications.html.

[(2)] http://www.cncps.cornell.edu/

Sheep production is an economically important enterprise in many countries[(3)]. Many feeding studies have been conducted with sheep to determine their nutritional requirements and dietary utilization of nutrients. However, there are fewer diet evaluation systems for sheep than for cattle, and they are often less developed. They are based on simpler approaches that are more biologically empirical than those developed for cattle. Similarly, production of meat from goats has increased considerably during the last decade, and goats have become an important livestock enterprise in several parts of the world. The Boer breed easily adapts to intense or harsh conditions, which has made it a popular choice for the production of animal protein for human consumption. Meat goats can also be used in crossbreeding programs to improve the quality and growth of dairy goat male kids.

In collaboration with Cornell University and the University of Sassari in Italy, we developed the Small Ruminant Nutrition System (**SRNS**, http://nutritionmodels.tamu.edu/srns.html). The SRNS, based on the structure of the CNCPS for Sheep, is a computer model for predicting the nutrient requirements of sheep and feed biological values on farms [11]. The SRNS predicts energy, protein, calcium and phosphorus requirements, accounting for animal factors (e.g., body weight, age, insulation, movement, milk production and composition, body reserves, mature weight, and pregnancy) and environmental factors (e.g., current and previous temperature, wind, and rainfall) factors. Feed biological values are predicted based on the pool size and fractional degradation and passage rates of carbohydrate and protein fractions, ruminal microbial growth, and physically effective fiber. The system predicts dry matter intake separately for different sheep categories based on equations developed for sheep fed indoors and on pasture. Based on this information, the SRNS predicts the energy balance of the animals. Energy balance is used to predict adult sheep's body condition score, body weight variations, and, in lactating ewes, the amount of milk produced. For growing sheep, based on the energy balance and on the relative size of the lambs, the SRNS predicts average daily gain and the composition of the gain (fat, protein, water, and minerals). For feed biological values, the SRNS predicts ruminal pH based on dietary physically effective fiber, rumen nitrogen and peptide balances, the digestibility of each nutrient by the rumen and by the whole digestive tract, metabolizable protein from ruminal microbial protein and ruminally-undegraded feed protein, and the energy cost of urea production and excretion. The system also predicts fecal and urinary excretions for each nutrient. Tedeschi, et al. [12] described the latest version of the SRNS model.

Modeling production efficiency

During the last decades, the production paradigm has shifted from the traditional goal of maximizing output to optimizing the use of resources and maximizing efficiency. It has long been hypothesized that producers failing to comply with market specifications (carcass yield and quality traits) would be penalized [13-15]. With that in mind, several segments in the global beef industry are transitioning to management and marketing of feedlot cattle individually to reduce excess fat produced, increase consistency and quality of products, enhance productivity, and increase economic returns. Management systems for individual cattle have to be developed to help bring individual animals to market at their optimum economical endpoint, avoiding

[(3)] http://faostat.fao.org

discounts and considering live and carcass incremental cost of gain and carcass prices for various grades.

Furthermore, determining the production efficiency of beef cattle requires accurately accounting for variables that influence animal performance in each specific condition of production as discussed above, including type of animals, feedstuffs, environment, and management practices. In reality, this task can be overwhelming or become almost infeasible mainly because beef cattle production in the United States, as well as many other countries, is organized into five major segments (seedstock or cow/calf, backgrounding, feedyard, packing plant, and marketing), and the information feedback among these segments is often incomplete or inadequate. The whole system can only be efficient if there is coordination throughout the production and marketing chain [16]. This coordination is typically incomplete or nonexistent even within the cattle production segments (seedstock or cow/calf, backgrounding, and feedyard) because there is no clear communication, and sometimes a segment's players make independent decisions based on marketing feedback, which is often delayed, risky, and full of interference from exogenous sources. Therefore, production efficiency is restrained to each individual category, and what is efficient in one category may not be efficient in another. This discontinuous feedback among the segments of the beef cattle industry prevents coordinated production, and it affects the fluctuation in product availability and consistency, production efficiency, and ultimately the price of the product. There are two ways to improve production efficiency within the limitations of the current U.S. beef production system. The first is the *status quo* solution of trying to improve the production efficiency within a segment independently of other segments. The second option is to use DSS to model selected segments of the beef industry and identify production alternatives that enhance production efficiency. This option can also feed back information on the factors limiting production efficiency and economic feasibility (profitability).

The Cattle Value Discovery System for growing cattle (**CVDSgc**; http://nutritionmodels.tamu.edu/cvds.html) represents an evolution of a growth model first published by Fox and Black [17] to account for differences in breed type and mature size when predicting performance and profitability of feedlot cattle with alternative management systems. Since then, modifications to the system, summarized by Tedeschi, et al. [18], have improved its accuracy to account for more of the variation in nutrient requirements and performance of growing beef cattle. The CVDS was developed for use in individual cattle management for growing beef cattle, and it provides (1) prediction of daily gain, incremental cost of gain and days to finish to optimize profits and marketing decisions while marketing within the window of acceptable carcass weights and composition; (2) predictions of carcass composition during growth to avoid discounts for under or over-weight carcasses and excess backfat; and (3) allocation of feed fed to pens to individual animals for the purpose of sorting of individuals into pens by days to reach target body composition and maximum individual profitability. This allows mixed ownership of individuals in pens, determination of individual animal cost of gain for the purposes of billing feed and predicting incremental cost of gain, and provision of information that can be used to select for feed efficiency and profitability.

Along with the CVDSgc, we developed two other models for beef cows and calves (**CVDSbc**) and dairy cows (**CVDSdc**). The CVDSbc was evaluated in collaboration with Dr. John Pollak, an animal breeder at Cornell University and currently the director of the U.S. Meat Animal Research Center in Clay Center, Nebraska, and Keith Long, a manager of the Bell Ranch beef herd in New Mexico [19,20]. In the CVDSbc, we implemented our concept of ranking cows in the herd by their energy efficiency index (**EEI**). The EEI is calculated as the ratio of the amount of metabolizable energy (**ME**, Mcal) needed by the cow (or by the cow and calf) during a reproductive cycle (conception to weaning) divided by the weaning weight of the calf. The EEI is calculated iteratively and it takes into account changes in body weight, fluxes of body reserves, milk production of the cows, forage quality throughout the reproductive cycle, and calf growth. Subsequently, we modified the CVDSbc to develop the CVDSdc [21], with the objectives of computing EEI based on the calculations of the requirements for dairy cows and the creation of a dynamic model to account for energy fluxes [22]. The EEI of the CVDSdc is also computed iteratively for a reproductive cycle.

Developing laboratory analytical techniques to support the nutrition modeling

A major challenge in developing and improving these ruminant nutrition DSS models is the acquisition of detailed and accurate inputs so the systems can function reliably. These nutrition models rely on accurate and precise predictions of nutrients' dietary supply, especially energy. The CVDSbc and CVDSdc technology use metabolizable energy required (**MER**) to estimate EEI, which requires an assessment of the diet quality to compute efficiency of use of energy for different physiological needs. To keep up, we had to utilize and modify analytical systems, including laboratory methods and methodological approaches, to systematically provide dietary information that could be used to predict diet energy. For ruminants, fractional passage rates of degradation (i.e., fermentation) of substrates in the rumen (**kd**) and the fractional passage rates of escape of substrates from the rumen (**kp**) are critical in estimating digestibility of nutrients and energy available for use by the ruminant animal. This is where the gas production fitting system (**Gasfit**; http://nutritionmodels.tamu.edu/gasfit.html) and the Gamma distribution function fitting system (**GnG1**; http://nutritionmodels.tamu.edu/gng1.html) come into play.

The *in vitro* gas production (**IVGP**) technique has frequently been used to assess biological values of feeds based on their pattern of accumulated gas during incubation with rumen fluid under anaerobic conditions. Menke, et al. [23] initially proposed the technique to assess digestibility and ME content of common ruminant feeds. At Cornell University, Dr. Alice Pell and Peter Schofield designed a computerized closed system using sixteen 50-ml Wheaton flasks, each connected to a pressure sensor [24,25]. At Texas A&M University, we re-engineered their IVGP system by adding larger flasks to minimize gas production variation, designed an analog-digital converter to work with highly sensitive pressure sensors, and streamlined the IVGP output pressure signals into the Gasfit software. Gasfit fits the pressure signals of each channel to virtually all known, relevant nonlinear functions and provides a report of goodness of fit. This report is imported into a Microsoft Excel template that automatically calculates fractional degradation rates of fiber and nonfiber carbohydrates using the fermentation kinetics plots, similar to that shown in Figure 2, and subsequently estimates the total digestible nutrients (**TDN**) and ME of the feeds. The feedstuff's value of kd, TDN, and ME can then be used with LRNS and SRNS to evaluate, formulate, and balance

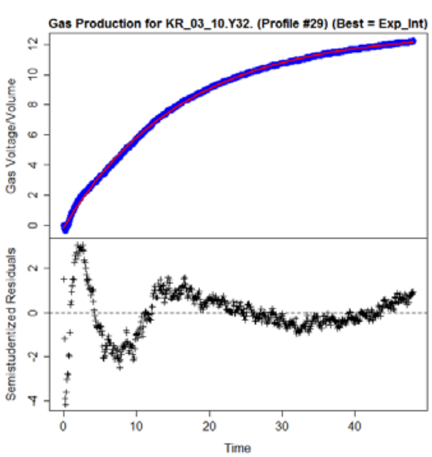

Figure 2. Fermentation kinetics of a forage.

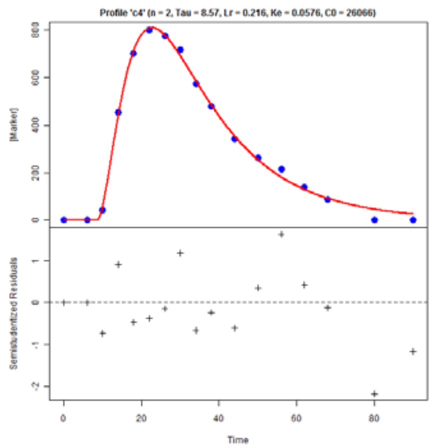

Figure 3. Pattern of particle appearance in the feces (blue dots) and GnG1 fitting the data (red line).

rations for ruminants. Afterwards, the dietary ME values obtained with LRNS or SRNS are used with CVDS models to compute EEI.

The GnG1 model is an even more specific DSS model whose application is confined to the realms of passage kinetics of feed particles from the rumen (Figure 3). The degree of complexity increases as digestion and passage phenomena are integrated among different approaches. Most mathematical models that simulate the dynamics of fiber degradation and passage assume the digesta fiber is part of a single pool. In fact, the ruminal fiber pool is heterogeneous in ruminants consuming enough fiber to promote the natural stratification of the digesta. We developed a computer DSS that uses the GnG1 technology to accommodate the digesta stratification, based on theoretical concepts and probability to generalize the rumen processes of fiber digestion [26,27]. Though the GnG1 model has limited application outside the research realm because it requires continuous sampling to obtain the pattern of a marker's excretion in the feces, it is a powerful tool for comparing digestive behaviors and feeding pattern across species [28].

The future use of nutrition modeling

Contemporary competition for use of resources, environmental, and economic challenges in animal agriculture have raised the bar for all major players in the animal industry. DSS are more important than ever because they give users the ability to quickly evaluate multiple scenarios of production and choose options that are more acceptable, sustainable, and resilient. The major contemporary challenges include:

(1) Optimizing the use of feed resources so that producing human food from ruminants results in more human food than would be available without them;
(2) The contribution of greenhouse gas by livestock, especially ruminants, and how to diminish it;
(3) The need to minimize risks and maximize profits in the feedlot sector;
(4) The need to build more responsive and accurate ruminant nutrition DSS models to account for the effects of climate change on animal welfare, nutrient needs, and productivity, while meeting consumer demand for high-quality protein food; and
(5) The grand challenge of feeding an exponentially growing world population while minimizing livestock's environmental carbon footprint.

"Understanding the nutrition, production, and economic policy feedback signals and planning ahead is crucial to build a robust and integrated production activity that can be managed under different production scenarios" [2]

With these issues in mind, we have been developing the Ruminant Nutrition System (**RNS**), a more comprehensive DSS model that integrates cattle, sheep, and goats into one platform. The main objective of the RNS is to provide a framework for incorporating and implementing new scientific knowledge and submodels to more accurately predict nutrient requirements and biological values of feedstuffs for ruminants in a perpetually challenging world.

In summary, as concluded by Tedeschi, et al. [2] and paraphrased here, "System Dynamics is a computer-aided modeling methodology that can be used to perform policy analysis and DSS applied to dynamic problems arising in complex social, managerial, economic, or ecological dynamic systems characterized by interdependence, mutual interaction, information feedback, and circular causality. System Dynamics can be used as a modeling tool to aggregate knowledge to solve different types of problems that have a limited scope to a specific location or have broad trends of applications across locations and areas of science. Important issues of broad application include the bearings of animal production in the climate change and the impacts of climate change in animal production, alternative production scenarios of animal and crop integration, associations between animal production and business (economics, marketing)." Bottom line, we know the issues were are facing or will be facing, and we also have the knowledge and tools in the toolbox that are needed to accomplish our mission.

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