Landscape of Formulation Platforms

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INTRODUCTION

Optimal diet formulation is critical for the profitability of dairy farms. Feed is usually the largest expense (50 to 75 %) and milk sales (fat, protein, and other solids) represent a significant portion of the revenue (80 to 95 % on most dairy farms). Maximization of income over feed costs (**IOFC**) as well as return on assets for a given dairy farm should be influential in ration formulation. Nutrition models are becoming more complex, as our understanding of the conversion of nutrients into milk and growth continue to evolve. Research has provided a plethora of knowledge of qualitative relationships (e.g. altered rumen biohydrogenation and production of conjugated linoleic acids); however, quantitative modeling of the complex biology of the cow is lagging behind in certain areas.

Application of nutrition models is useful to provide a baseline accounting system, directional guidance, and to improve our understanding of biology; however, it is imperative that one have an understanding of what nutrition formulation models can predict accurately and what they cannot predict well at all. Many nutrition models have continued to evolve and improve our ability to detect the most limiting nutrient(s), to predict apparent total digestible nutrients (**TDN**), to manipulate productive efficiency, and to predict excretion of important environmental emission compounds (VanAmburgh et al., 2015). However, nutrition models in general struggle to describe the interactions of nutrient concentrations (i.e. associative effects), diet effects on dry matter intake (**DMI**), and partitioning of nutrients for milk components and growth (Allen, 2011). Human intelligence and intervention is still a major factor in formulating economically optimal diets for dairy cattle.

If economics, environmental outputs, variables of the individual farm operation, and cow health were ignored, formulation of nutritional diets would be much simpler, as the primary goal would be maximum milk production. Unfortunately, the overarching ration parameters that nutritionists typically target are often not independent and some even are negatively correlated (feed efficiency vs. profit maximization). Software formulation strategies that increase predicted energy concentration of the diet typically do result in model-predicted higher energy allowable milk; however, changing the diet energy concentration often has negative effect(s) on factors such as neutral detergent fiber digestibility (**NDFD**), DMI, and rumen pH. Factors such as DMI, rumen pH, or predicted amino acid (**AA**) supply are, in fact, not considered quantitatively when using software optimizers to formulate diets. Because of this, it is prudent to design an array of formulation restrictions based on pragmatic, experience-based guidelines that take into account the intangibles of cow health and fermentation.

In general, ruminant formulation models will be underpinned on a nutritional requirement system. Users input milk yield, body weight (**BW**), days in milk (**DIM**), BW loss/gain, and environment characteristics. Dry matter intake is predicted based on BW, milk yield, and

DIM. Actual observed DMI is usually inputted during routine diet formulation; however, one must consider that any ration change may alter subsequent DMI. Most models (NRC, 2001 and CNCPSv6.5) predict dietary energy supply quite well, if the inputs and outputs are well-described (VanAmburgh et al., 2015); however, substantial departure of predicted vs actual energy supply can occur, largely due to the variation of diet NDFD (Weiss, 2010). Prediction of protein supply is quite varied across nutrition software platforms, as models differ in predicted microbial protein yield (empirical vs. mechanistic), efficiency of utilization of metabolizable protein (**MP**), rumen degradable protein (**RDP**) and rumen undegradable protein (**RUP**) fractions, and AA requirements (Schwab et al., 2014).

ENERGY PREDICTIONS BY NUTRITION MODELS

The NRC (2001) model and its derivations predict energy using the net energy system. Actual DMI and diet digestibility affect the conversion of dietary gross energy (**GE**) to digestible energy (**DE**). Higher DMI (i.e. intake over maintenance) and increased dietary TDN concentrations result in reduced conversion of diet GE to diet DE (NRC, 2001). What this means is that the calculated DE of a diet is always equal to or less (most cases) than the weighted average DE of the individual ingredients. For calculation of dietary metabolizable energy (**ME**), dietary DE and ether extract concentrations are considered. Usage of ME for maintenance, milk energy, and BW maintenance are fixed efficiencies, regardless of diet characteristics (except for fat concentration) in the NRC (2001). CPM-Dairy and CNCPSv6.5 estimate ME supply of diets by modeling of the apparent TDN (or DE) and by utilizing a fixed efficiency value for predicting energy utilized for milk production, growth, etc.

Dietary energy originates from primarily five fractions (NDF, starch, protein, fats, and other) and approximately 60 % of DE in a diet originates from starch and neutral detergent fiber (**NDF**) in a typical lactating cow diet (Weiss, 2010). Starch total tract digestibility is usually high and has been described as ranging from 92.6 to 93.9 % mean digestibility for major starch sources such as barley, corn, and wheat (Ferraretto et al., 2013). The apparent digestibility of starch usually does not vary substantially from diet to diet. Across 237 observations of total tract starch digestibility, the coefficient of variation for starch digestibility was 3.8 % (Weiss, 2010). However, the range of rumen degradable starch is quite variable, 54.1 to 78.9 % rumen digestibility across barley, corn, and wheat (Ferratetto et al., 2013). Within corn grain, rumen degradable starch can vary substantially depending on particle size, storage process, and endosperm characteristics. We know that this variation in site of starch digestion will affect DMI, microbial protein yield, and milk, fat, and protein yields; therefore, effective modeling of the site of starch digestion should be beneficial for field nutritionists. The NRC (2001) model and its derivations do not predict site of nutrient digestion. The CNCPSv6.5 model and its derivations do offer nutritionists some insight into fermentable starch concentrations of diets.

In contrast to the low observed variance associated with starch digestibility, variation in total tract NDFD is substantial. The coefficient of variation was 23.7 % for NDF diet digestibility across 237 observations (Weiss, 2010). Digestibility of NDF is usually model-predicted via a combination of lignin and *in vitro* NDF measurements; however, the relationship between lignin and *in vitro* digestible NDF has been shown to be quite variable. In the animal, the digestibility of NDF can be greatly affected by DMI and other nutrient concentrations as well. The NRC (2001) model estimates NDFD using the "lignified surface area equation" or suggests that users can utilize 48-hr NDFD measurements (NRC, 2001). The CPM-Dairy model calculates the pool of potentially digestible NDF (**pdNDF**) using the following equation:

lignin * 2.4 = pool of pdNDF

CNCPSv6.5 determines the pool of pdNDF using the *in vitro* measurement of NDFD at 240 hr or the previously described equation (VanAmburgh et al., 2015). For some non-forage feeds, the measured NDFD at 120 hr and 240 hr appears to be significantly different than the previous lignin based equations utilized by the CPM-Dairy and NRC, 2001 models (Zontini et al., 2015). In some studies, the lack of a strong relationship between lignin and NDFD has also been demonstrated in forages and this has correlated with observed cow responses (Cotanch et al., 2014).

In vitro measurements for starch and NDFD of individual feed ingredients have value for understanding and ranking ingredients; however, one must consider that NDF and starch digestibility are not independent of dietary factors (e.g. DMI, starch concentration, rumen protein balance, and particle size). Predicted rumen fermentable starch concentration (as well as other carbohydrate fractions) should, at the minimum, provide directional inference when making diet formulation changes. However, it should be recognized that modeling fermentable starch is highly complex. The inability to predict the passage rate of individual feeds, represents one key limitation as the passage rate of some feeds, e.g. dry fine ground corn vs. high moisture corn, varies significantly (Ying and Allen, 2005).

Increases in digestibility of NDF usually cause increases in DMI which can somewhat depress overall diet digestibility. *In vitro* NDFD will typically be less than *in vivo* values, because of associative effects (Weiss, 2010). Highly fermentable diets (i.e. high starch content) will depress NDFD (Ferraretto et al., 2013). Replacing forage NDF with byproduct NDF increases the theoretical digestible NDF concentration of diets; however, the negative associative effects of increased passage rate and/or possible reductions in rumen pH may wipe out potential benefits of higher NDFD. For example, diets with similar model predicted energy concentrations (0.73 and 0.72 NE_L, Mcal/lb), but differing in forage NDF concentrations (22 % vs. 16.8 % DM) and analyzed 30 hr *in vitro* NDFD (59.8 vs. 62.7), resulted in the cows fed the lower forage NDF diet increasing DMI by 2.2 lb and producing numerically more milk (1.8 lbs; Weiss, 2012). However, cows fed the lower forage NDF diet had reduced milk fat concentrations and lower energy corrected milk (**ECM**) yield. The estimated dietary energy concentrations were 0.68 NE_L, Mcal/lb with the low forage NDF diet and 0.76 NE_L, Mcal/lb with the high forage NDF diet when accounting for DMI, body weight change, and ECM yield; which are very different estimates than the NRC, 2001 model had predicted. During routine diet formulation, consideration for the dietary effects on DMI and associative effects on rumen digestibility should be considered as the quantitative modeling of this effect is limited to nonexistent.

Associative effects on rumen fermentation result from the interaction of all diet characteristics and feed intake. Linear optimization is much easier if NE_L is assigned to individual feed ingredients; however, this approach may lead to a predicted dietary NE_L concentration that ignores associative effects. Nutrition software models that assign NE_L and/or MP concentrations to individual feed ingredients may over predict NE_L and MP diet concentrations and subsequently, milk yield. Nutritionists should be aware of whether their ration software estimates energy and MP based on values for individual feeds or if it is computed from the total diet. Lab reported energy values for feed ingredient are irrelevant in NRC (2001), CPM-Dairy, and CNCPSv6.5 based nutrition models, as these platforms do compute energy from the total diet.

The largest losses of energy occur during transformation of GE to DE and ME to NE. Research related to residual feed intake (**RFI**) has shown that heat increment (conversion of ME to NE) possibly contributes 37 % to the variation of observed RFI in the beef population (Herd et al., 2004). We have also known that the theoretical conversion efficiencies for carbohydrate to body fat, lipid to body fat, protein to body fat, and protein to body protein are different: 0.80, 0.96, 0.66, and 0.86 (Blaxter, 1989). Application of a mechanistic model (Baldwin, 1980) by simulating varying dietary acetate, propionate, lipid, and protein inputs yields very different efficiencies for milk production or growth. In addition, changes in AA supply or efficiency of MP efficiency usage likely are closely associated with changes in ME utilization for milk yield (VanAmburgh et al., 2015), which potentially represents an opportunity for more mechanistic modeling of the conversion of ME to NE. Overall, this suggests that efficiency might be improved through dietary manipulation if we better understood predicted metabolic end-products.

Individual feed ingredients can vary substantially in NDFD and starch fermentability and these factors will affect DMI, rumen health, partitioning of nutrients, and digestibility of the total diet. Modeling of *in vitro* digestibility measurements for feed ingredients is useful; however, one must recognize that the digestibility of a particular nutrient is not an independent variable in the cow and that digestibility in the cow of dietary nutrients (e.g. NDF) may be significantly different than *in vitro* measurements would suggest (positive or negative). More mechanistic models are needed to help us better understand and represent digestion to optimally formulate diets.

PROTEIN PREDICTIONS BY NUTRITION MODELS

Most nutrition models (NRC, 2001; CPM-Dairy; and CNCPSv6.5) predict MP supply and estimate MP allowable milk. Metabolizable protein is the summation of absorbed microbial protein, digestible RUP, and endogenous protein. The assumed efficiency of MP utilization for protein synthesis is 67 % for CNCPSv6.5 and NRC (2001) and 65 % efficiency for CPM-Dairy. NRC (2001) and its derivations predict microbial protein from model calculated diet TDN intake. Rumen degradable protein and RUP are predicted by fractionating protein into 3 pools (fractions A, B, and C) and rumen degradation rates are estimated using *in situ* data. Amino acid requirements were not established in the NRC (2001), therefore, are not explicitly provided in NRC (2001) based ration software programs. The CPM-Dairy and CNCPSv6.5 based models differ from the NRC (2001) with a more mechanistic prediction of microbial protein production, prediction of AA requirements, protein fractions, consideration of urea recycling, and several other factors (VanAmburgh et al., 2015). For more complete review of protein predictions by NRC and CNCPSv6.5 based models, please see the following papers:

Schwab et al., 2014; VanAmburgh et al., 2015.

Important considerations for evaluating commercial software programs are that estimation of MP is calculated from the diet, not individual feed ingredients. If MP is estimated on individual feeds vs estimated from the total diet, the associative effects of DMI, RDP, or ammonia concentrations, and carbohydrate digestibility are not considered. Least cost optimization for supply of MP does not consider the benefit of feeding a variety of protein feed ingredients and/or balancing for limiting AA versus a diet formulated with only corn protein. The benefits of providing an improved dietary AA profile have been well documented (Schwab et al., 2014); however, nutrition models do not consider the effect of diet on efficiency of MP utilized for milk protein synthesis, as an example. Improved quantitative modeling of carbohydrate metabolism, as discussed earlier in the paper on CNCPSv6.5, may provide a platform for improving our ability to optimize microbial protein yield, for troubleshooting diets with perceived protein supply issues, and for formulating lower CP diets to improve N efficiency.

NUTRITION MODEL FEED LIBRARIES

Accurate characterization of feed ingredients is critical for successful diet formulation in terms of meeting animal requirements, accuracy of model predictions, and economic selection of ingredients. Most nutritionists analyze forages and some concentrates on a routine basis for individual farms and do not rely on stock library values. This is highly recommended, as the individual farm has been shown to be a significant source of variation for forages and some concentrates (St-Pierre and Weiss, 2015). Chemical analyses for feed ingredients continue to evolve, in part driven by the increased mechanization of the CNCPS model. The major nutrient concentration inputs for the NRC (2001) model are DM, CP, NDF, lignin, fat, ash, minerals, and to a lesser extent, ADICP and NDICP. For the more mechanistic models, the major additional inputs are soluble CP; ammonia; NDFD at the following time points, 30 hr, 120 hr, and 240 hr; undigestible NDF; sugar; starch; starch 7 hr digestibility; total fatty acids; and volatile fatty acids (**VFA**; lactic, acetic, and butyric). The CNCPSv6.5 model calculates the rate of degradation of NDF (multiple time points of digestion) and starch (single time point of digestion).

While NDF and starch digestibility *in vitro* measurements are important for describing feed ingredients, inter-assay variation, lab-to-lab variation, and sampling variation will limit the accuracy of these absolute values for appropriate characterization in a mechanistic model. Sampling has been shown to contribute anywhere from 9.2 to 80.6 % of the variance for nutrient concentrations in feed ingredients (St-Pierre and Weiss, 2015). The use of data from a single sample should be avoided in ration formulation (particularly for populations that pose sampling representation issues, i.e. large corn silage bunker). Several commercial nutrition platforms possess a function to allow averaging (simple or weighted average) of analyses for individual feed ingredients. From a user standpoint, the ability to electronically import sample analyses and the ability to automatically average samples within the software are 2 software functions that users may want to consider when selecting a ration software platform.

As noted above, lab-to-lab variation needs to be considered and selection of a single lab for an individual farm is recommended to remove this source of variance. Important nutrients such as NDF might be assayed slightly different from lab-to-lab and it is suggested that nutritionists pay attention to the assay being used by a given lab (Hall and Mertens, 2012). On average, 30 hr NDFD inter-assay variation was shown to be +/- 5 percentage units (95% confidence interval) and +/- 6.5 percentage units across labs for forages (Hall and Mertens, 2012). The repeatability of *in vitro* NDFD assay for ranking ingredients has been shown to be quite good. CPM-Dairy and CNCPSv6.5 utilize *in vitro* measurements as absolute values for prediction of digestibility of NDF and starch; therefore, users should pay attention to lab assay variance associated with these measurements. For example, determination of rumen starch degradation is complex, i.e. particle size, grain type, and fermentation (e.g. HMSC) (Ferraretto et al., 2013) and assay repeatability of *in vitro* 7 hr starch measurements may be suspect. Starch degradation (rate and passage) should be assessed across a range of starchy based ingredients. Caution is suggested when using *in vitro* results (especially from single samples) as absolute values in mechanistic models. If a nutritionist is utilizing multiple labs and a single sampling technique, the noise (variance unassociated with real ingredient change in starch degradation concentration) is likely quite high and, therefore, should be avoided within an individual farm. Nutritionists should always use their own experience and knowledge of feed ingredients (i.e. particle size, floury vs. vitreous endosperm) as part of a feedback loop for more accurately describing starch degradation rate in mechanistic models. In addition, special attention should be paid to base library values for feed ingredients, as those values might be outdated or significantly different than commercial lab reported values. For example, corn silage (35 % DM, 41 % NDF, processed, medium) in the CPM-Dairy and CNCPSv6.5 feed libraries is described with a starch degradation rate of 32 % hr, which infers an 89.4 % starch 7-hr digestibility value. This value for starch degradation may be outdated as genetics for the corn endosperm may have changed substantially in recent years. For example, the reported average 7-hr starch degradability of corn silage submitted from US-based accounts was 77.8 % and the standard deviation was 5.7 % (n=16,479) for the time period of January 1, 2015 to June 30, 2015 (Cumberland Valley Analytical Services, Hagerstown, MD, www.foragelab.com). When *in vitro* measurements are not conducted on major dietary ingredients, users should consider if they want to adjust library values for starch degradation rates in mechanistic models. For example, if a nutritionist is formulating diets with consideration of fermentable starch concentrations then concentrations across diets might look different, if the starch degradability of corn silage is measured on some farms and library values used on other farms. The degradation rate of starch (corn grain) has been shown to be the most sensitive input for prediction of MP milk within the CNCPSv6.5 model (Higgs et al., 2015). A change of 1 standard deviation increase in the degradation rate of starch in corn grain increased model MP allowable milk by 4.1 pounds (Higgs et al., 2015).

Model feed libraries are often utilized for concentrates such as corn grain, soybean meal, whole cottonseed, etc. and variation of most concentrates from farm-to-farm has been shown to be limited (St-Pierre and Weiss, 2015). However, differences appear to exist across nutrition model platforms and, in the case of the NRC (2001) database, the nutrient concentrations of some feeds may have changed over time (Yoder et al., 2014). Nutrient concentrations of common

Table 1. Various feed ingredients nutrient concentrations and calculated MP concentration from several formulation platforms and a summarized database.

Item[1]	CPMv3.0	CNCPSv6.5	NRC, 2001	Yoder et al., 2014[2]
Citrus Pulp, dry				
DM, %	88.6	88.6	85.8	87.0
CP, % DM	7.0	7.3	6.9	7.0
NDF, % DM	23.9	23.9	24.2	22.3
EE, % DM	3.1	2.9	4.9	2.8
MP, % DM	13.0	11.3	8.1	
Cost ($/lb of MP)	$0.93	$1.07	$1.55	
Soybean Meal, 48 %				
DM, %	90.0	90.0	89.5	88.3
CP, % DM	55.0	51.5	53.8	52.9
NDF, % DM	10.0	10.0	9.8	8.7
EE, % DM	2.8	2.8	1.1	1.6
MP, % DM	24.9	26.5	26.9	
Cost($/lb of MP)	$0.78	$0.73	$0.73	
Blood Meal[3]				
DM, %	90.0	90.0	90.2	89.9
CP, % DM	93.0	95.0	95.5	99.4
NDF, % DM	37.8	-	-	6.0
EE, % DM	2.0	1.5	1.2	0.7
MP, % DM	68.7	50.5	65.2	
Cost ($/lb of MP)	$1.23	$1.68	$1.30	
DDGS - Ethanol				
DM, %	88.8	88.8	90.2	89.6
CP, % DM	30.3	30.3	29.7	29.5
NDF, % DM	32.2	33.6	38.8	33.0
EE, % DM	14.5	14.5	10.0	12.6
MP, % DM	17.0	18.6	18.5	
Cost ($/lb of MP)	$0.58	$0.53	$0.52	

[1] Feed ingredient nutrient concentration values were obtained from the libraries of the respective nutritional models, CPM-Dairy v3.0, NDS Professional v3.8.10.01, and NRC (2001).

[2] Ingredient nutrient concentrations were obtained from summaries provided by Yoder et al., 2014

[3] Blood meal was listed with the following descriptions within each model; blood meal (CPM-Dairy v3.0, blood meal average (NDS Professional v3.8.10.01), and ring dried blood meal (NRC, 2001)

[4] Metabolizable protein was estimated using a standardized and balanced diet (52 % forage), cow description inputs, and intake at 54 lb of DMI across CMP-Dairy v3.0, NDS Professional v3.8.10.01, and NRC (2001)

[5] Prices of the ingredients were same across nutrition models and the prices were the following; citrus pulp - $215/ton, soybean meal 48 % - $350/ton, blood meal - $1525/ton, and distillers ethanol - $175/ton.

feed ingredients vary across ration software platforms, as well as predictions of model calculated nutrient (ME and MP) concentrations for some ingredients (**Table 1**). We often hear in the field that an individual model *prefers* certain feed ingredients. Feedstuffs such as blood meal may have significant differences across models with its calculated MP concentration (% of DM) varying 18.2 percentage units across CPM-Dairy, CNCPSv6.5, and NRC (2001). A feed high in sugar and soluble fiber content, such as citrus pulp, is predicted to provide significantly more MP in CPM-Dairy vs. an empirically based model such as NRC (2001). With the updates in the partitioning of N supply (ruminally and post-ruminally) of feed ingredients within CNCPSv6.5, some feed ingredients may have more or less predicted MP contributions compared to earlier versions of CNCPS (e.g. CPM-Dairy; Table 1).

DIET FORMULATION AND OPTIMIZATION

Formulation and optimization of diets usually involves adjusting the nutrient concentration of a diet (e.g. ME allowable milk) and the designation of optimal inclusion of individual feed ingredients to meet a specified supply of nutrients. A change in dietary energy concentration often leads to a change in DMI or the impact of an associative effect on digestibility (Conrad et al., 1964). For example, formulating for a higher energy concentration often leads to reduced DMI which means energy intake will be less than expected. Increasing dietary NDFD (e.g. BMR corn silage or byproduct NDF) will increase the predicted energy concentration of the diet by the model, but the observed response is potentially increased DMI and reduced observed dietary energy concentration. The inability of current models to predict changes in DMI from a diet is a limitation that must be considered during formulation and optimization. While a particular optimized diet solution might predict increased IOFC, if DMI changes from the resulting diet solution, then the improved IOFC model prediction may not occur and, in some cases, might be negatively affected from the dietary change.

While optimization of IOFC by a software model represents a tool for improving profitability on dairy farms, we must recognize the limitations of computer optimization. Optimizers evaluate feed ingredients in terms of nutrient concentrations (considered static) and costs. However, feed ingredient nutrient concentrations are not constant, but variable, and the level of variation in nutrient concentrations is substantial across some feeds (e.g. CP concentration of distillers grains vs. soybean meal). The associated economic costs of nutrient variation within feed ingredients is not considered by current model optimizers. Statistical algorithms for assessing the costs of variation of feeds during least cost formulation have been proposed and discussed (St-Pierre and Harvey, 1986). Least-cost solutions might lead to an increased likelihood of diets formulated that have greater negative associative effects (e.g. preference for high unsaturated fatty acid concentrated feed ingredients, which may increase risk of milk fat depression) as most nutrition models don’t quantitatively model well-documented associative effects. Although the effects of associative effects are widely understood, nutritionists often only consider nutrient guidelines and not the quantitative relationships of associative effects within most commercially available ration software. Nutritional models cannot predict responses in milk component concentrations from dietary changes and this limitation should be considered when formulating diets for increased milk yield, as most producers are compensated for milk component yield, not fluid milk. In summary, optimization has value for selection of feed ingredients to deliver a predetermined supply of nutrient(s); however, the limitations of optimizing for increased milk yield and/or IOFC should be considered, as the optimization algorithm does not consider that changes in DMI or the partitioning of nutrients that are likely to occur with a changed dietary nutrient concentration.

COMMERICAL NUTRITION MODELS

Most field nutrition models in the US that are available to the public are based on the NRC (2001) (or NRC, 1989), CPM-Dairy, or CNCPSv6.5 model framework. For this paper, only a few platforms, i.e. AMTS, NDS, CPM-Dairy, and Formulate2 software will be discussed. In the US, the CNCPSv6.5 model platform is licensed and marketed by the following companies; Agricultural Modeling and Training Systems (AMTS, https://agmodelsystems.com), Nutritional Dynamic System (NDS, www.rumen.it), and Dalex Livestock Solutions (www.dalex.com) to the author's knowledge. Trial versions of AMTS and NDS are both available for download from the respective websites. The latest CNCPS released feed library is contained within both nutritional software platforms. The CNCPS library contains the majority of commercial products utilized in dairy rations today. The NDS software also contains another feed library, RUMEN, which contains feed ingredients not provided in the CNCPS feed library and commercial feed products. AMTS and NDS platforms both contain nonlinear optimizers that allow optimization on dietary concentrations of a number of diet calculated nonlinear nutrients (i.e. MP-lysine supply). Other features pertaining to AMTS and NDS can be found on their respective websites. In general however, functions for managing pricing, electronic importing of feed analyses, creating mix composites, user nutrients, and an array of report formats exist in both of these software platforms.

CPM-Dairy v3.0 continues to be utilized by a number of field nutritionists from the author's observations. The CPM Dairy v3.0 software is available for download; however, the development of the model by Cornell University, The University of Pennsylvania, and the Miner Institute has officially ended. Based upon a recent review, the CPM Dairy v3.0 was evaluated and its ability to predict milk production from ME and MP supply at the farm level given animal inputs, appropriate feed characterization, and feed intake was concluded to be accurate by the authors (Tedeschi et al., 2008). The University of Pennsylvania has recently released an updated version of CPM v3.0 titled ***UPenn Dairy Ration Analyzer*** and the major updates are related to the liquid passage rate, efficiency of MP utilization, and NDF digestion parameters. Information related to the software and a demo version for download is available at: cahpwww.vet.upenn.edu/doku.php/software:dra:start.

Formulate2 is a commercial software platform that fully implements the NRC (2001) and contains an optimizer that accounts for the nonlinear equations present in the NRC (2001) model. Formulate2 is marketed and supported by Central Valley Nutritional Associates LLC (www.formulate2.com). A new Formulate2 version is currently under development and key updates involve moving to a new development platform (Delphi XE6) and improving user functionality. The current version of Formulate2 for download to demo has been suspended in anticipation of the release of the new version. Formulate2 contains a robust nonlinear optimizer, a range of reports, and several user functionality options.

Other major commercial formulate software available are Spartan Dairy Ration Evaluator/Balancer version 3.0 (http://spartandairy.msu.edu/spartandairy/home), NittanyCow Dairy Ration Evaluator (http://www.nittanycow.com/App_content/home.aspx), and AminoCow (http://www.nittanydairynutrition.com/App_Content/aminocow.aspx). Several other nutrition software platforms do exist, but are not listed in this paper.

A number of factors appear to determine selection of ration formulation software by practicing nutritionists. These include computer software functionality, underlying biology of the model, robustness of the feed library, optimization functionality, linear or nonlinear estimation of calculated nutrients (e.g. ME allowable milk), cost of software, training and technical support, user functionality (e.g. user generated report(s) format, electronic import of feed analyses, database structure (i.e. diets, farms, feeds, prices, etc.)), and previous formulation software experience (mechanistic vs. empirical based). From a model structure standpoint, estimation of calculated nonlinear nutrients on the diet vs. on individual feeds, mechanistic vs. empirical modeling of apparent TDN (or conversion of GE to DE) and microbial protein yield, and the accuracy of model predictions should be key factors for selection of ration software.

SUMMARY

Diet formulation for lactating dairy cows is complex with many interacting factors to consider. Quantitative modeling continues to evolve with incorporation of new research that potentially may improve ration software models. In general, nutrition models account for the transformation of nutrients into NE with good accuracy when provided good descriptions of intake, BW, environment, milk production, and BW change. The advent of more mechanistic based models and the development of *in vitro* assays provide tools to better characterize and determine the economic value of feed ingredients. Ration models that quantitatively model major sources of variation, e.g. NDFD and site of starch digestibility, may have the potential to better predict on farm performance, be more useful for troubleshooting, and improve decision making related to ingredient selection. Mechanistic models may also improve the accuracy and sensitivity of predicting N supply to the cow.

Nutrition models are useful tools for addressing the complex issue of optimal diet formulation. However, one must recognize what nutrition models predict well and also the limitations of nutrition models. Nutritionists should probably keep in mind the instructive comment of Box (1979) that "All models are wrong, but some are useful." It is important to appreciate that current nutrition models do not predict the effect of diet on the following variables; DMI (limited consideration for associative effects), conversion of ME to NE (except fat), and partitioning of nutrients (e.g. milk components). The need for human intelligence is still immensely necessary for optimal ration formulation.

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