Ration Formulation Models: Biological Reality vs. Models

H.A. Rossow, Ph.D.
Veterinary Medicine Teaching and Research Center
UC Davis School of Veterinary Medicine, Tulare, CA
Email: heidi.rossow@gmail.com

ABSTRACT

Ration formulation programs are composed of basically 2 parts; the first is the model that represents nutrient requirements of the cow given her stage of life and level of production and the second is the algorithm that solves the ration to provide either the cheapest diet that meets the model (cow) requirements or maximizes milk income over feed costs. Early ration formulation programs used the simplex algorithm to solve the ration, which was based on maximizing or minimizing profit over cost based on linear model equations. The model, made up of linear, static nutrient relationships between milk production and nutrient inputs, was used to set nutrient requirements such as the tables in the Nutrient Requirements of Dairy Cattle (NRC, 1989 and earlier). At this level, the programs work, but are limited by the fact that life is not linear. As cattle eat more and produce more milk, the gain in milk production per unit of feed consumed gets smaller and smaller. As the focus changes from minimizing costs or maximizing profit to increasing efficiency, models and the algorithms used to solve them become more complicated. As the programs become more complicated, both the model and the algorithm influence the resulting ration solution. So to examine how well ration programs reflect reality or what nutrient inputs are really needed to formulate a diet, both the model and algorithm must be examined. The 2 main ration programs used today, **AMTS** (Agricultural Modeling & Training Systems, LLC) and **NDS** (Nutritional Dynamic Systems, RU.M.&N., Italy) both use the Cornell Net Carbohydrate and Protein System (**CNCPS;** Tylutki et al., 2008); but, because they use different solution algorithms and settings, will produce different rations.

INTRODUCTION

Models of dairy cow nutrient use are dependent on how nutrients are defined and how important those nutrients are to the nutritional physiology of the cow. Early ration formulation was based on nutrient definitions according to proximate analysis. However, proximate analysis had several problems including a non-homogenous category of nutrient, *Nitrogen Free Extract*, that had no relation to cow physiology and a lack of continuity between crude fiber (**CF**), and newer fiber analysis techniques, acid detergent fiber (**ADF**) and neutral detergent fiber (**NDF**). The basic idea of proximate analysis has stayed in nutrient analyses techniques through the use of total digestible nutrients (**TDN**) and more recently many analyses have been added to the basic framework of proximate analysis, and ADF, NDF through further development of CNCPS model. If all of the new analyses were needed to formulate a ration, laboratory costs would be extremely high. Therefore the goals of this paper are:

1) To use sensitivity analyses to determine the relative importance of a nutrient to the ration program,
2) To explore how changes in the nutrient affect the ration solution, and
3) To examine if ration program behavior would matter to the cow (reality).

The methods presented to evaluate the ration programs could be done by anyone and should be done before changing programs or upgrading to a new CNCPS model or algorithm.

Nutrient Descriptions

Chemical analyses of nutrients must be measurable with accuracy and precision, relevant to cow physiology, and must improve model predictions of production. Unfortunately none of the current systems meet all of these criteria. For instance, NDF was originally developed to quantify fiber from forages, but results for the same sample were not consistent. Due to the importance of feeds that contain both fiber and grain (i. e. corn silage), NDF was also used for high starch feeds. Because these feeds were nearly impossible to filter and complete the assay, the technique was modified to add amylase, noted as **aNDF**. But, since results were still not consistent (lack of precision), the ash content of NDF was removed (**aNDFom**). Then, because whether a fiber was digestible in the rumen and therefore available to microbes for microbial growth would link NDF better with rumen physiology, digestible NDF (**dNDF as % NDF or NDFd as % DM**) was created. But these were determined chemically using an *in vitro* incubation system, which becomes more unlike rumen fermentation the longer it lasts. Consequently NDFd became defined according to length of incubation: **NDFd24** (24 h), **NDFd30** (30 h), etc. In recognition that some NDF is degraded more rapidly than others, NDF was also classified into undegradable NDF at 30 h (**uNDF30**), at 120 h (**uNDF120**) and at 240 h (**uNDF240**). These chemical analyses were used to define pool sizes in CNCPS for rapidly degrading NDF, slow degrading NDF, and unavailable NDF (lignin); respectively, to define how much NDF was potentially degradable (pdNDF = aNDFom - uNDF) and how much NDF was essentially not degradable at all in the rumen. While the development of these assays parallels how NDF has been observed to be degraded in the rumen, the nutrient NDF is not a substance that microbes degrade to produce specific products. Neutral detergent fiber is not unique and its components (cellulose, hemicellulose, lignin, and ash) are fermented through different pathways. Therefore NDF, while relevant to plant physiology, is not necessarily relevant to rumen physiology and so refining it further, according to rumen physiology, will not improve its representation of reality. It would be better to start with nutrient descriptions that were more homogeneous such as cellulose, hemicellulose, and lignin instead of trying to correct an already flawed nutrient description. This has been acknowledged by the developers of CNCPS and in a perfect world, the analyses to determine cellulose, hemicellulose, pectin, and lignin would already be developed and consistent with forage quality. Unfortunately this has not happened yet due to the focus on NDF.

METHODS

Evaluating the importance of a nutrient to the model and ration formulation

If a nutrient was measurable with accuracy and precision and a change in that nutrient supplied to the cow caused a change in cow health or production, the ration formulation program should reflect the importance of the nutrient. In modeling terms, the ration formulation should be sensitive to changes in the nutrient supplied by either changing the resulting ration or changing the requirements of other nutrients, or both. Essentially there are at least 2 questions that can be answered by this analyses:

1) "How important is it that I know that nutrient 's level in the feed (diet)?" or conversely "Should I spend the money for wet chemistry analyses?" and
2) "If I'm wrong about this nutrient's level in the feed, will it change the ingredient composition of the diet?"

The second question is impacted by both the nutrient requirement model and the algorithm used to solve the ration and may be different for different ration formulation programs. These analyses can be done by anyone and should be done before choosing which ration formulation program to use.

RESULTS AND DISCUSSION

The following are examples of these analyses using AMTS. Table 1 lists the baseline ration and ingredient constraints before any nutrients or nutrient variables were changed. The nutrient constraint column lists the nutrients that were constrained to get the ration solution. For each sensitivity analysis that compares changes in a model nutrient to ration changes, constraints were held constant and only the nutrient was changed.

Example 1.

Evaluate the importance of knowing physically effective (**pe**) factor in corn silage to meet the peNDF requirement for the ration. For a feed (corn silage), **peNDF = % NDF * pef** and pe factor is the percent of feed above the 1.1 or 4 mm screen of the Penn State Particle Sorter (**PSPS**). Physically effective NDF should be between 22 - 35 % according to constraints built into AMTS. Because corn silage is a major component of the baseline diet and pef is large for corn silage (82 %), pef was changed in 10 % increments to see the effect on ingredient content of the diet and peNDF. Figure 1 shows the impact of changing pef on peNDF. The dashed lines indicate the constraints for peNDF. For corn silage, there is not much impact on peNDF until pef is above 60 %. This makes sense because the amount of large fiber particles (above 4 mm) should be at least above 60 % of total corn silage. Figure 2 shows that as pef gets below 60 %, AMTS changes the ingredient composition of the TMR from corn silage to wheat silage. This also causes small changes in citrus, dried distillers grains (**DDG**), and corn to continue to balance the TMR. Above 60 % pef for an

Table 1. High milking cow ration solution (DMI 55 lb/d)

Ingredient	AMTS Ration (lb)	Min (lb)	Max (lb)	Nutrient Constraints
Corn silage	15	7	15	DMI
Wheat silage	0.3	0	6.5	ME
Corn	10	6	11	MP
Alfalfa	15	6	15	Rumen ammonia
Almond hulls	2	2	4.5	NFC
Dried distillers grains	3.5	2	3.5	peNDF
Wheat mill run	0	0	5	EE
Canola meal	0	0	6	Lys
Corn gluten	0.18	0	3.3	Met
Soybean meal	3.2	0	3.2	
Cottonseed	3.6	0	3.6	
Citrus pulp	0	0	1	
Molasses	0	0	0.65	

approximate 30 % change in pef, TMR peNDF changes by 5 %.

Reality Check

It is very difficult to get repeatable results with the PSPS. Results can commonly vary between 10 - 20 %. But, with only a 5 % change in peNDF of the TMR for a 30 % change in pef, getting good results from the PSPS is probably not an issue. However, it also implies that this number is not important for the ration (62 % pef is the same as 92 % pef) and could be excluded as a constraint and as a term in the program. In addition, particle size of the TMR can change greatly during mixing and feeding of the TMR due to mixing time, operating condition of the mixer wagon, and sorting of TMR by the cows (crowding, feeding frequency, etc.). Therefore including particle size as a constraint in a ration formulation program will not be a major contributor to impacting rumen function as it was originally intended.

Figure 1. Effect of changes in physically effective factor (pef) on peNDF. Constraints for peNDF is area between dashed lines.

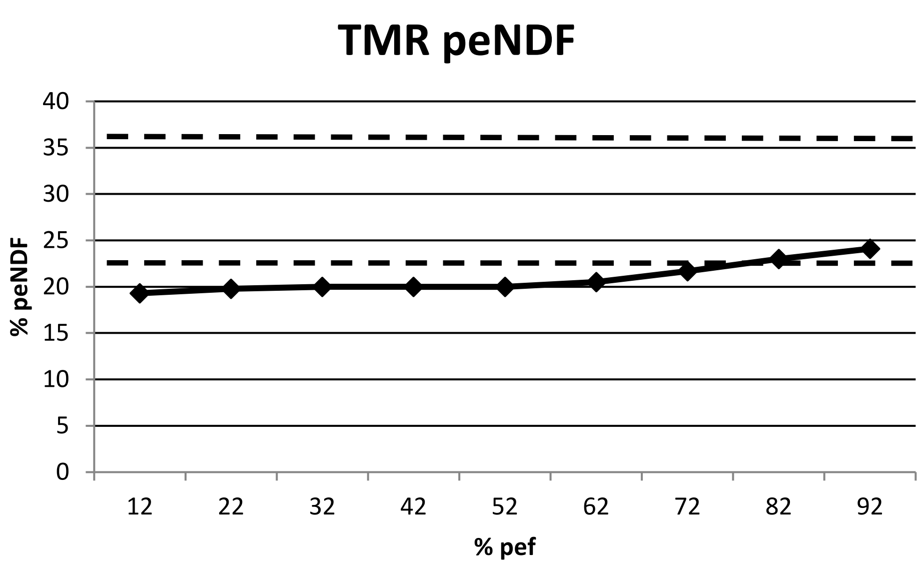
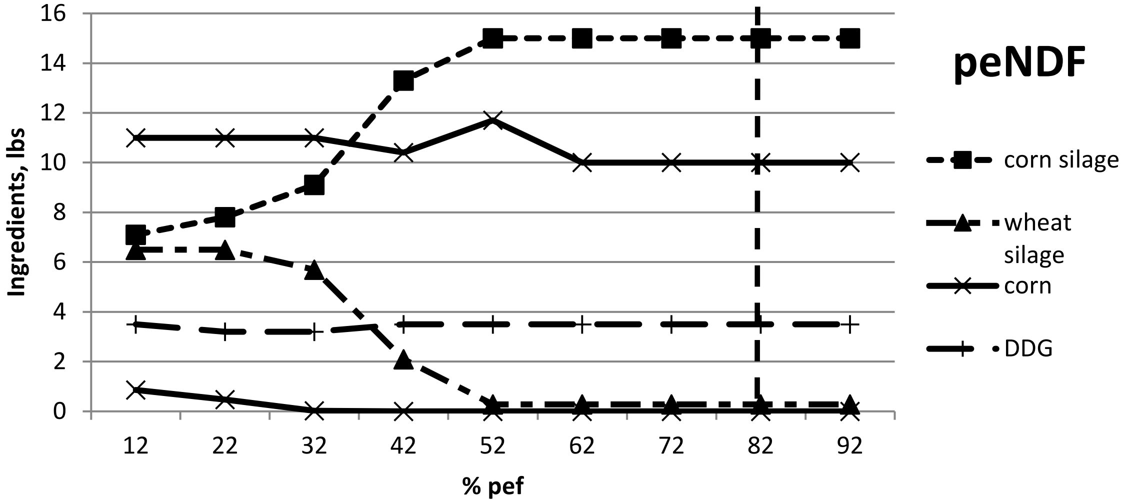


Figure 2. Changes in ingredient content of ration as pef is decreased. The pef for corn silage is depicted by the vertical dashed line.



Example 2.

How would the ration solution be changed if the starch content in corn was inaccurate? Starch is a major component of non-fiber carbohydrate (**NFC**), which has a maximum limit of 40 % DM in the AMTS program. Corn was used to vary the amount of starch because it was the major contributor to starch in the diet. Changes in starch were counter balanced with changes in NDFom (Figures 3 and 4) and then sugar (Figures 5 and 6) to ensure the nutrient content of corn still summed to 100 %. Note that a decrease in corn starch content (about 10 %) replaced with NDFom caused a similar decrease in NFC (about 10 %) and large changes in the TMR, especially between corn and corn silage. But when starch was replaced with sugar, there was no change in NFC and very little change in the TMR. See Figure 6 where wheat silage is replaced with corn gluten (1:1 change by 0.13 lb).

Figure 3. Changes in NFC and TMR starch with replacing corn starch content with NDFom. Constraints for NDFom depicted by dashed line.

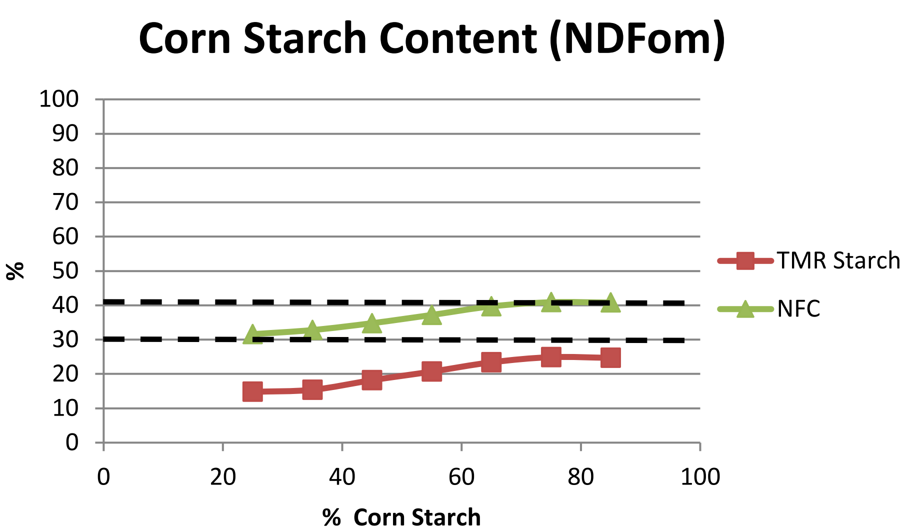
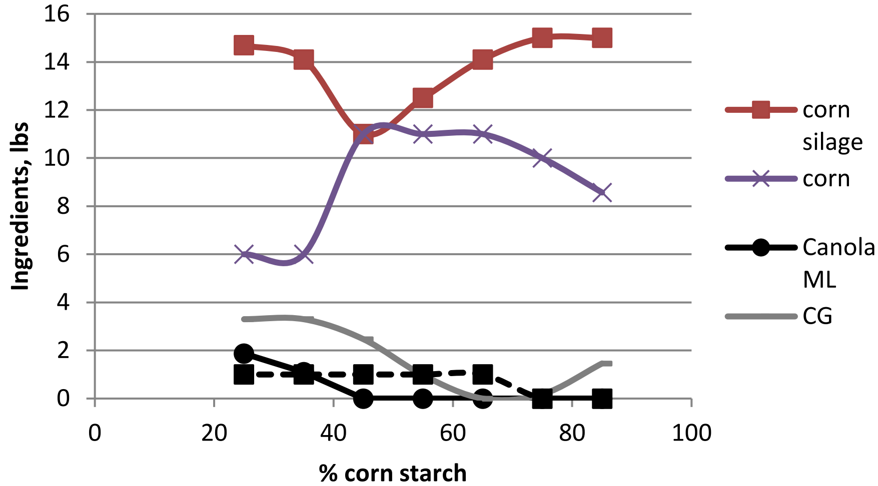


Figure 4. Changes in the ingredient composition in the TMR as a result of replacing starch percent in corn with NDFom.



Reality Check

Of all the macro nutrient analyses performed by laboratories, methods and results from starch analyses are the most variable. This analysis examines the impact on the ration solution if starch content in corn was wrong and either the *missing* nutrient percent ended up in NDFom or in sugars. If starch content is mis-identified as sugars, there is very little impact on the TMR ingredient composition; which also implies it may not be important to distinguish starch and sugars and sub-components of NFC. Knowledge of NFC may be enough. However, if starch content is mis-identified as NDFom, the impact to the TMR is much greater. Therefore it is important to know NFC and NDFom, but not-sub categories of nutrients within NFC.

Figure 5. Changes in NFC and TMR starch with replacing corn starch content with sugar. Constraints for sugar depicted by dashed line.

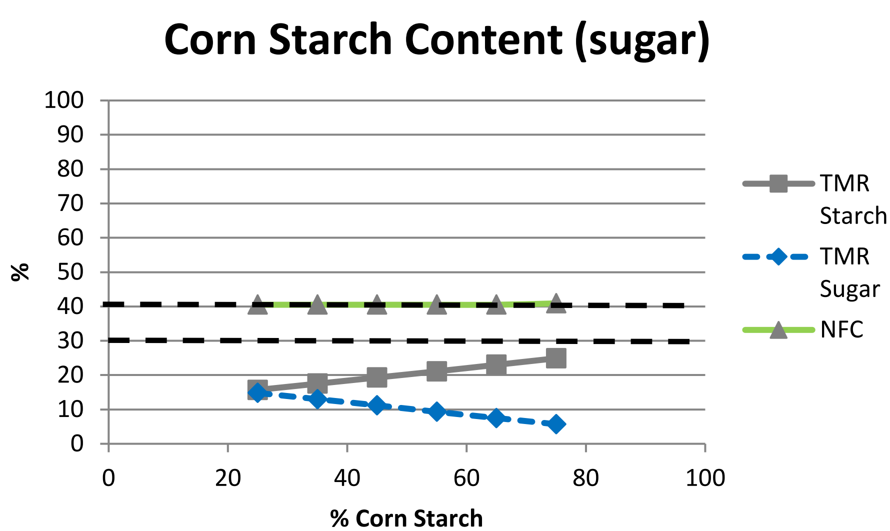
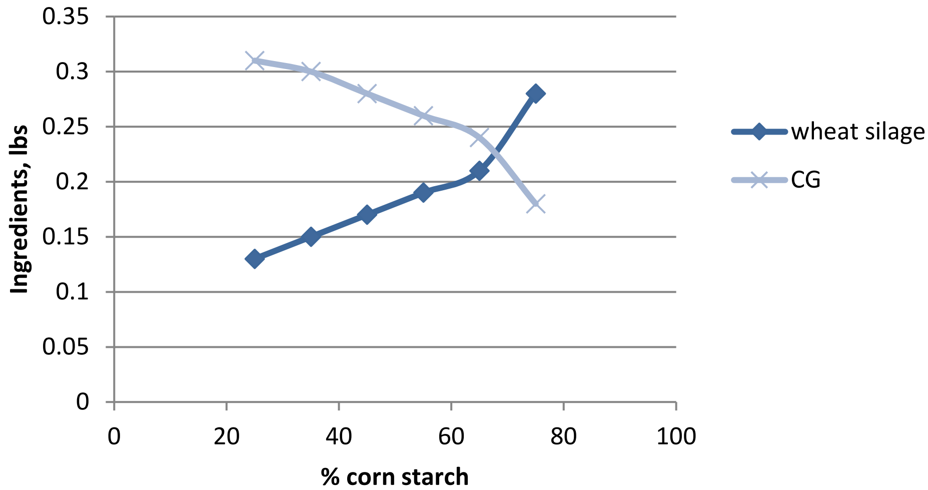


Figure 6. Changes in NFC and TMR starch with replacing corn starch content with sugar.



CONCLUSIONS

The Reality of Model Evaluation

Nutrient descriptions should be closely linked to how their nutrient inputs are described and measured. The CNCPS model has been very good at using well defined nutrient analyses to develop model concepts. However those nutrient definitions don't necessarily reflect differences in feed quality or changes in cow production. For the model, nutrient descriptions must adequately describe inputs for predicting cow physiology such as rumen function, ATP creation and use, and nitrogen and carbon for microbial growth. For the real cow, a change in a nutrient should result in a change in health or production. Unfortunately because cows are not usually managed or monitored individually, there is significant noise present in determining the impact of a nutrient in a real dairy herd. This makes model evaluation extremely difficult. For instance, glucose levels are extremely important in a transition dairy cow to prevent ketosis and the associated high economic costs of the disease. But until recently, subclinical ketosis, as defined by blood ketone (and glucose) levels, was largely ignored because cows generally did not show clinical signs and so the cost of the disease was thought to be inconsequential. However, once the associative effects of subclinical ketosis and their costs were estimated ($78/cow; Geishauser et al., 2001), prevention of subclinical ketosis (low blood glucose) through monitoring individual cows is becoming more common now. Using current nutrient descriptions, however, there is no way to predict glucose supply from a given diet with precision and accuracy. Even if we could predict glucose supply to the cow, there are many other health, stress, and management factors that would have a bigger impact than diet on glucose levels in cows at any one point in time. Therefore instead of trying to refine existing nutrients descriptions and analyses, it may be better to look to identifiers of feed quality that impact the production of the cow paying attention to methods of analysis that are precise and accurate.

LITERATURE CITED

Geishauser, T., K. Leslie, D. Kelton, and T. Duffield. 2001. Monitoring for subclinical ketosis in dairy herds. Food Anim. Comp. 23:S65-S71.

National Research Council. 1989. Nutrient Requirements of Dairy Cows. 6th rev. ed., Natl. Acad. Sci., Washington, D.C.

Tylutki, T.P., D.G. Fox, V.M. Durbal, L.O. Tedeschi, J.B. Russell, M.E. Van Amburgh, T.R. Overton, L.E. Chase, and A.N. Pell. 2008. Cornell Net Carbohydrate and Protein System: A model for precision feeding of dairy cattle. Anim. Feed Sci. Technol. 143:174-202.

Van Amburgh, M.E., E.A. Collao-Saenz, R.J. Higgs, D.A. Ross, E.B. Recktenwald, E. Raffrenato, L.E. Chase, T.R. Overton, J.K. Mills, and A. Foskolos. 2015. The Cornell Net Carbohydrate and Protein System: Updates to the model and evaluation of version 6.5. J. Dairy Sci. 98:1-20.