Formulation suggestions for lactating cow diets

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EFFECTIVE diet formulation requires processing information and relationships to achieve a goal. The information is often incomplete or inaccurate. Some relationships are quantitative and can be represented in mathematical models, but others are qualitative and difficult to describe with numbers.

The goal may be to increase production, maintain animal health, enhance fertility, increase efficiency, increase profitability or some combination of these. Which goal is most important varies from farm to farm, for animals or groups within a farm and over time. Philosophies regarding diet formulation vary according to experiences, depth of knowledge, economics, dogma and paradigms that are shaped by conventional wisdom, tradition, trends as well as product marketing.

The complexity of formulation programs varies greatly, but it is our view that complexity is not related to success. Although formulation programs are helpful tools, the overriding determinant of success in nutritional consulting is the competence of the nutritionists, including their understanding of practical nutrition and their ability to communicate effectively.

Oftentimes, we have observed that some inputs and outputs of diet formulation programs receive attention even though they are unimportant, while other inputs and outputs that are critical to success are ignored.

This article will address aspects of diet formulation for lactating cows that we believe are most important for success, as well as those that we think should receive little or no attention.

Diet formulation

Diet formulation begins with selecting a representative cow from the group being offered the ration to calculate nutrient requirements (including maintenance, growth, lactation and loss or repletion of body condition). The cow selected doesn't really exist, but inputs like milk component yield, bodyweight and expected gain or loss in bodyweight are chosen to be representative of the group as a whole. It is important to note that nutrient requirements of individual cows in the group will differ from this "representative" cow, and the extent to which they differ depends on the amount of variation in the group.

Formulation programs in use in the U.S. determine requirements in a similar manner and are generally based on the latest "Nutrient Requirements of Dairy Cattle" publication from the National Research Council (NRC, 2001).

Dry matter intake (DMI) is then usually predicted from milk yield and bodyweight, with an adjustment for decreased DMI in the postpartum period. While equations to predict DMI might vary somewhat across programs, characteristics of the diet known to greatly affect DMI are generally not included — a common deficiency among programs.

Where formulation programs diverge greatly is in how they predict the supply of energy and protein. Ruminal fermentation greatly affects the digestibility of dry matter (DM), especially neutral detergent fiber (NDF), as well as the supply of protein available for absorption in the small intestine.

To determine the rumen undegraded protein (RUP) required, the microbial protein supply to the small intestine is predicted from the diet and subtracted from the calculated protein required for absorption in the small intestine. The requirement for rumen degraded protein (RDP) is estimated to provide adequate protein for microbial growth.

Models differ greatly on how they predict DM digestibility as well as microbial protein and digested RUP supply to the small intestine and RDP supply. Some use empirical predictions and table values, while others include more mechanistic relationships. Most models use equations similar to those of the 2001 NRC to estimate the utilization of energy and protein after absorption. Ingredients are then combined so the nutrient supply meets the requirements of the representative cow. Finally, amounts of ingredients and nutrients are divided by DMI to determine concentrations.

Mechanistic models

Mechanistic models have been developed and have evolved over the last several decades in an attempt to more accurately predict absorbed energy and protein. While several different groups have developed models, the Cornell Net Protein & Carbohydrate System (CNCPS) and its derivatives (CPM, NTS, AMTS) have been dominant for diet formulation in the U.S.

While these programs have greatly contributed to educating students and nutritionists about the complexities of the rumen, it is our view that they have not in-

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creased the accuracy of the nutrient supply needed to meet requirements beyond simpler models. Rather, because of the great complexity of the rumen, the many interactions among feeds, the animal and microbes, as well as a lack of knowledge, lack of accurate data and known faults in model structure, these models likely *reduce* the ability to accurately supply nutrients to meet requirements compared with empirical models.

While models have evolved over time with the additions of amino acid and fatty acid sub-models, the basic limitations and flaws of the original model persist. Furthermore, it is unrealistic to think that these limitations can be overcome anytime soon.

Model flaws and limitations. The basic concept of mechanistic rumen models is that digestion/degradation of organic matter in the rumen is a competition between the rates of digestion and passage. If we knew the *actual* rates of digestion and passage for a specific nutrient fraction (e.g., protein fraction B2) within a feed, and if these rates were constant, then the digestibility of the nutrient fraction could be calculated as the rate of digestion as a percent of the total rate of disappearance (rate of digestion plus rate of passage).

Because rates of digestion vary greatly among specific feed nutrient fractions, it is critical that each feed fraction have reasonably uniform rates of digestion and passage. Then, the digestibility of the feed can be calculated as a weighted average of the individual fractions. While this is appealing conceptually, *its application is problematic* for several reasons described in more detail elsewhere (Allen, 2011).

The most important problems are as follows: Whereas feeds can be fractionated and rates of digestion of fractions can be measured, the rates obtained do not represent actual rates *in vivo* because of differences in particle size (surface area), enzyme activity and pH between measurement conditions and in the rumen of cows. For example, digestion rates are typically measured on ground, dried samples, which are *not* representative of the material consumed by the cow.

Also, accurate passage rates for each nutrient fraction that correspond to rates of digestion are nonexistent. Moreover, interactions among feeds, microbial populations and the animal greatly affect rates of both digestion and passage and make accurate modeling for ruminal digestion impossible.

These problems are intractable and prevent rumen models from *ever* increasing the accuracy of predicting the supply of absorbed nutrients. Therefore, we view the incorporation of mechanistic rumen models into practical diet formulation software as an exercise in futility.

So, why are programs with rumen models so widely used, despite their failure to improve accuracy? We suggest two general reasons:

1. More complicated models are seductive for those who use them. These models provide a competitive marketing edge because of the common perception that precision and complication translate into greater accuracy. Of course, as mentioned earlier, this is rarely the case. Complicated models are often promoted by feed test laboratories because more feed analytes are required, which increases revenue, and by some companies because the models show that their products are needed (even though direct experiments may demonstrate little effect). Complicated models also provide numerous opportunities for presentations and consulting by academics and others.

Complicated models can lead to self-delusion. Humans tend to notice evidence that supports their opinion while ignoring evidence against it. When a model correctly predicts a response to a ration change, the value of the model is reinforced; when the model is incorrect, the error is more likely discounted. Furthermore, a common problem with any complicated model is that the developers and users, over time, will fail to recognize model deficiencies and reject any critical evaluation of alternatives. This phenomenon is called "groupthink" (I.L. Janis, 1971).

If you use a complicated model, we exhort you to keep a scorecard. Some say that the model must be "calibrated" to each farm. So, initially, the model is not accurate, but after tweaking this and that, "Voila, the model is amazing!"

However, please consider that, with an almost infinite number of combinations of inputs, you can get any outcome you want. The question is: What did you learn, and does it reflect reality? Please ask yourself if tweaking all the inputs does anything to enhance productivity or effectiveness.

We believe that mechanistic models can, indeed, improve the ability of some people to formulate diets, but generally, this is because the model stimulates mechanistic thinking, not because it improves accuracy. We strongly promote mechanistic thinking; we just don't think you need a complicated model to do it.

2. The published validation of complicated models is frequently faulty and misleading, thus giving the false impression that the models are accurate. For instance, the predicted versus measured flow of methionine to the small intestine shows remarkable agreement in Figure 5-10 of the 2001 NRC. However, that figure and others like it are extremely misleading and do not depict the actual accuracy of prediction. One problem with Figure 5-10 is that the data set used to validate the equations was the same as the one used to develop them; proper validation, however, requires a different data set.

When we actually formulate diets, we don't use these equations to predict methionine flow in the original database. Another problem is that NRC used the actual DMI measured during the experiments, while DMI is often predicted during diet formulation.

However, the biggest problem with Figure 5-10 and most other validations is that study is included in the validation statistics as a "random study effect." Random study effects are included in statistics because we know that the results of one study will differ from another simply because of measurement techniques, base forages and feeds and cow conditions (for reasons that we really don't know). In any case, the study effect removes most of the variation that we must be able to predict when formulating diets.

Proper statistical validations require that the study effect be zero for new data not used in developing the equations. It is no surprise to us that the ability of the NRC model to predict when a methionine supplement is needed is very poor compared to the accuracy presented in Figure 5-10.

Diet formulation programs provide much more information than is necessary to formulate diets optimally. It is our view that most, if not all, diet formulation programs can be successfully used to formulate diets as long as the nutritionist knows what information is useful and what is not. The success of the nutrition program is much more dependent upon the nutritionist and the interaction and communication between the nutritionist and farm management, as well as personnel who feed, harvest the crops and purchase feeds.

We view diet formulation programs incorporating mechanistic models as overly complicated and unnecessary for successful nutrition programs.

What is important?

Diet formulation programs usually focus on supplying adequate nutrient concentrations of consumed DM but completely ignore two of the most important factors for practical feeding: (1) the effects of the diet on feed and energy intake and (2) the effects of the diet on nutrient partitioning.

Most programs require milk yield, bodyweight and bodyweight change as model inputs, thus determining feed intake and how much energy is partitioned to milk versus body tissues. However, in reality, intake and partitioning cannot be model inputs but, instead, are determined by the cows and the diet they consume. *This is a major limitation of all diet formulation programs* and is not likely to be solved anytime soon because of the biological complexity and lack of quantitative relationships for use in models.

For instance, while we know many of the factors affecting the filling effect of rations — such as the content, digestibility, particle length and fragility of forage NDF — our measures of these factors are crude and provide only relative differences that cannot be used quantitatively. In addition, these factors interact with each other to affect fill. Furthermore, ruminal distention dominates the control of feed intake differently as cows progress through lactation; feed intake is also affected by metabolic and other physiological mechanisms.

The situation is the same for our ability to predict the partitioning of energy between milk and body reserves. We know that energy partitioning is greatly affected by diet as well as many of the other factors involved, but we do not have the ability to quantify the effects of these factors and their interactions on energy partitioning for inclusion in diet formulation programs.

For instance, we know that milk fat depression (MFD) decreases energy output in milk and increases body energy reserves, and we know that MFD is often the result of altered biohydrogenation of long-chain fatty acids by rumen microbes that has several risk factors, including the dietary content of polyunsaturated fatty acids, starch and starch fermentability, among others. However, we cannot even begin to predict these conditions or the extent of MFD accurately with quantitative equations in a computer program.

Although we cannot quantitatively describe all of the important nutritional relationships in a computer program to optimize diets, we do have broad qualitative knowledge that can be used to better formulate diets right now.

Successful application requires a paradigm shift for some nutritionists. Instead of focusing on computer programs, optimal diet formulation requires understanding the variation in feeds and cows and working to reduce it, understanding and evaluating cow responses to diets and letting go of the many factors that just don't matter.

Variation in feeds. Minimizing variation in feeds is imperative to optimize diets, particularly for high-producing cows. Nutrient composition can vary widely in forages and some byproduct feeds, while it is much more consistent in other feeds (e.g., dry corn and high-protein soybean meal). The feed composition table in the 2001 dairy NRC includes data on variation in nutrient composition for feeds and is a good resource.

Each lot of purchased or harvested feed that might be variable should be tested frequently (twice monthly) for, at the least, crude protein (CP) and NDF until the extent of variation is understood. Silages and wet feeds should be tested for DM content at least twice weekly. Variation can be reduced in harvested feeds by considering quality differences and then storing feeds of various qualities separately when possible.

Variation among cows. The production response of lactating cows to diets varies greatly because of differences in their physiological state. In the postpartum period, blood insulin concentration and insulin sensitivity of tissues is low, resulting in mobilization of body reserves, increasing blood non-esterified fatty acid concentrations and suppressing feed intake (Allen and Piantoni, 2013).

As milk yield increases, non-esterified fatty acid export as milk fat and DMI increases, control of feed intake becomes dominated by ruminal distention and low-fill, high-starch rations promote maximum milk. As lactation progresses and milk yield declines, concentrations of glucose and insulin in blood, insulin sensitivity of tissues and body energy reserves increase. These changes in metabolic priority are difficult to accurately include in a computer program, but top-notch nutritionists who understand cows can use the qualitative knowledge to optimize nutrition programs.

Grouping. Because of the wide variation in the physiological state among cows, we recommend three rations as cows progress through lactation: fresh, high and maintenance rations.

The fresh ration should be moderately filling, with about 22-24% forage NDF to maintain adequate rumen fill and buffering and reduce the risk of displaced abomasum. Starch content should be approximately 24-26% to provide the glucose and glucose precursors needed as milk yield increases. Higher ration starch content can be fed if highly fermentable starch sources such as high-moisture corn are limited. Cows should be switched to the high ration after 10 days postpartum if they are healthy and eat aggressively when feed is offered.

As feed intake increases, rumen distention begins to limit DMI, so the high ration should be less filling, containing 17-20% forage NDF, and should contain a greater starch content of 28-32% to drive milk yield. Actual concentrations of forage NDF and starch in the high ration depend on cow responses and space for cows within groups; rations with less fill and higher starch content might result in higher peak milk yield but will also result in faster restoration of body condition and the need to move cows to the maintenance group more quickly.

Once restored to a body condition score (BCS) of about 3.0 on a five-point scale, cows should be fed a maintenance ration to maintain milk yield and minimize additional gain in body condition. The maintenance ration should have less starch (18-22%) and somewhat higher forage NDF content; these should be adjusted by evaluating cows' BCS changes at dry-off. Protein should also vary in these diets.

The fresh ration should contain about 17% CP, with the supplemental protein coming from high-quality proteins that have at least 40% RUP. The protein sources should vary and have complementary amino acid profiles. The high ration should also be about 17% CP, and if the diet has plenty of starch, special RUP sources may provide little benefit. Protein can be reduced to 15-16% CP in the maintenance group. Formulation programs can help determine the types of protein supplements that will be most beneficial, but the user must recognize that they are frequently inaccurate. Lower-protein rations might be fed to the high and maintenance groups by evaluating cow responses.

This grouping strategy will help optimize cow health, production and efficiency of nutrient utilization compared with feeding one ration to all cows in a herd or compared with feeding rations according to milk yield. For additional details, see Allen and Piantoni (2014).

Feed testing. We think the time and money it takes to formulate diets with complicated programs could be better spent on activities that actually help meet the goals in feeding cows. For example, nutritionists could use the extra time to ensure that feeds are tested routinely, that variation in feeds is monitored, feed mixing is accurate and uniform and that cows have access to feed for most of the day.

We recommend more frequent feed testing for fewer nutrients. Variable feeds, including forages, many byproducts and other feeds, should be tested for DM, NDF and CP on a regular basis to assess true variation. Starch should be included in tests for feeds with variable starch content (such as corn, sorghum and small grain silages). We recommend testing forages and byproduct feeds for minerals (macro and micro) to better formulate mineral supplements, but such testing can be less frequent.

It is useful to keep a spreadsheet with these DM, NDF, CP and starch results for silages and other feeds and retest when deviations occur. This will help identify actual changes in composition and trends over time. Testing forages for *in vitro* NDF digestibility may help optimize forage allocation to groups and identify reasons for changes in production when forages are switched. Because it is a biological measure with variation from run to run, it is most useful to have all forages compared at the same time.

Diet formulation. While we recommend testing and quantitatively balancing for only a few nutrients, many qualitative feed characteristics also should be considered when formulating diets. Chief among these are feed characteristics that affect intake and partitioning — something even complicated computer programs are not able to do. The filling effect of a ration is a function of forage NDF, forage digestibility and forage fragility and is a primary consideration for all groups.

Effective NDF should be adequate to form a rumen mat to retain small fibrous particles and increase their digestibility. However, excessive particle length should be avoided because it can reduce feed intake and increase sorting. Starch content and fermentability must be considered. Starch is needed to drive milk yield, but rations with excessive ruminal starch digestion can cause reductions in feed intake, ruminal pH and milk fat yield and can partition more energy to body condition at the expense of milk.

While starch fermentability can be tested in laboratories, we don't think it's necessary for routine diet formulation because it can be estimated reasonably well from inspecting the feeds (e.g., for moisture content, hardness, particle size, etc.).

Mechanistic rumen models were developed primarily to improve the prediction of absorbed protein and, later, amino acids. At this, we think they fail miserably. Some think that success in reducing the CP content of diets while maintaining milk yield can be attributed to mechanistic models. While we think that minimizing nitrogen excretion is an important objective, we have little confidence that any success can be attributed to these models because they cannot predict microbial protein production or RUP accurately, never mind specific amino acid flows to the duodenum.

We think simpler models, in combination with evaluating cow responses, are more likely to be successful in this regard. We test feeds for CP and use this, combined with table values for RUP/RDP, empirical prediction of microbial protein production, knowledge of complementary feeds for the amino acid profile and cow feedback, to formulate diets.

Cow feedback. Evaluation of cow responses is a critical component of successful diet formulation. Responses include milk yield, milk component yield, milk composition (fat, protein and milk urea nitrogen), DMI, BCS, rumen score, fecal consistency and cow behavior (eating aggressiveness, sorting, etc.). Making feed substitutions and monitoring responses can help refine diet formulation, especially when new forages are being offered.

The degree to which rumen fill limits DMI can be evaluated by substituting less-filling non-forage NDF (e.g., soy hulls) for more-filling forage NDF for the high cows. The need for glucose precursors can be evaluated by substituting ground corn for non-forage NDF, while protein can be evaluated by substituting soybean meal for ground corn or treated soybean meal for solvent-extracted soybean meal.

Other important factors. The success of any diet formulation process is determined by the genetics and environment of the cows. Cow comfort and access to quality air, water and feed trump all but the most drastic changes in diet formulation. An evaluation of health, reproduction, lactation curves, BCS and bodyweight records all give important information.

In addition, differences in composition among rations formulated, offered and consumed might be substantial. Observations on the farm are critical to success. Do feeders always correctly estimate the required amounts called for when mixing the total mixed ration (impossible), or do they return excess or get additional feeds? Are the ingredients added to the mixer in the correct order? Is the mixer wagon maintained?

Evaluating rations in the feed bunks is sometimes overlooked: Do the cows have feed most of the day (and especially in the middle of the night, when the managers are sleeping)? Is the ration over-mixed? Does the ration heat in the feed bunk? Do the feed bunks get cleaned? Are silage faces maintained? Are silages stable? These factors are an integral part of a successful diet formulation process.

Conclusion

Diet formulation for lactating cows is a complex process because cows vary in their response to the diets as lactation progresses, because of the great variation in nutrient composition of feeds and because of the complexity of the rumen ecosystem. While complex rumen models have been developed in an attempt to predict changes to the nutrient supply to the cow by ruminal microbes, we believe that they do not improve accuracy and only hinder the process of diet formulation.

Much of the information provided and predicted by these programs does not benefit diet formulation. While most programs can be used to formulate diets, it is beneficial for the nutritionist to understand what information is useful and what should be ignored.

The good, the bad and the ugly in diet formulation. We offer the following based on our assessment of published dairy nutrition research, our observations of successful nutrition programs on farms and our 50-plus collective years of conducting research in dairy nutrition.

The good:

- Understanding the effects of rations on intake, partitioning, production and nutrient requirements;
- Increasing the consistency of rations by reducing variation in feeds;
- Grouping to reduce variation among cows being fed the same ration;
- Using models only as a guide while considering feedback from the cows, and
- Forming a management team, with training and excellent communication among the nutritionist, feeders, crop and feed purchasing personnel and veterinarian.

The bad:

- Wasting time and resources on overly complicated models with flawed logic.

The ugly:

- A lack of understanding the cows' response to diets;
- A lack of objectiveness due to self-delusion and groupthink, and
- Selecting feed products based only on model output, not research or critical evaluation.

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