Feeding Dairy Cows the Best We Know:

It Starts with the Rumen

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Take-Home Message

Feeding the cow starts in the rumen. The rumen response helps explain the benefit of improving forage quality or grain processing for optimum carbohydrate digestibility and the ability to convert that fermentable energy into microbial cells that provide the majority of amino acids to the animal. Providing enough—but not too much—starch improves microbial protein synthesis and guards against erratic feed intakes, whereas excess starch fermentability depresses NDF digestibility and decreases the efficiency of microbial protein synthesis. Maximizing the supply of microbial protein improves the benefit of bypass amino acids from supplements or in the rumen-undegraded protein (RUP) fraction. Because models are imperfect, consideration of the rumen optimizes balancing rumen-degraded protein (RDP) and RUP properly to optimize diet costs, limit undesirable (and often unknown) side effects, and minimize environmental impact from urinary nitrogen excretion relative to milk production.

Introduction

Ruminal efficiency is a double-edged sword. Optimization of ruminal efficiency means implementing practices that should increase efficiency (front edge) while minimizing practices that could decrease efficiency (back edge). Because we don't always have good yardsticks to measure these issues in practice, I recommend relying on controlled research and then having some confidence in your expectation from that research while also testing the yard stick that is available (measured inputs or outputs on farms) when making dietary changes to improve profit or reduce costs. As a researcher, I look for grounded practices that centralize our expectations (including risk of being wrong in our decisions), whereas field nutritionists need to also deal with climate and economic issues that are relevant to their region and current growing year and often have limited controlled research on which to fall back. Even so, even regional differences can and should be considered with respect to physiological and nutritional principles. My goal is to emphasize important fundamental concepts that start in the rumen to have more confidence in your field decisions to feed the dairy cow the best you know.

Rumen Microbes

Often described colloquially as "bugs", we have learned much in the past decade about the rumen microbial community using DNA sequencing tools that have increased in throughput and decreased in cost. Remember the adage: "there are the 20% of people who do 80% of the work (or is it now 10 and 90%?)"? Similarly, there are 10 to 20% of so-called "keystone" bacteria that most effectively break down fiber (and resistant starch is like fiber) in the rumen…doing the most critical work for the entire rumen microbial community. They are key specialists. Obviously, we want to maintain or support those specialist populations because they improve fiber digestibility and support efficient growth of all microbes. There also are those microbes in the community that do important service such as biohydrogenating unsaturated fatty acids that would otherwise be toxic and those that convert urea to ammonia for others. Some of these colonize the rumen wall also help maintain a proper balance with the animal's immune system. On the other edge of the sword, there also are undesirable microbes. For example, a lactate producer might be desired in the silo but not in the rumen. Also, some microbes waste nutrients such as valuable RDP. Some of these microbes can be replaced by more desirable microbes that compete in the same niche.

Several studies are evaluating rumen microbial community members that are associated with desirable and undesirable rumen characteristics that are related to feed efficiency. We have heard a lot about methane in the past decade, and we need to remember that methanogens are on both edges of the sword; they do important service work, but they also probably contribute to inefficient energy usage. An analogy is that we need electricity to run a dairy farm. Much of the electricity is used in very important functions (e.g., to power pumps and cool milk), some electricity is used in general service such as providing light or airflow that is needed some of the time but not all of the time, and some can be wasted (e.g., stray voltage). The point is that methanogens help the keystone microbes do their job, and overly aggressive approaches to inhibit the methane-producing microbes (analogous to stray voltage) carries over to inhibit important keystone populations. Because lactic acid is a stronger acid than the volatile fatty acids, it has been implicated in problematic dietary situations. However, under the right situations, lactic acid production might actually be a benefit so long as it is further metabolized. Finding the "sweet spot" is key to preventing dietary manipulations from doing more harm than good.

Current research has highlighted some microbial populations are strong indicators of feed efficiency. A pen of animals might be fed the same diet, but some cows are more efficient at converting feed into milk than are others. Conversely, other microbes are indicators of worse feed efficiency among individual animals. They might not do anything bad themselves but pattern with undesirable outcomes. Some of these patterns appear random. However, current research is showing less randomness associated with chance and revealing more randomness associated with discovery of previously unknown factors that hopefully lend themselves to dietary manipulation. For example, many studies have shown that yeast and yeast products tend to support desirable populations of microbes (e.g., those that break down fiber), and ionophores do appear to control some of the undesirables (e.g., those that promote subacute rumen acidosis, SARA, or those that waste rumen-degraded protein, RDP). However, a properly balanced diet also provides a proper consortium of all the microbes, as I will discuss; some of the associations with "good" or "bad" microbes might depend on the base diet. Moreover, some research is showing that selective inoculation of calves, particularly during the transition period into weaning, might have lasting effects into their subsequent lactation.

Carbohydrates and Effective Fiber

Neutral detergent fiber (NDF) that stimulates rumination is termed "physically effective" (abbreviated as "pe"), whereas NDF that is not physically effective but reduces risk for SARA is often termed "chemically effective". The peNDF gets a lot of attention, but unfortunately it typically is estimated rather than measured appropriately. The Penn State shaker box separates particles on an as fed basis (those sieve fractions typically are not dried before weighing). Thus, wet forages make up more of the large particles on an as fed basis than on a dry basis. NDF could be measured on whichever screen is used (probably 4 mm and higher) to assess peNDF rather than merely taking the as fed particle distribution and multiplying by the dietary NDF concentration (DM basis). However, my colleagues (Drs. Kononoff, Hall, and White) and I developed a procedure that is being converted into a mobile app; we call this "physically adjusted" NDF (paNDF) as distinguished from peNDF. This app estimates the particle length needed without multiplying the sieve fraction by dietary NDF. When relying on wet forages, we recommend the simple practice of drying sieved fractions with a Koster oven or microwave.

Of course, peNDF and manure sieving still have value in dairy nutrition compared with no information, but paNDF can also provide a different perspective. To explain this paNDF concept, we need to remember that cows need to consume enough particles of adequate length to form a good rumen mat. This mat "consistency" (i.e., firmness) has two edges to the sword. Cows need the mat to be consistent enough to stimulate rumination and to retain smaller fibrous particles; on the other hand, too many coarse particles can depress dry matter intake (DMI). I note here that whole cottonseed helps to firm up the mat about as well as long forage particles. Also, this optimum range (enough but not too much) of coarse particles probably moves up and down different types of diets depending on the amount of starch and perhaps other factors. Generally, the more starch in the diet, the more paNDF (or peNDF) is needed to stimulate rumination for salivation to buffer the fermentation acids. However, more coarse particles also limit the amount of TMR consumed per meal. In contrast, low starch diets can fit into some rations when fibrous byproducts are cheaper and more available. Even though starch is decreased, long particles still need to be adequate to help retain those small byproducts in the rumen. Without a firm mat, small particles slip through the rumen mat and are increased in the feces, limiting feed efficiency and wasting the opportunity to extract all the value out of that byproduct fiber. Moreover, some evidence suggests that even grains can pass more quickly from the rumen and wind up with higher starch in feces.

Dry Matter Intake and Feeding Behavior

We've all heard these types of adages: "when you feed the cow, you first feed the rumen" and the three most important words in dairy nutrition are "dry matter intake". I will condition DMI in that appropriately high DMI starts with forage quality, proper rations, cow comfort, and bunk management. Excessive rumen-degraded starch consumption typically increases propionate production, and resultant propionate metabolism as fuel in the liver (more than is needed for glucose synthesis) can limit DMI especially for those animals that would respond the most. However, high propionate is also a symptom of excessive carbohydrate availability to rumen microbes. Worse yet, energy from fermentable carbohydrate is not only in excess but also is intentionally metabolized to "spill" (intentionally waste) energy that could have been used to grow more microbial cells. The hidden result is that the cow would have lower microbial protein reaching her intestine relative to a computer model's predicted value.

Appropriately high intake of a properly balanced diet provides all the nutrients that microbes need to break down fiber and to grow microbial protein. That is, the three most important words in microbial protein synthesis also are "dry matter intake", assuming it is appropriately high DMI. Conversely, disproportionately high DMI relative to milk production could be from too high or too low intakes of peNDF, as explained above. The question is how do we predict and therefore model a proper balance of nutrients to optimize DMI? Results from synchronizing rumen-degraded starch with RDP have been mixed. When studied in the lab, the benefit of this synchrony is clearly established. However, in cow studies, we see less value because the cow eats multiple meals per day and spreads out the varying degradation rates; she self-synchronizes nutrients available in the rumen (the front edge of the synchrony sword is dull). That said, in controlled research, cows are not in competition with each other, and problem cows and other sources of variation are minimized. When group-fed, though, competition promotes cow sorting in which some cows get too much starch and some get too much forage. Probably the same goes with RDP; that is, more competition probably makes some cows consume excess RDP and some get insufficient RDP. Therefore, I think software that considers synchrony of carbohydrate and RDP decreases the risk associated with sorting and erratic feeding behavior in the field (the back edge might be sharp!).

Several studies now have documented that yeast or yeast extract can (but not always) stimulate cows to consume feed more consistently. That is, the average amount of DM or starch consumed per meal goes down while the average number of meals goes up. A few studies have shown the same kind of behavior with ionophores. A more even feeding pattern lessens the spikes in rumen acidity and increases periods in the feeding cycle when the concentration of growth factors such as RDP are available for microbes. That is, there is more self-synchronization of nutrients. With the more consistent feeding behavior by any single cow, there could be more consistent feeding of multiple cows within a pen. These patterns could result in either a greater milk production because DMI increased or, alternatively, yield the same milk production with slightly less DMI. Either way of improving feed efficiency should dilute fixed maintenance costs by cows and also improve income over feed costs.

Rumen-Degraded Protein and Isoacids

Numerous papers (including my own) have addressed RDP guidelines by dairy cows. Results are inconsistent, but adding RDP to a diet moderately deficient in RDP never has a negative response, whereas adding RDP sometimes has a positive response in microbial protein production or NDF digestibility in the rumen. The most consistent response associated with adequate RDP is its positive association with DMI. Whether the response is only in the rumen (as might be expected based for rumen-degraded protein) or has a post-absorptive role (RDP products absorbed into blood and influencing the brain's satiety center) is not fully clear. However, benefits of having adequate RDP start in the rumen. Moreover, numerous studies swapping soybean meal for some other bypass protein source on an equal protein basis have documented a depressed microbial protein flow (because RDP became deficient) that partially offset the benefit in post-ruminal supply of RUP. Because microbial protein is a well-balanced source of amino acids (perhaps with the exception of threonine) and is cheaper, RDP should not be limited. What constitutes "limiting" depends on several factors, including methods in papers. I think RDP should be 9 to 10%, with maybe some limiting returns in benefit up to 12%. However, the low fuel indicator should go off at 9% and never be lower than 8% of DM.

Why higher RDP? Lab studies have documented that many microbes benefit from preformed amino acids. Nearly all bacteria can use ammonia as their N source and make their own amino acids as would a growing plant. When energy is plentiful (as when rumen-degraded starch is moderate to high in the diet), a preformed supply of amino acids improves their efficiency of growth. An analogy could be like this: if a manager improved the flow of cows to and from a parlor, the parlor efficiency (milk per time) would improve. Preformed amino acids allows more efficient growth (more cells per time). The amino acids most beneficial appear to be phenylalanine followed by the branched chain amino acids and then potentially some others such as methionine. Because specific cellular proteins require specific amino acids, having a steady concentration of needed amino acids inside their cell maximizes the rate of protein synthesis. The aromatic and branched chain amino acids probably are more limiting intracellularly. Because microbial cells are over 50% protein, preformed amino acids in RDP improves the efficiency of microbial cells flowing to the intestine; on the other edge of the sword, less consistent amino acid availability promotes energy spilling and would limit microbial protein reaching the intestine.

Relying on non-protein nitrogen in the diet or blood urea transfer into the rumen (for conversion to ammonia) can save money and be a valuable resource in low protein diets. Grazing beef cattle and sheep have taken advantage of this phenomenon for centuries. However, providing adequate ammonia can increase the need for preformed amino acids and vice versa if the efficiency of microbial growth is increased up to its potential. In lactating dairy cows, ruminal passage rate would be increased dramatically compared with grazing beef cows, and those same microbes move from a dirt road to an autobahn. Models still are limited by (as yet) unexplained mechanisms and limitations in research. Databases lack representation by high producing cows, so even empirical (statistics-based) results have limitations. Hence, we need to go back to rely on what we know.

Using lab approaches, stable isotopes, and meta-analyses, my colleagues (especially Drs. Lee and Moraes) and I have been researching for the past few years whether or not isoacids (the carbon skeletons of branched chain amino acids) can replace RDP for proper bacterial activity. Although not always consistent, the combination of research results and known issues from the microbiology literature suggests an important role for isoacids in dairy diets with moderate RDP. First, we know that isoacids are important precursors either as the carbon skeletons needed to make the branched chain amino acids or else that can be elongated and incorporated into bacterial membranes. These isoacids can benefit all bacteria if the concentration in the rumen is increased below a certain threshold. However, we also have known for decades that certain critically important fiber-degrading keystone bacteria require one or more of these isoacids. If we limit these keystone degraders, then less effective fiber degraders probably trespass into that niche. From the microbiology literature, branched chain amino acids might be feedback indicators for cellular functions, so the corresponding isoacids appear more likely to consistently improve ruminal efficiency of microbial protein synthesis.

In the 1980's a commercial product was developed to provide isoacids to successfully improve milk production albeit with some circumstances when these isoacids might not be needed or some other considerations associated with cost or palatability. Researchers from the 1980's and 1990's reckoned that the concentration in the rumen was sufficient for lactating cows. However, with steadily increasing DMI, the passage rate of rumen contents increases (as does washout of soluble nutrients such as isoacids), so bacterial efficiency and need for growth factors such as isoacids probably also increases accordingly. By analogy, if a manager had decreasing time available to do X functions for the day, that manager would need to streamline his or her ability to improve the efficiency of each of those X functions to get them all done or look for employment elsewhere. If someone partially prepares task needed for X rather than starting from scratch, the preformed information would improve efficiency. Even if isoacids could be derived by microbes from scratch, dietary supplementation appears to improve efficiency of using those isoacids. The second consideration is for isoacids to replace RDP to decrease cost or decrease the environmental impact or possible energy wasted from N excretion into urine.

Our on-going research is establishing the benefit of isoacids to replace a portion of the RDP in the diet. First, we have noted relatively consistent improvements in NDF digestibility in lab-based studies (and we are undergoing research to test these effects in lactating cows). Second, either improved substrate availability should increase the amount or else the efficiency of microbial protein synthesis. Third, a lactation study showed that isoacids improved feed efficiency (energy-corrected milk/DMI). Fourth, our survey of the literature supports a benefit to the branched-chain amino acid for milk production. Consequently, we are continuing to investigate if isoacids substitute for those amino acids more effectively to improve efficiency of milk production or if they can help substitute for RDP and therefore maintain milk production with lower protein diets. So far, results are encouraging.

Final Thoughts

The "best we know" starts with *what we know* and how to glean information to substitute for *what we do not know*. I've tried to explain the importance of feeding the rumen using analogies from applied dairy nutrition and management. For anyone looking at more scientific details, please see my paper in the 2015 Western Canadian Dairy Seminar https://wcds.ualberta.ca/2017/08/22/2015/