Feeding the Rumen to Maximize Milk Components

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Abstract

Current milk prices should cause reflection on methods to improve milk component production with minimal increase in feed costs. Improved milk components in this market still have positive return on investment. The market pressure provides an opportunity for dairy producers and nutritionists to review basic cow and diet management, and how these play into rumen fermentative efficiency. Rumen microbes are central to biohydrogenation induced milk fat depression – both in causing and preventing it. Improving fiber digestibility not only reduces risk to milk fat depression but will increase milk fat synthesis by the mammary gland from acetate and butyrate absorption. General mechanisms and relationships within the rumen are reviewed, as well as the influence of calf management, diet delivery, feeding frequency, and feed shrink on the rumen microbial population.

Introduction

We are all acutely aware of the current milk market challenges imposed on the dairy industry. Increased global production and weak exports from a strong U.S. dollar paired with gains in domestic supply have put strong downward pressure on farm-gate milk prices. With feed responsible for an excess of 50% of dairy production costs, now is a good time to reflect on the basics of ruminant nutrition as well as recent research to refine nutrient formulation in order to lend value on the farm. Previously at this conference, St-Pierre and Weiss (2012) demonstrated the clear value of producing additional pounds of milk protein or fat by dilution of feed cost beyond maintenance. Other solids in milk are correlated with milk volume and contribute negligible value to monthly milk value. Water in the milk does not contribute to farm productivity and necessitates discussion on improvement in milk component yield over growing volume. Increasing milk volume without gains in components likely has a negative return on nutrient investment through much of 2018, whereas gains in milk fat or protein still pay dividends. One can easily calculate the value of component production between 2 herds typical of what we may see in this region (Table 1), with improved profitability in the higher component herd milking lesser volume (Table 2) (USDA, 2018).

A shift in consumer perspective towards reduced demonization of saturated fat dairy products has boosted butterfat value, while dairy products based in protein (cheese and nonfat dry milk) are in abundance and abnormally hamper current milk protein component value. As such, my current focus is in how to improve milk fat yield rather than milk protein via the rumen. Many factors contribute to overall farm profitability in today's down market, including calf rearing efficacy, replacement

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heifer development, reproductive efficiency, forage quality, feed ingredient value (nutrient deliverables for purchase price), feed storage shrink, and consistency of total mixed ration (**TMR**) delivered to the cow. Just as all roads "lead to Rome", many of these considerations converge in the rumen and influence the microbial efficiency with which the dairy cow takes feed and converts it to volatile fatty acids (**VFA**) and metabolizable protein (**MP**) that serve as precursors for milk component biosynthesis.

Rumen Contribution to Milk Fat Synthesis

Milk fat within the mammary gland stems from 2 energy sources: long chain fatty acids (**LCFA**) that are provided from dietary intake of LCFA or mobilization of adipose stores of LCFA and also from rumen-derived acetate and butyrate. In the udder, LCFA and de novo synthesized short and medium chain FA are attached to glycerol to form milk triglycerides (Palmquist, 2006). While butyrate is considered important for gut health and rumen epithelia (Baldwin, 1999; Guilloteau et al., 2010; Laarman et al., 2013), it plays a smaller role in de novo fatty acid synthesis – estimated around 8% of VFA (Palmquist, 2006). This leaves the bulk of the responsibility for milk fat synthesis to acetate which is traditionally associated with fiber digestion in the rumen (Murphy et al., 1982) and recently demonstrated to directly increase milk fat synthesis (Urritia and Harvatine, 2017). In diets with low forage, variability in VFA composition can account for a large proportion of variation in milk composition (Sutton, 1989). Thus, while there are diverse pathways for substrate fermentation and conversion in the rumen, it is logical that improved fiber digestibility is a substantial target to increase milk fat yield.

What makes ruminants unique is their capacity to consume human indigestible cellulose- and hemicellulose-based forages and through rumen microbial symbiosis generate VFA as a primary energy source for the ruminant. The rumen is essentially a giant fermentation vat where the nutrients consumed by the cow are broken down at varying rates influenced by intake levels, chewing patterns, rumen buffering, microbial populations, and chemical structures. Unsaturated fatty acids have toxicity towards rumen microbes and highly degradable carbohydrates can lead to rapid fermentation and quickly increase acidity in the rumen. We have learned that some unsaturated fatty acids are more toxic to microbes than others. There is a hierarchy of microbes who biohydrogenate unsaturated fatty acids to whatever saturation level removes the risk of toxicity for that particular species (Jenkins et al., 2008). As fatty acids are biohydrogenated down particular pathways, the process can bottleneck if biohydrogenation specialist bacteria become inhibited by rumen conditions or if supply of unsaturated fatty acids exceeds these species's capacity to biohydogenate (Jenkins et al., 2008). Specific biohydrogenation intermediates have been identified as key indicators of milk fat depression, with trans-10, cis-12 C18:2 conjugated linoleic acid (**CLA**) known as a potent inhibitor of milk fat synthesis (Bauman and Griinari, 2003; Urrutia and Harvatine, 2017). Biohydrogenation-induced milk fat depression (**MFD**) should be considered separately from opportunities to increase milk fat synthesis in generally low-producing cows. To better understand the role of the rumen in supporting milk fat production, we must understand a bit about the diversity of the rumen microbiome.

Diversity Within the Rumen

The rumen hosts a vast consortium of microbial species in 3 main categories:

bacteria, protozoa, and fungi. Bacteria can be further classified by their function (fiber, starch, protein, and sugar digesters). Most microbes have a competitive niche to fill that justifies their survival, either specializing in a specific substrate or generalizing to permit flexibility between substrates (Hungate, 1966; Dehority, 2003). Culturing rumen microbes is fairly difficult – such that we can put a man on the moon, but 50 years later, we still have limited knowledge of the roles of many species within a cow's stomach. Cultured bacterial species to date represent less than 7% of the genetic sequences recovered in the rumen, indicating the potential for several thousand uncharacterized species in the rumen (Kim et al., 2011). What we do know is that **diet** is the primary determinant of rumen microbial populations more than host species, with 30 top microbial groups represented in 90% of species across the globe (Henderson et al., 2015).

Generally speaking, cellulolytic bacteria are gram-positive and either mediate attachment to fiber or adhere purely based on local cation concentration (Dehority, 2003). Bacteria transition among fiber particles, first inoculating and then multiplying enzymatic degradation of fiber within the rumen. The gap between first inoculation and full degradation is commonly called "lag phase" and is modeled by *in vitro* lab digestibility assays. Some *Butyrivibrio* species have also been associated with fiber digestion (Dehority, 2003; Hackmann and Firkins, 2015a), as well as credited a key role in the final stage of biohydrogenation (Jenkins et al., 2008). Most cellulolytics are involved in biohydrogenation to some extent. Starch-digesting bacteria might be best exemplified by the infamous *Streptococcus bovis* (Russell, 2002) known for rapid fermentation in unadjusted cattle that leads to a downward spiral in clinical acidosis. Typically, starch digesters ferment readily fermentable substrates more rapidly at a lower return of growth for substrate digested (i.e., they are less efficient). Starch-fermenting species fit in the balance of an adapted rumen on high starch inclusions for both beef and dairy cattle, but rapid transition away from forage towards a high starch diet shifts the rumen microbiome (Petri et al., 2013). Protein degraders in the rumen are a significant contribution to amino acid breakdown, and the rumen is also full of generalists with agile metabolisms capable of involvement in a buffet of substrates (Russell, 2002).

Rumen protozoa are commonly associated with consumption of bacteria, leading to degradation and deamination, contributing to inefficiencies in microbial utilization of ruminal degradable protein (**RDP**) and the waste of amino acids and peptides (Newbold et al., 2015). Often forgotten is protozoal contribution to rumen buffering and fiber digestibility (Newbold et al., 2015) by rapid consumption of starch and subsequent internal sequestration of it as glycogen (Denton et al., 2015), in essence pulling it from circulation and preventing rapid declines in rumen pH by opportunistic starch digesters, such as *S. bovis*. Protozoa are sensitive to pH (Dehority, 2005) and migrate the rumen in search of nutrients (Dehority, 2003); *in vitro* work has shown protozoa align cell division in response to feeding patterns (Sylvester et al., 2009).

Fungi are the most likely to be an underappreciated species in the rumen microbiome, mostly because they have been least studied. Rumen fungi have complex cellulolytic machinery akin to protozoa, and once embedded in lignified fiber, they can fracture it apart (Russell, 2002). Fungal digestive action on fiber that is resistant to degradation opens up surface area for cellulolytic bacteria, but it is a thankless task; bacteria release antifungal secretions (Russell, 2002). Fungi have

been implicated in biohydrogenation within the rumen, but their rate is such that they are likely a minor player (Nam and Garnsworthy, 2007).

Nutrient Contribution of Rumen Microbes

With the advent of bypass protein feed ingredients and rumen-protected amino acids (**AA**) inspired by limiting AA supplementation success of non-ruminant feeding operations, less attention has been paid to the value of microbial protein to the ruminant. Yet, commercial models in the industry still attribute microbial protein contribution to MP to be approximately 45 to 55% in a typical lactating diet (Sok et al., 2017). Rumen bacteria and protozoa have differential amino acid concentrations, with protozoa possessing 45% more lysine and 17% more isoleucine (Sok et al., 2017). However, protozoal contribution to total microbial biomass is in doubt and certainly does not approach early estimates of 50% (Fessenden, 2016; Wenner et al., 2017). Particle-associated bacteria also appear to differ in AA composition compared with fluid-associated bacteria, with 7% more leucine, 8% more phenylalanine, and 6% less threonine (Sok et al., 2017). Dry matter intake drives microbial protein production because increased passage rates force microbes to grow faster and greater microbial growth rates increase microbial protein outflow to the omasum (Dijkstra et al., 1998; Firkins et al., 2007). Small increases in microbial outflow in a lactating dairy cow can have significant effects on downstream AA supply (Table 3). For example, based on an estimated microbial N daily flow of 325 g (Hristov, 2007), an increase of only 3% microbial N flow to the duodenum would increase lysine flow by 5 g/day – an equivalent savings of $0.08/cow/day in synthetic lysine supplementation.

Rumen microbes also contribute fatty acids to the ruminant. Bacteria range from 5 to 15% fatty acids on a DM basis (Vlaeminck et al., 2006a), and fatty acids are primarily associated with microbial membranes. Vlaeminck et al. (2006b) demonstrated large shifts in fatty acid composition of rumen bacteria when fed decreasing quantity of forage in the diet, but the primary 2 fatty acids, palmitic and stearic, remained fairly constant. Stearic acid is the primary fatty acid in bacteria, while protozoa more heavily favor palmitic (Harfoot and Hazlewood, 1997). Because microbial lipid composition is largely influenced by dietary conditions and cellulolytics have characteristic odd-chain fatty acids compared to non-cellulolytic bacteria, microbial-specific fatty acids that are incorporated into milk triglycerides can be an effective indicator of rumen fiber digesting activity with a detailed milk fatty acid analysis (Fievez et al., 2012). Ruminal contributions of both AA and fatty acids to ruminant absorption can be significant and are typically attained at much smaller cost than a purchased supplement. Thus, it is apparent that maximizing rumen microbial growth adds value to a dairy producer's bottom line.

Microbial Response to pH

Protozoa are most notoriously sensitive to rumen pH; protozoal viability declined sharply in vitro when culture pH was allowed to drop below 5.6 (Dehority, 2005). Rumen cellulolytics can also be generalized as pH sensitive, both decreased in cell quantities by low pH (Petri et al., 2013) and also decreased in cellulolytic activity with pH dropping below optimum levels for attachment, cellulase function, and cell growth (Russell, 2002). Declining pH has lesser effects on cellulolytic cell numbers but decreases fiber digestibility until pH returns to more desirable levels (Russell, 2002), where fiber digestibility has been shown to compensate for periods of low pH (Calsamiglia et al., 2002; Cerrato-Sanchez et al., 2008; Wenner et al.,

2017). If pH remains too low, then digestibility will suffer (Calsamiglia et al., 2002; Cerrato-Sanchez et al., 2008) as microbial populations are shifted (Fuentes et al., 2009).

Diet plays a role in pH decline and microbial shifts due to introduction of rapidly fermentable carbohydrates and/or lack of effective fiber. Lowering pH independent of diet will shift microbial fermentation activity (Calsamiglia et al., 2009; Fuentes et al., 2009), but recovery of pH to optimal cellulolytic conditions will encourage compensatory fermentation (Wenner et al., 2017) (Figure 1). Animal intake behavior and ruminal pH must be interrelated as cows with reversed rumen contents will revert to previous populations just weeks after a complete ruminal exchange (Weimer et al., 2010), and the effect of SARA-induction can be temporary if the insult is removed (Plazier et al., 2017). As rumen pH declines by any variety of dietary imbalances on the farm, cellulolytic species are inhibited in the process. These cellulolytic species inhibited by low pH or inconsistent pH are the same cellulolytic species implicated in complete biohydrogenation, and their inhibition limits ruminal biohydrogenation capability (Fievez et al., 2012). Loss of function can bottleneck biohydrogenation intermediates and increase the likelihood of omasal flow for undesirable unsaturated fatty acids, such as trans-10, cis-12 CLA (Jenkins et al, 2008). Microbial growth will also be limited by lower rumen pH and outflow of microbial MP could also be lowered.

Unfavorable Biohydrogenation Risk Factors

Trans-10, cis-12 linoleic acid is known to be a strong inhibitor of milk fat synthesis in the mammary gland and just 10 g/day passing to the small intestine triggered milk fat depression of 23% (Urritia and Harvatine, 2017). There is typically no shortage of unsaturated fatty acids in corn- and corn silage-based diets (Baldin et al., 2018), but unsaturated fatty acid load in the rumen (**RUFAL**) merely provides the opportunity for MFD. Additional risk factors make cows more susceptible to incomplete biohydrogenation whether it be slug feeding depressing rumen pH, rapid starch fermentation, imbalance of carbohydrate and N pools and degradation rates, transition cow disruptions, or reduced intake of effective neutral detergent fiber (**NDF**). Knowing the fatty acid composition of feedstuffs can improve your understanding of how much unsaturated fatty acid risk you've provided in your diet. Prevention of rapid starch fermentation or slug feeding responsible for sharp declines in pH helps protect cellulolytics responsible for supporting biohydrogenation. Animals that are adapted to more highly fermentable diets may be more likely to absorb VFA from the rumen more efficiently and decrease acid load of the rumen (Bannink et al., 2008). Lastly, feed additives that disturb the rumen ecosystem may provide immediate gains in milk volume under most conditions but also leave less margin for error in a feeding program. Care should be taken to limit cumulative risk for fat depression by keeping an eye on the combination of rumen pH, unsaturated fatty acid load, and destabilization of the rumen ecosystem.

Improving Fiber Digestibility Through Management

Fiber digestibility is not only important in limiting MFD risk, but improved fiber digestibility translates well to greater milk fat concentration and improved overall diet fermentability provides an additional energy boost that can help improve milk fat yield. Improving diet fermentability provides additional energy for milk synthesis, including VFA for *de novo* fatty acid synthesis. Rather than debate

which pricey feed additives should be used to boost milk production, my preference is to focus on feed management issues that contribute to ruminal stability and maximized digestibility rather than pricey alternatives that can have situational efficacy. Primary areas of opportunity to evaluate at this time include calf growth/heifer development, feed ingredient quality, TMR delivery, shrink, and feed additives. All of these can support a healthy, consistent rumen.

Calves and heifers

Too many farms still operate on the "no news is good news" plan when it comes to raising calves, but these animals are the investment in your operation's future 2 years down the road. The high producing cows you want when the milk prices turn around are being born in your barn today, and now is a perfect time to re-evaluate your calf program to capitalize on any management opportunities. While there is debate on how much milk replacer to provide calves, there is certainly a lot of data to support the concept that pre-weaning gain translates to first lactation milk (Van Amburgh, 2017) and faster maturing heifers with a more economical age at first calving (St-Pierre, 2002). Increased stress during weaning can erase gain so attention should be paid to transitioning calves and limiting lost time on feed. Calves generally learn more quickly if housed together pre-weaning and are more likely to return to feed post-weaning if previously raised in a larger social group (De Paula Veira et al., 2010; Gaillard et al., 2014) or led by example from older calves (De Paula Veira et al., 2012). Getting calves onto starter early is critical for rumen development (Laarman et al., 2012) and exposure to some long-stemmed forage also adds value (Khan et al., 2011). Early rumen microbial populations are diverse in calves and likely susceptible to volatility but develop into a core microbiome by adulthood (Jami et al., 2013). Learned intake patterns may also translate to feeding behavior in mature cows (Miller-Cushon amd DeVroes, 2016). Care in the development of calves improves rumen function and leads to easy-transitioning, early-maturing heifers with strong lifetime potential.

Feed ingredient quality

Given the high degree of variability in the market for some feed ingredients, there is money to be saved or wasted on ingredient sampling. If you're spending money on feed sampling, you surely want to spend enough money to get details that you have a high degree of confidence in – starting with the quality of samples taken at the farm in the first place. True feed variability (St-Pierre and Weiss, 2015) and the value in paying for detailed analysis can best be illustrated by looking at blood meal. Valued for high bypass protein values (CP can exceed 100%) and high metabolizable lysine and histidine, blood meal prices have ranged from $600 to $1200/ton in the past calendar year and consistently vary $300/ton across suppliers within any one week. Despite nearly a decade of knowing how variable the market can be (Boucher et al., 2011), we often ignore the importance of ingredient testing. Figure 2 illustrates the distribution of a group of blood meals analyzed in 2017. In panel A, the CP is seen to be fairly consistent and lysine as percent of CP would be similar if represented alongside. However, when subjected to the Ross assay for unavailable N (Ross, 2013), a discrepancy arises where the distribution of blood begins to widen first for RUP (%CP basis, panel B) and then for dRUP (%DM basis, panel C). If charted for unavailable N (%DM basis, panel D), we can see the actual quantity of protein purchased that is expected to be excreted from the ruminant. Values for unavailable N demonstrate product value excreted and wasted for the producer, averaging 45% and at $800/ton would be a

loss of $360/ton to the end user! I would much rather see poor rumen bypass numbers with some product available to rumen microbes than to have cows excreting expensive protein ingredients in the feed.

The quality of feed in a diet also relates to the source of N provided to rumen microbes. For a long time, we've known that cellulolytics respond favorably to rumen ammonia (NH_3) (Russell, 2002; Dehority, 2003) and so urea supplementation is used as a safety factor to ensure that daily fluctuations in rumen NH_3 concentration never leave microbes starved for N with access to degradable starch. Microbes do not adhere to a sharing policy; if they do not allocate energy into growth, they are more likely to burn the energy in wasteful cycles (Hackmann and Firkins, 2015b). Cellulolytic activity has been increased in vitro where non-NH_3 RDP sources are provided in replacement of some NH_3, indicating cellulolytics respond favorably to amino acids or peptides in addition to NH_3 (Gorosito et al., 1985; Atasoglu et al., 2001; Hackmann and Firkins, 2015b). Lowering dietary CP from urea and substituting in higher quality RDP sources should lead to improved fiber digestibility, more rapid growth, and greater stability of the cellulolytic niche in the rumen. Prioritizing RDP and rumen degradable starch over bypass will ensure that you are providing microbes all they need to thrive in the rumen.

Attention to TMR delivery details

A dairy producer may not currently have a lot of cash flow to invest in feed ingredients, but they still have time to invest in the accuracy and efficacy of ration delivery to the herd. Farm walk-throughs must note timing of TMR preparation, thoroughness of delivery to the bunk, weighbacks, frequency of TMR push-ups, degree of TMR sorting, and overcrowding at the bunk. All of these factors relate directly to DMI and rumen pH in a group of cows, affecting fiber and overall TMR digestibility and influencing the milk fat production of that group. Whether or not cows are fed to a slick bunk can also influence rumen pH and diet fermentability. When feeding a ration that simulated ignoring heavy rain events, McBeth et al. (2013) demonstrated that constant ingredient weights (underformulated forage DM) had little effect on milk production or intake over the course of a few weeks when cows were fed *ad libitum*. Collings et al. (2011) demonstrated that cows on a restricted feed diet shifted intake patterns towards slug feeding more so than cows penned at a 200% stocking density measured in bunk space; this slug feeding would negatively impact rumen pH and instigate SARA in a proportion of the pen. Limit fed cows are much more susceptible to large fluctuations in DM within the TMR and feed shortages that lead to time without feed, representing opportunity for rumen bugs to be deficient in either readily degradable starch or ruminal ammonia concentrations.

Some research would indicate an advantage to delivering feed at an alternative time to when cows return from milking (DeVries and Von Keyserlingk, 2005; King et al., 2016) or more than once per day (DeVries et al., 2005; Bannink et al., 2016). What is most important is availability of TMR to cows throughout the day with the least exposure to sorting. Sova et al. (2013) reported that every 2% increase in sorting against longer particles represented a 2.2 lb decrease in milk production, and an improved milk fat yield attributed to stabilized rumen pH with increased fiber intake (DeVries et al., 2008). Unevenness in dietary intake or forage content can lead to larger decreases in pH post-feeding (Allen, 1997), partially due to decreased salivary secretion (Beauchemin et al., 2008). Increasing feeding frequency or push-up of feed to stimulate meal frequency also has the advantage of increasing passage rate in the

rumen and thereby increasing microbial growth efficiency (Le Liboux and Peyraud, 1999) for gains in microbial MP flow to the duodenum. The greatest gains to feed push up may be in the first couple hours post-feeding (Armstrong et al., 2008) when TMR can quickly be eaten out of reach for less dominant cows.

Feed shrink's real but unknown cost

As an industry, feed shrink is nebulous and often avoided because it is difficult to estimate. There is limited research for book values and feed tracking data is painstaking to sort through to determine cost savings estimates. Nevertheless, feed shrink has real cost and with tight margin between feed costs and milk production, now is a good time to explore strategies to decrease shrink loss starting with the most expensive ingredients, either by volume or cost per ton. For example, if a ration costs $6.00/cow/day and shrink is reduced by just 2%, that equates to a savings of $0.12/cow/day. It's probably worth taking a look at reducing your shrink before you cut feed additives that may be promoting milk component production. Tracking shrink becomes an issue of scale usage. Diet delivery weights are typically easy to estimate, but without weighbacks to know TMR intake, it is difficult to know how much TMR is left unfed and essentially wasted. Feeding a pen of cows to 3% weighback is much easier if the weights are tracked and a visual reference is established for the feeder; otherwise, you are just pretending to feed to a target DMI and hoping to get lucky often.

Fine particles in mixes are susceptible to loss by the wind, especially in loose storage, and shrink can be increased by 8 to 20% if wind exceeds 15 mph (Harner et al., 2011). Fine particles are also commonly the most expensive. Historical weather for 2018 indicates wind has exceeded 20 mph every week this year. Exposure to rain can promote spoilage, even in commodity sheds built facing away from typical weather directions (Standaert et al., 1997; Harner et al., 2011). Fine particles, primarily starch and fat, are lost to rodents and birds. A recent paper (Carlson et al., 2018) estimated worst case scenarios of 100 birds/cow could reduce TMR energy concentration by 5%. You would have to be a regular Annie Oakley to continuously reduce pest depredation of TMR and ingredient storage across the farm, but a regimented pest control protocol can prevent populations from getting out of hand. Poor forage packing and covering can increase loss by spoilage and increased linear feed rates beyond 12 cm/day can decrease DM loss by 10% (Ruppel et al., 1995). It is generally better to remove spoilage than to try to feed your way through it; remember, you are trying to provide consistency in the rumen. All of this shrink can contribute to a variation in ration delivered compared to what is formulated, ultimately at the expense of rumen microbes for which you balanced the diet or at a loss of valuable rumen bypass fat or protein expected to deliver nutrients to the cow.

Feed additives and rumen fermentation

My approach to rations is fairly simplistic; I prefer to focus on high quality feed ingredients at best value purchases rather than a plethora of trendy feed additives. This especially includes the value of digestible forages that provide effective NDF to induce rumination, salivation, and a resilient rumen mat. The physical effectiveness of fiber can be influenced by the degradability of both NDF and starch in a given diet (White et al., 2017). In this paper, I want to avoid recommendations on feed additives but would rather focus giving 2 examples of how feed additives can interact to influence the rumen microbial population. A quick look will reveal the complexity of the rumen environment and how small changes can have large downstream effects.

Methionine analogs have been commercially available for ruminant diets for several decades. While they come in different forms with varying data on rumen bioavailability (Graulet et al., 2005; Nofstger et al., 2005; Fowler et al., 2015), it is becoming clear that they can have a stimulatory effect on cellulolytic activity (Martin et al., 2013; Fowler et al., 2015) that prevents milk fat depression in acidosis challenge diets (Baldin et al., 2018). It is interesting to note that cellulolytic bacterial numbers do not change (Martin et al., 2013), but their activity appears to increase with supplementation (Fowler et al., 2015). Metabolic activity is positively associated with biohydrogenation activity by cellulolytics (i.e., more biohydrogenation with growth) and it is likely the stimulatory effect of a methionine analog on cellulolytics that helps to limit risk of high producing dairy cows to MFD (Baldin et al., 2015). Further, supplementation with methionine analogs appears to improve microbial N flow (Fowler et al., 2015; Lee et al., 2015). If you think that you have milk fat on the table and want to pursue changes to the diet beyond management considerations, methionine in the rumen to stimulate fiber digestion might be a good place to look.

Mineral sources can also have complex interactions in the rumen. Copper, specifically, can be inhibitory to cellulolytics in the rumen (Martinez and Church, 1970). Recently, mineral source was found to have an effect on fiber digestibility *in vivo*, with greater effect in a forage fiber diet than a byproduct fiber diet (Faulkner and Weiss, 2017). Mineral sources can also affect microbial populations downstream in hindgut fermentation (Faulkner et al., 2017), potentially changing fecal excretion of bacteria that could be implicated in hoof infections plaguing the dairy industy (Klitgaard et al., 2014; Faulkner et al., 2017). Magnesium source was also recently shown to interact with monensin in lactating dairy cows on NDF digestibility (Tebbe et al., 2018), possibly because of the countering stimulatory effects of available magnesium on NDF digestibility versus monensin's activity against gram-positive cellulolytics. We still understand very little about the interactive effects of minerals within the rumen on microbial activity, and it is best to remember for now that choices may have consequences.

Summary

The current milk market is challenging but provides us the motivation to clean up inefficiencies on the farm for cost savings. Milk fat production still provides value to the farm and can be boosted with the following strategies: 1) limiting risk for induced milk fat depression via biohydrogenation intermediates, and 2) improving fiber digestibility in the rumen. The rumen is a complex place with many interactions between microbes, the diet, and cow feeding behavior. While many feed additives promise improved milk fat production, proper diet management and TMR delivery will promote DMI and ruminal stability from weaned calves through multiparous high cows. Management practices can have a high return on investment during a time when producers would like to keep feed costs low. Proper TMR delivery, continual access to unsorted TMR, and diets balanced for N responses of cellulolytic microbes afford producers the opportunity to capitalize on greater stability in rumen pH, passage rate, and fermentable carbohydrate fractions. Attention to detail is practically free and has more value now than ever.

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Table 1. Two sample herds with varying component production.

	Dairy 1	Dairy 2
Cows	200	200
Milk (lb/day)	90	85
Fat (%)	3.6	3.9
Protein (%)	2.9	3.1
Other Solids (%)	5.7	5.7

Table 2. Value of milk from two sample herds with varying milk and component yields.[1]

	Dairy 1		Dairy 2	
	2017	2018	2017	2018
Fat ($/cow)	$8.20	$7.94	$8.39	$8.12
Protein ($/cow)	$5.69	$4.33	$5.74	$4.37
Other Solids ($/cow)	$1.28	$0.41	$1.21	$0.39
Total Value ($/cow)	$15.17	$12.68	$15.34	$12.88
Herd Value ($/day)	$3,033.90	$2,536.20	$3,068.50	$2,576.69

[1]Prices taken from FMMO 33 for February, 2018 (NMPF, 2018; USDA, 2018).

Table 3. Contribution of microbial N to metabolizable protein amino acids (AA) in a typical dairy cow.

Amino Acid	Microbial AA (g AA/100 g true protein)[1]	Microbial AA Flow (g/day)[2]		
		Decreased 3%	Average	Increased 3%
Ala	7.4	120.1	123.9	127.6
Arg	5.3	86.0	88.7	91.4
Asp	13.4	217.6	224.3	231.0
Cys	2.2	35.7	36.8	37.9
Glu	15.0	243.5	251.1	258.6
Gly	6.2	100.7	103.8	106.9
His	2.1	34.1	35.1	36.2
Ile	7.0	113.6	117.2	120.7
Leu	9.2	149.4	154.0	158.6
Lys	9.4	152.6	157.3	162.1
Met	2.6	42.2	43.5	44.8
Phe	6.4	103.9	107.1	110.3
Pro	4.3	69.8	72.0	74.1
Ser	5.4	87.7	90.4	93.1
Thr	6.3	102.3	105.4	108.6
Trp	1.4	22.7	23.4	24.1
Tyr	6.1	99.0	102.1	105.2
Val	6.9	112.0	115.5	119.0

[1]Composite microbial AA taken from Sok et al. (2017, Table 4).

[2]Average microbial AA flow based on Hristov (2007) at 325 g/day of microbial N.

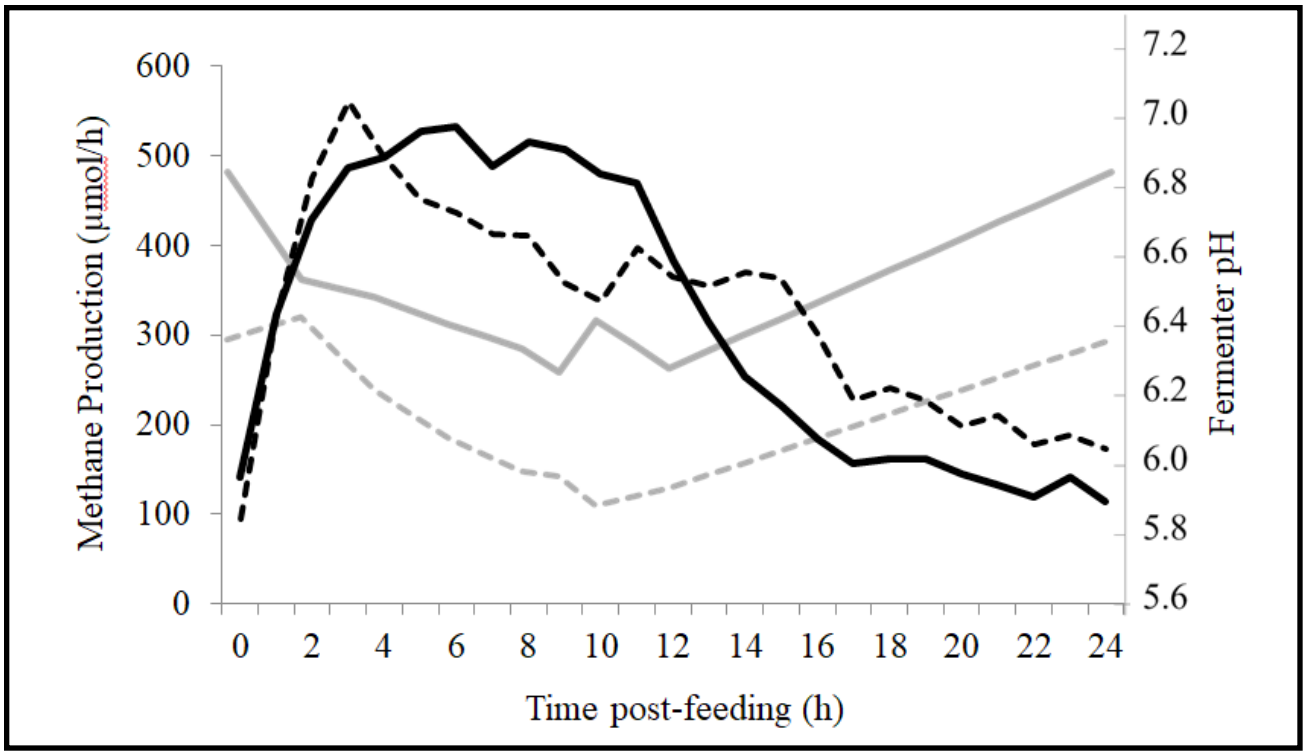

Figure 1. The effect of continuous culture fermenter pH on fermentation activity as quantified by methanogenesis on the same diet (adapted from Wenner et al., 2017; gray lines = pH, black lines = methane, dotted lines = low pH, and solid lines - control). The recovery of pH enables fermentation to compensate in later hours post-feeding.

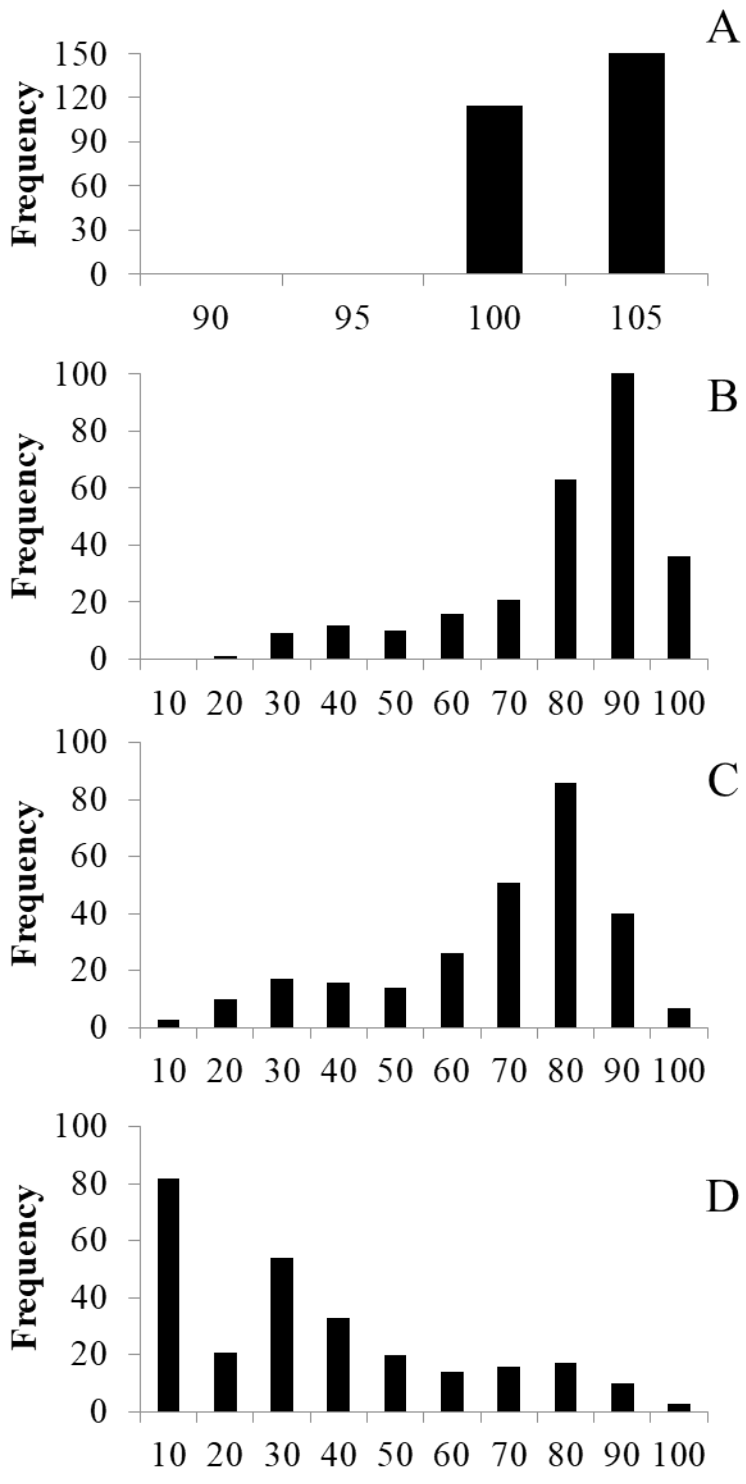

Figure 2. Relative distribution of a composited dataset of 2017 blood meal samples (n = 270). Panel A represents frequency of CP (%DM). Panel B represents RUP (%CP). Panel C represents digestible RUP (%DM). Panel D represents unavailable (%DM) (Ross, 2013). Courtesy of both Cumberland Valley Analytical Services and Dairyland Laboratories, Inc.