Making Milk Protein: The Single Most Important Ingredient is EVERYTHING

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Summary

The manner in which lactating dairy cows react to additional protein in the diet is certainly at least partly dependent on the amino acid (**AA**) proportions in that protein. The commonly held model follows the "uneven barrel staves" analogy of one clearly most limiting AA in the metabolizable protein (**MP**). In fact, this model is clearly an oversimplification. Microbial protein production in the rumen responds to AA balance in the rumen degraded protein and does not always follow the simple single limiting AA model. Within the cow, the biological drive to produce milk protein is separable from the requirement for the most limiting AA needed to sustain that drive. This protein secretion drive is dependent on energy, endocrine, and even non-limiting AA facets of feeding. The presence of nearly co-limiting AA, variance among diets, and variation among cows, makes interpretation of experimental data based only on the single limiting AA model a bad idea. Since even well designed experiments do not, and maybe cannot, include all necessary treatment combinations, other possible reasons for milk protein yield responses should be considered unless they are eliminated by the experimental design.

Introduction

This talk is a product of the American Dairy Science Associations 27th Discover Conference (https://www.adsa.org/Meetings/DiscoverConference.aspx) which was the second conference in that series that focused on AA in dairy cattle feeding. There were many worthwhile topics covered in that conference by expert speakers, but many of the talks may have been heard through this filter: that dairy cow milk protein yield responses are explained by the ability to meet the required delivery of the most limiting essential AA in the MP flow. This model is shown in Figure 1. This model has been applied successfully in monogastric meat animals and in experimental rodent models. By providing the most limiting AA (methionine in Figure 1, typical of chickens fed corn-soy diets) the dietary protein can be lowered. Thus, the methionine stave is lengthened while the others are shortened. This allows optimal rate of gain and protein production efficiency by feeding less crude protein (**CP**), but with a better biological value. After dealing with the most limiting AA, the concept can next be extended to a second limiting AA (lysine in Figure 1), etc. An important implication of this model is that the animal will not respond to addition of any secondary limiting AA unless the first limiting AA is dealt with first. Also if 2 AA are exactly equally co-limiting, the animal can only respond to both but neither fed alone. I think this model is useful and important, but I think assuming it explains all responses is a bad idea if it excludes knowing other possible explanations or even other experimental scenarios to test. I was

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asked to summarize the Discover conference for a group in Australia, and that talk led to this invitation. While I did work in AA and proteins early in my career, and somewhat thereafter, in this paper, I draw heavily on the talks presented at this Discover conference by Jeff Firkins, Mark Hannigan and Alex Hristov. They are not co-authors of this paper, and any opinions expressed or mistakes are on me, but much of what is written here was based on my interpretation of what they presented.

Protein and Energy Feeding

Any separation between protein and energy in ruminant feeding is a tenuous separation at best. Energy characteristics of the diet drive microbial protein yield in a tightly coupled process. Part of this linkage is shown in Figure 2.Without deriving energy from fermentable carbohydrates, microbes cannot reproduce. They must reproduce in order to provide a daily output of microbial protein to the small intestine, an important part of the MP for the cow. But Figure 2 should not be interpreted only as energy driving MP yield. If microbial production is limited by some deficiency of the quantity, or quality, of the rumen degradable protein (**RDP**), then carbohydrate fermentation can suffer as the rumen microbial population fails to maintain itself. This reduction in carbohydrate disappearance reduces volatile fatty acid absorption for the host cow and can limit carbohydrate disappearance in the rumen. The latter may enhance fill and limit intake. So the 2 processes are completely interdependent in the rumen. As we shall see, they are interdependent in the host animal metabolism as well.

Energy characteristics of the diet effect response to dietary protein in other ways as well. Changing dietary energy source can increase or decrease intake, which then changes intake of protein at any fixed protein concentration in the diet. Experiments with cows are almost always with ad libitum intake, so this effect can never be ignored. As intake increases, rate of passage increases, and this increases the proportion of dietary protein that is rumen undegraded if the degradation rate stays the same. Energy intake and nature of dietary energy also affects milk protein yield and drive to produce milk protein, which will be partly discussed later. The flip side of this is that increasing dietary protein concentration can influence energy nutrition of the cow. Increased dietary protein concentration may increase intake which affects energy balance and also further increases AA intake.

Microbial Protein

Microbial protein makes up about half of the MP available to the lactating cow. It is relatively constant in its AA make up. Based on the proportions of AA in this protein, it looks like rumen bacteria is a good match for milk protein, at least in methionine and lysine (Figure 3). It is similarly a pretty good match in histidine, which has about the same concentration as methionine in both milk and rumen bacteria. However, the reader must be aware that this is only true if the efficiency of converting methionine to milk protein is exactly the same as for lysine and other AA. Not shown in Figure 3 is the histidine content of milk and bacteria. These concentrations in milk are similar to methionine, although His in bacteria may be slightly lower (Volden and Harstad, 1998). Histidine in feeds ranges from 1.7 to 3.2% of CP.

Because the AA pattern of microbes differs from that in the feed, rumen undegraded protein (**RUP**), and is fairly constant and of good quality, maximizing microbial growth is important. Figure 4 shows that microbial population growth rate can respond to differences in AA. In this in vitro experiment, microbial growth was clearly stimulated by adding all

20 AA compared to only using ammonia. This shows that the AA content of the RDP is important. What is more interesting is that removing leucine and valine from this mix of AA reduces microbial growth. That would suggest that one or both of these is limiting for this population if we want to apply the barrel to a mixed population of microbes. However, if we now remove the third branched chain AA, isoleucine, we restore most of the lost growth! And even more interesting is the same thing happens with the 2 aromatic AA, tyrosine and phenylalanine. Removing tyrosine reduced growth and then additionally removing phenylalanine restored it. These are examples of an imbalance or antagonism, and is likely due to competition among microbial strains, but it definitely does not fit the concept of a single limiting AA. Also, note that this relates to the ideal composition of the AA content of the RDP, not the RUP. Granted these are extreme changes, the RDP will never be totally devoid of any AA as is done in these in vitro experiments. Still, it shows the potential influence of AA in the RDP, and these AA are not methionine, lysine, and histidine, which are commonly the ones that are thought to be limiting in RUP.

Efficiency and Co-Limiting Amino Acids

The efficiency with which an AA is converted to the same AA in milk protein cannot be a biological constant. Amino acids are subject to an obligatory waste.This is dependent on absorption, but if we consider only MP which by definition is absorbed, there is almost certainly some minimal catabolism of AA post-absorptively which cannot be avoided. It is likely that as the absolute requirement is approached, this catabolism may increase. Even if this is not true in an individual cow, it will almost certainly look this way in a group of cows. What is of most consequence is that once we exceed the requirement, then we induce inefficiency (Figure 5). Therefore, anytime the efficiency of use of an AA is calculated from a study, we must consider where we are in the supplementation range (Figure 6). If a second limiting AA is closely co-limiting, adding the first will result in reduced efficiency of this first limiting AA.

Figure 7 is a summary I did quite a while ago when the main supplements for AA where methionine is alone or supplemented with lysine. Therefore, studies were done as either methionine supplemented or both, but not lysine without methionine. Note there is a small response in protein concentration to supplemental methionine alone, and this small response was significant; therefore, it must have been pretty consistent across studies. The response to both methionine and lysine is clearly larger. Does this mean methionine is consistently first limiting and lysine is very close? This would mean that even small amounts of added methionine cross over to lysine becoming first limiting. This is the only logical interpretation under the barrel model, but is it correct?

Although methionine and lysine have received the most attention, it is clear that histidine is also important. Figure 8 shows a response fo histidine alone, with not additional statistical response to additional methionine or lysine on top. There may be some indication of a response with methionine added. According to the barrel model, this means histidine is first limiting, and maybe methionine is second limiting and lysine is not important. However, this study did not test the effects of either methionine or lysine alone. By the barrel model, we assume the cows would not have responded, but we do not know this for sure from the data.

Figure 9 shows the response to histidine, methionine and lysine alone and separately. Is there a small response to each of the AA that

then sums up? If each is exactly co-limiting, there should be no response to any of them alone. Maybe some cows are first limiting in methionine, others in histidine and still others in lysine. If they are very closely co-limiting in the diet, that kind of cow-to-cow variation would not be surprising. The strategy in this and many other more recent AA studies is to add AA as a replacement for dietary protein. This study, which is a very well designed study with already many treatments and controls, does not answer the question of what would have happened if these AA were added to the high MP diet. The barrel model would suggest we would not get an increase as long as the high MP was high enough, but we do not know that from these data.

Figure 10 diagrams a problem with studies where a high protein diet is compared to a low protein diet with one or more added AA. These kind of studies should really be run as a factorial if they want to prove that the AA addition substitutes for the added protein. Just comparing a high protein diet to a low protein diet plus AA and seeing no difference proves very little. At least a low protein diet should be included (as in the study in Figure 9). But even then, if we want to say the added AA allowed us to lower protein with no loss in production, a fourth diet high in protein with the same AA should be tested. In other words, we want to know if there is an interaction (non-parallel lines) that show the added protein removes the AA response (and vice versa) or if there is simply a response to both protein and AA. An example of 2 studies which actually applied this type of factorial is shown in Figure 11. Neither study follows the barrel hypothesis showing that adding AA lowers the protein required for maximum production, actually both show a positive response to added methionine on the higher protein diets. Granted the response to methionine on the low protein diets was negative, which is certainly not the typical response, but the point is many studies never measure the interaction and the evidence for the interaction (which would occur under the barrel model) is simply lacking.

If Not the Barrel, What Else?

Molecular biologists like to give nicknames to molecules that regulate cell behavior. One of these is a protein called mTOR. When it is phosphorylated, it is activated. When it is activated, it increases milk protein synthesis. Figure 12 shows that when mammary cells are incubated in vitro with either insulin or essential AA, then mTOR is activated. The effect seems additive. Let us compare that to what we know added protein and insulin do to a live cow as shown in Figure 13. Here we see that adding both insulin and infusing casein into the cow each increase milk protein synthesis independently. Note that if the basal diet was limiting milk protein yield by starving the mammary gland of AA, it is difficult to explain the insulin response. What is most interesting in these data is there is synergy (shown by the significant interaction) so that together insulin and casein really increase milk protein synthesis more than can be explained by adding their effects. Presumable, insulin preps the mammary gland to make more milk protein (likely at least partly due to mTOR), and at the same time, the added casein amplifies this mTOR effect while providing any needed added AA to actually make the protein. What is perhaps most interesting is that while a mixture of essential AA quadruples mTOR, the effect is reduced by omitting AA like leucine, arginine, and isoleucine (Figure 14). All this suggests that poor patterns of AA may not just limit milk protein production by depriving it of needed AA in the protein assembly process, but that the balance of AA, including one not 'limiting', can be part of the stimulatory messaging that promotes more milk protein secretion.

The mTOR story is intriguing. The complete biology of this almost certainly includes other mechanisms that can explain responses "outside the barrel". It is important to keep our minds open about what causes responses of increased milk protein yield in cows. Many data sets that may "fit" the barrel model do not really firmly prove it and should be understood accordingly. A summary of the interacting factors discussed in this paper are shown in Figure 15.

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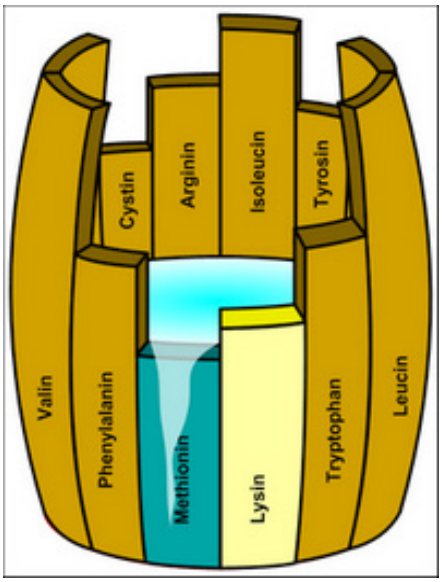

Figure 1. Classic description of amino acid balance. Amino acid levels (represented by stave length) is expressed as fraction of the requirement, not in absolute concentration in the diet.

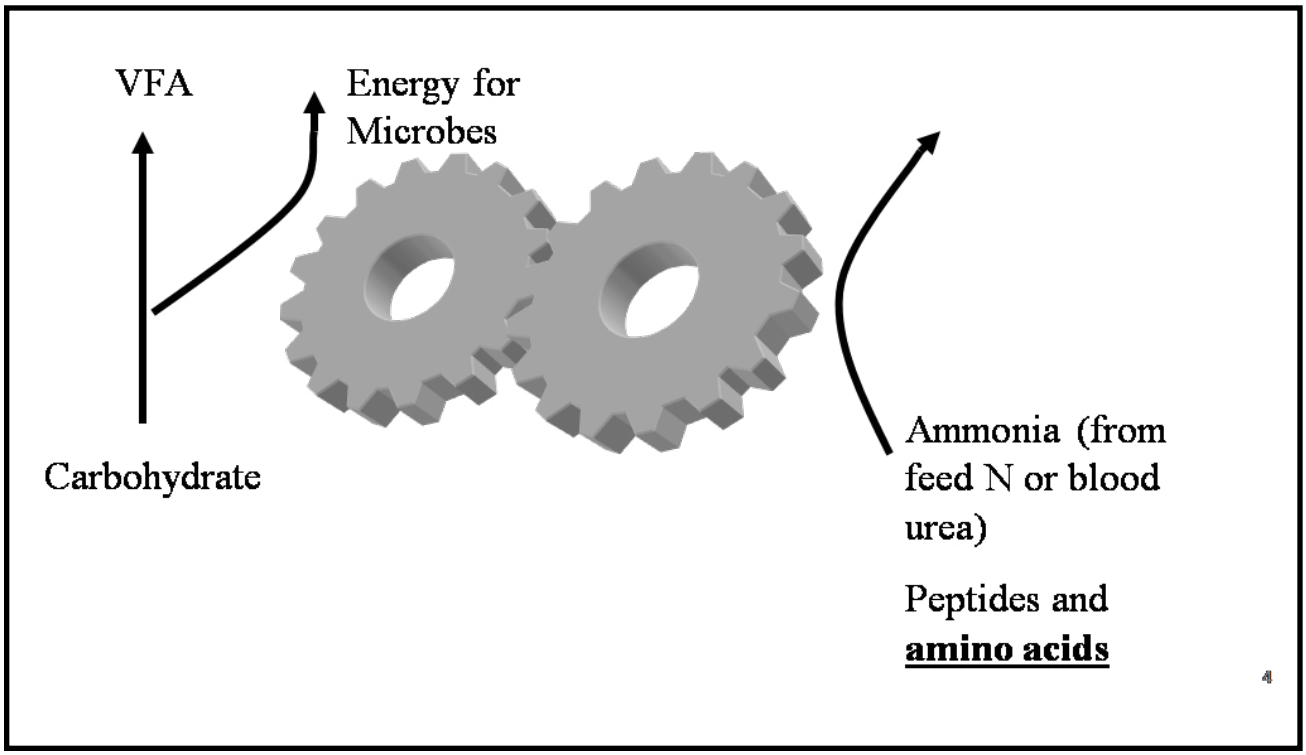

Figure 2. Microbial energy, mostly derived from fermentation of carbohydrate, drives microbial reproduction which is microbial protein yield. Microbial reproduction can also be limited by the amount or nature of the rumen degraded protein (**RDP**) in the diet. If the microbial population replacement is limited by the dietary RDP, energy fermentation, production of volatile fatty acids for the host cow, and degradation of dietary carbohydrate is reduced as well (**VFA** = volatile fatty acids).

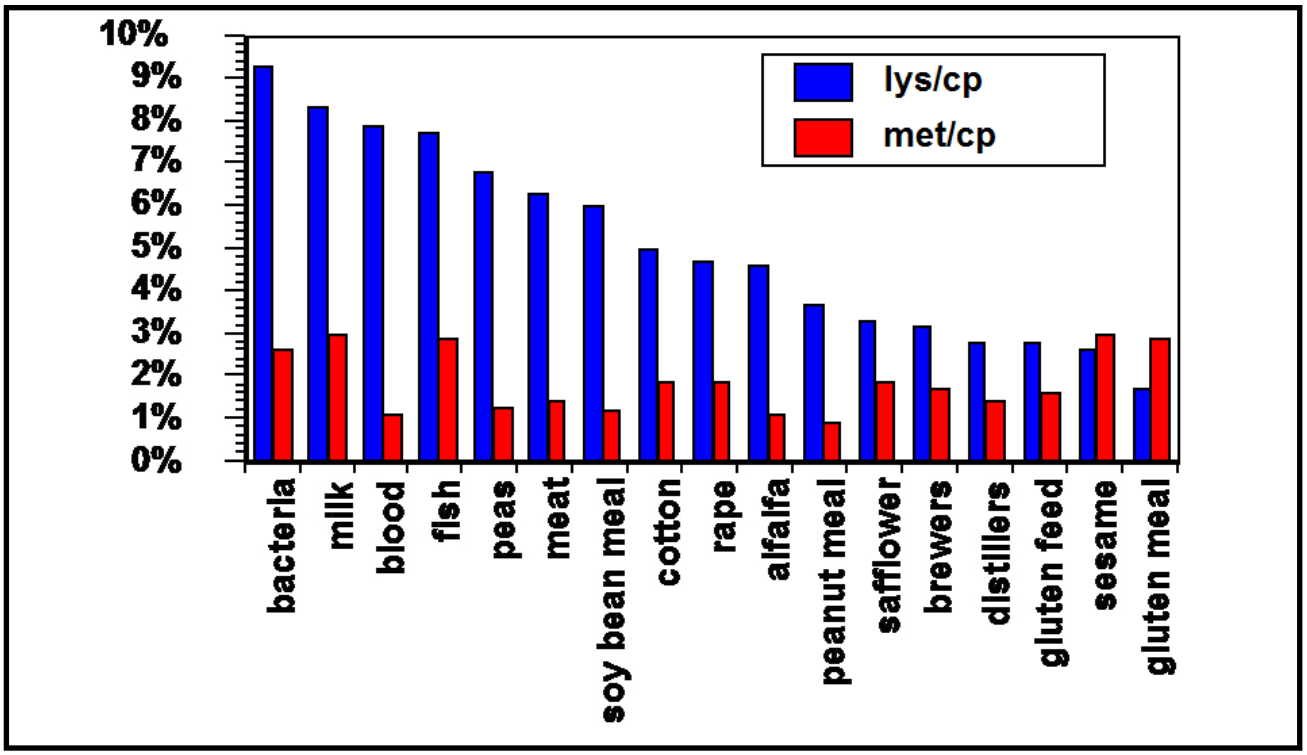

Figure 3. Content of methionine (**met**) and lysine (**lys**) in milk, rumen bacteria, and various feed sources. If lysine and methionine are used with identical efficiency to make milk protein, then rumen bacteria are a pretty good source for milk protein , but with methionine more limiting than lysine. There is no reason to assume the efficiency of utilization is the same as pathways of catabolism are quite separate.

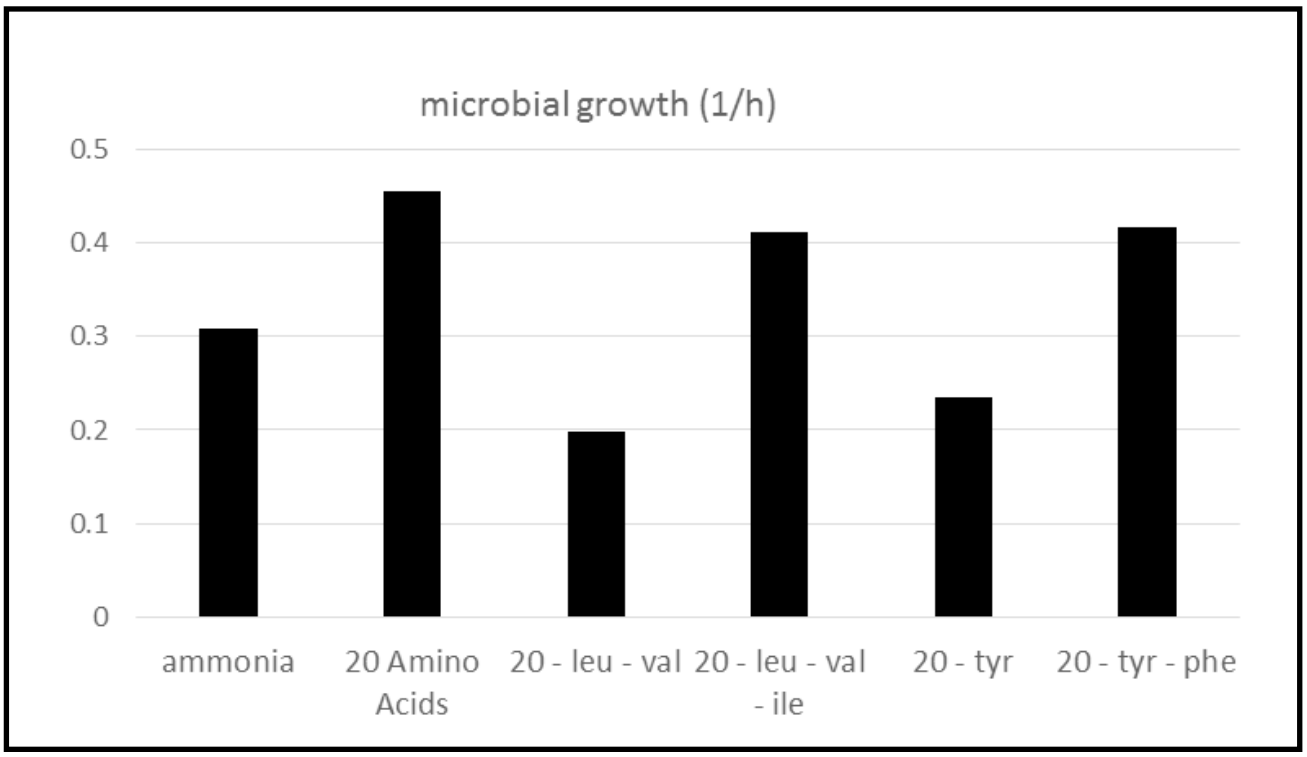

Figure 4. Response of a mixed rumen microbial population to sequential subtraction of amino acids from the media. (Kajikawa et al., 2005)

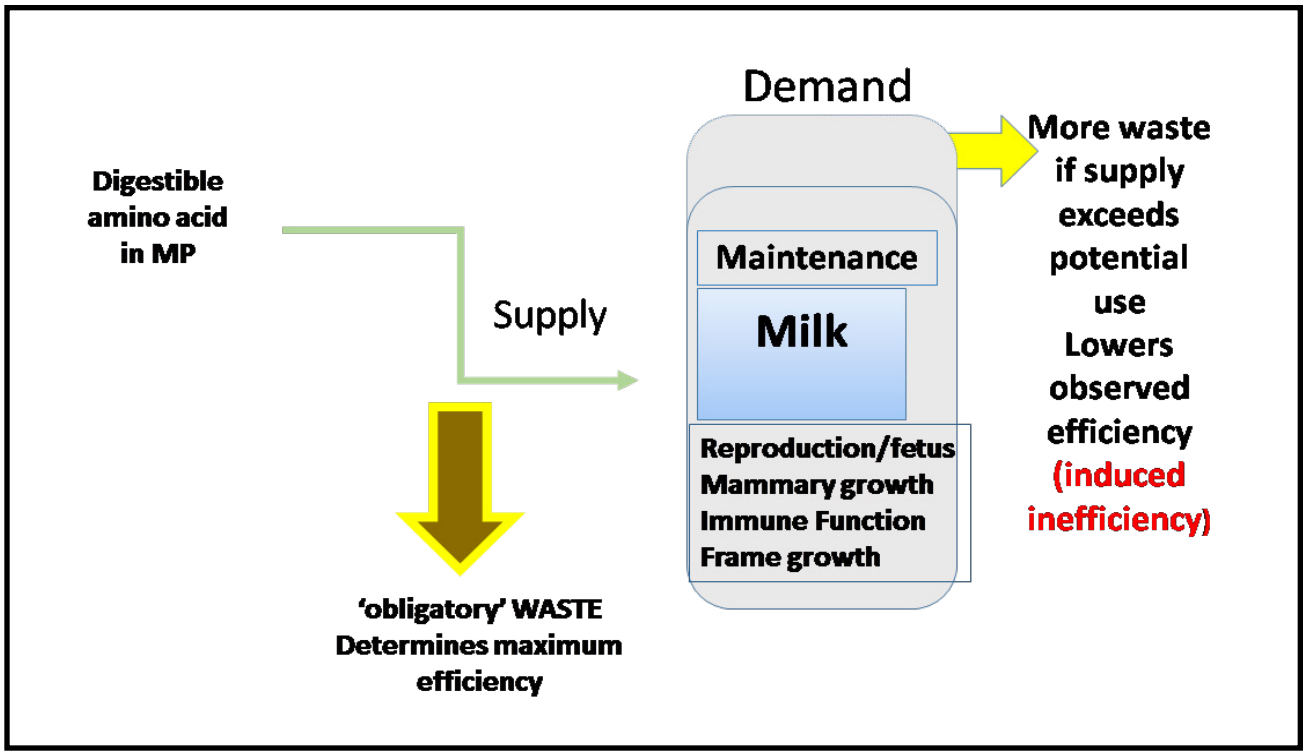

Figure 5. Amino acids are subject to obligatory and induced inefficiency. If amino acid supply is elevated above the potential milk secretion rate, inneficiancy is induced. Likewise if milk yield potential is reduced by some other cause, amino acid inefficiency of conversion to milk protein will also be induced (**MP** = metabolizable protein).

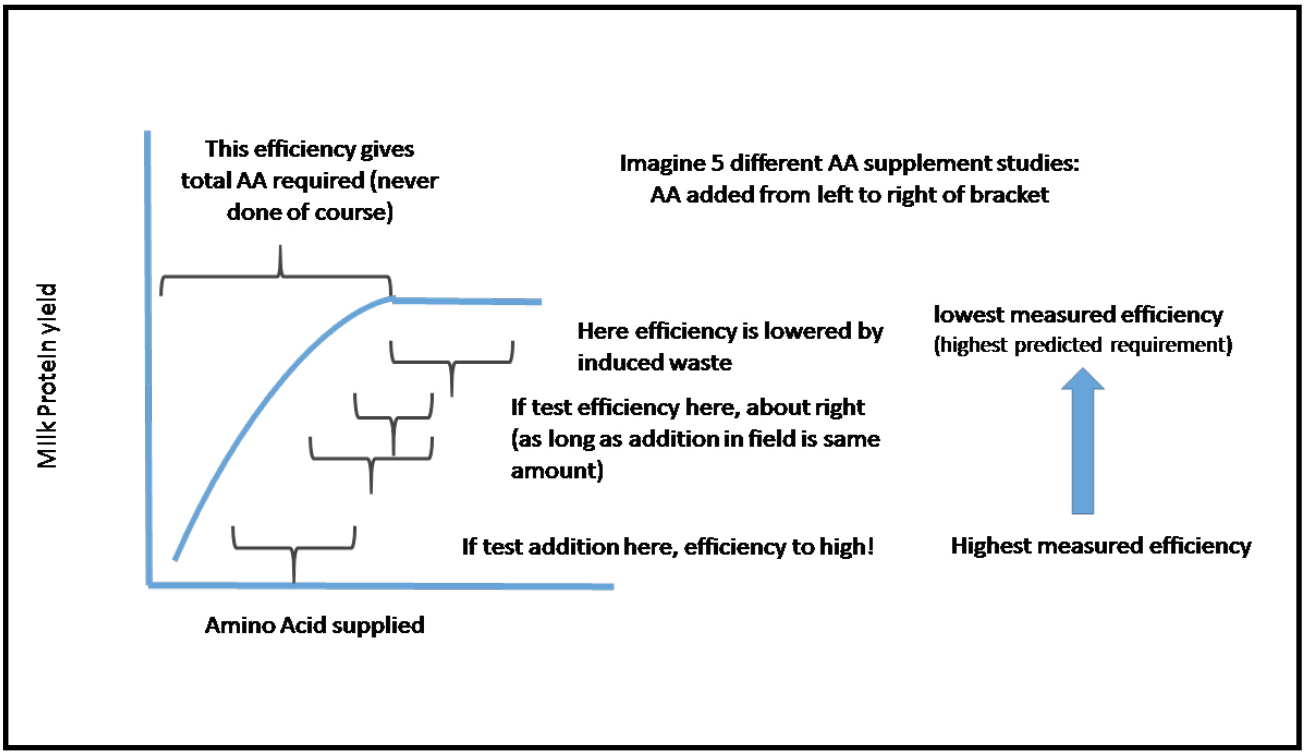

Figure 6. The efficiency with which an amino acid or total protein is used is dependent on the range over which it is fed and the overall maximal potential for milk yield (**AA** = amino acids).

	n	DMI	MYIE	PYIE	PPER	FYIE	FPER
		kg/d		g/d	%	g/d	%
Control	34	22.4	34.5	1033	2.99	1201	3.57
Methionine	60	22.3	34.3	1045	3.04	1214	3.61
SEM		.7	1.6	49	.04	60	.15
*P*value		.65	.28	.04	<.0001	.20	.03

	n	DMI	MYIE	PYIE	PPER	FYIE	FPER
		kg/d		g/d	%	g/d	%
Control	31	23.1	31.8	969	3.08	1116	3.56
Met + Lys	71	23.1	32.3	1011	3.16	1118	3.52
SEM		.8	1.5	41	.03	37	.08
*P*value		.99	.07	<.0001	<.0001	.87	.18

Figure 7. Response to only supplemental methionine or methionine plus lysine, for intake, milk yield (**MYIE**), protein yield (**PYIE**) and concentration (**PPER**), and fat yield (**FYIE**) and concentration (**FPER**). For a more recent review of different methionine supplement methods, see Zanton et al., 2014.

	basal	His	His Met	His Lys	His Met Lys
Milk (kg/day)	22.9*	23.6	23.7	24.2	23.7
Protein (g/day)	695*	721	728	717	729

*P < 0.05

Figure 8. Response to histidine (**His**), or histidine with added methionine (**Met**) and lysine (**Lys**). Note this makes a good case for His as the first limiting amino acid, with maybe methionine being second. But nowhere do we measure the effect of methionine and/or lysine alone (Vanhatlo et al., 1999).

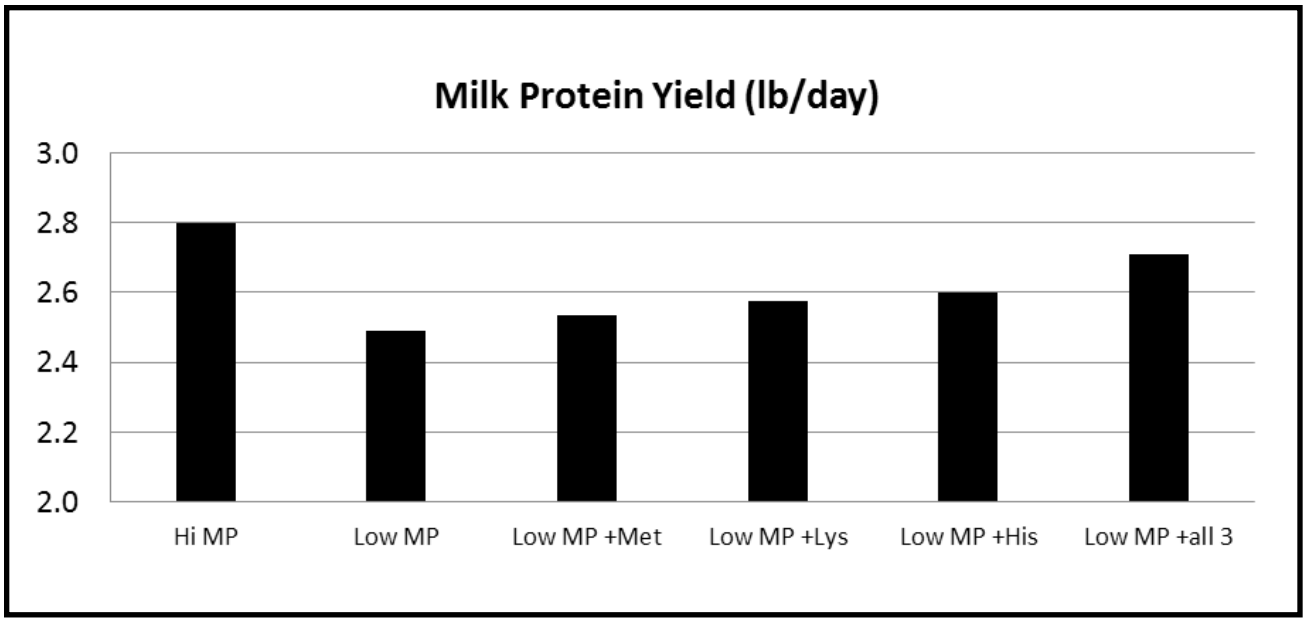

Figure 9. Response to histidine (**His**), methionine (**Met**), and lysine (**Lys**) separately and combined. This study tests each amino acid separately and only gets a significant response to the three combined. This study also has a low and high metabolizable protein diet to serve as negative and positive control. Note there is no test of added amino acids to the high MP diet (Giallongo et al., 2016) (**MP** = metabolizable protein).

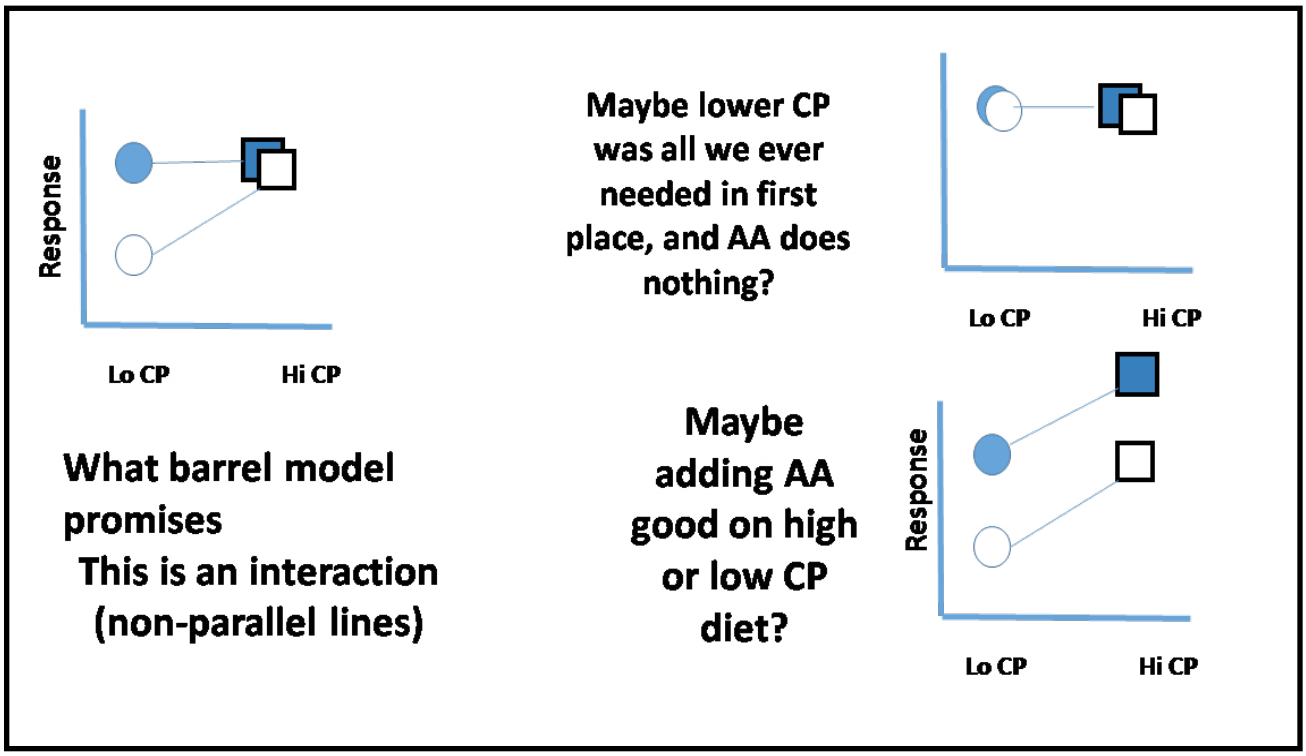

Figure 10. Open squares mean no amino acid (**AA**) added, closed means amino acid added. Studies often include the closed circle (low protein plus amino acid) and the open square (high protein with no amino acids). To really prove the barrel model can be used to safely lower dietary protein, the graph should look like the upper left response. The upper right response says any diet is ok, and low protein without amino acid is probably the cheapest diet to feed. The lower right figure says animals respond to both more protein and added amino acids.

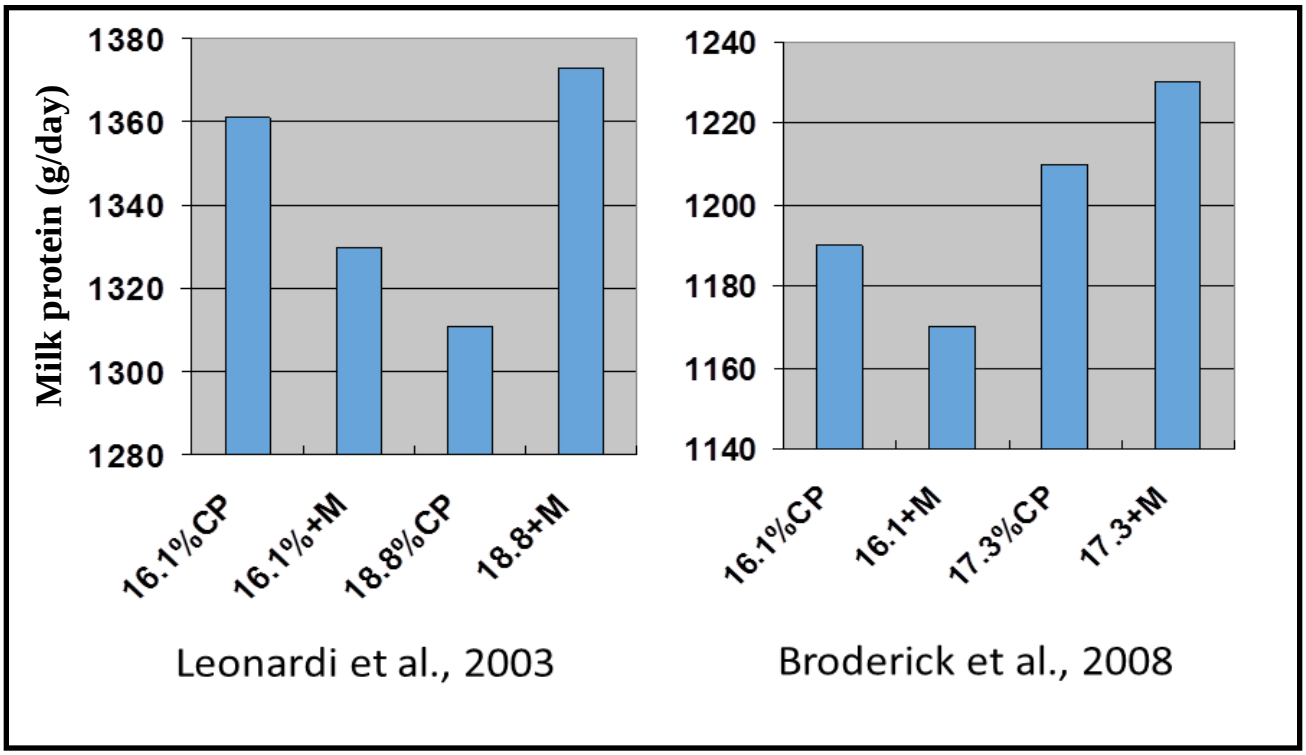

Figure 11. Studies that did factorial treatments of protein and amino acids. These studies actually only showed a response to methionine (**M**) on the high protein diets.

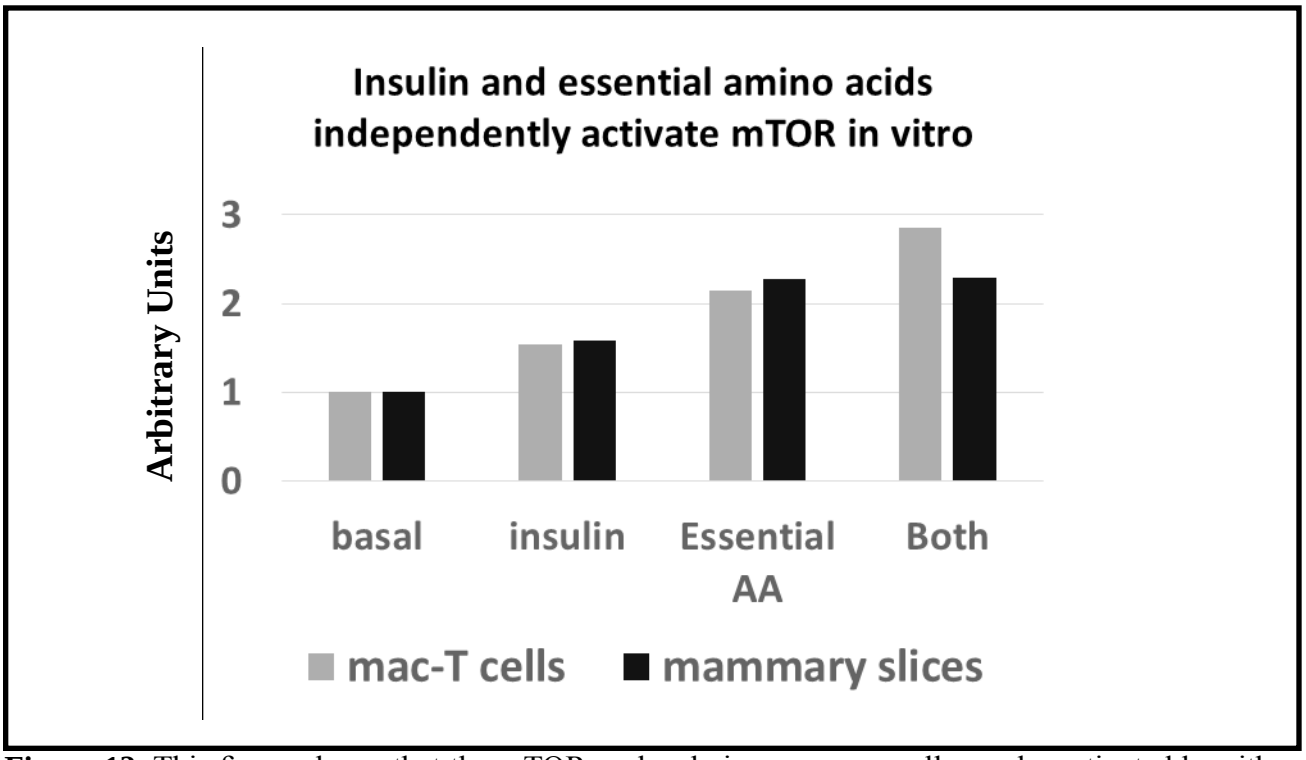

Figure 12. This figure shows that the mTOR molecule in mammary cells can be activated by either insulin or a mixture of essential amino acids (**AA**). Once activated (by phosphorylation), the mTOR protein should signal the mammary cells to make more protein (but protein synthesis not measured here) (Appuhamy et al., 2011).

	Control	Insulin	Casein	Both	P < 0.05
Insulin, ng/ml	1.5	6.3	1.6	7.3	insulin (I)
Milk, kg/day	26.3	27.0	28.6	30.5	casein (C)
Protein, kg/day	0.81	0.84	0.89	1.04	C, I, C*I

Figure 13. Insulin or abomasal casein increase milk protein secretion separately, but when combined, the effect is more than additive. This could be due to increased mTOR signaling by both and also increased supply of amino acids for protein building blocks (Griinari et al., 1997).

In vitro, direct effect of essential amino acid removal on mTOR

Note: Essential AA with biggest effects are not thought of as limiting

Treatment	mTOR
	Fold of +EAA
+EAA	1.00
−Lys	1.08
−Thr	0.88
−Phe	0.82
−Trp	0.73
−His	0.71
−Met	0.65
−Arg	0.51*
−Val	0.56
−Leu	0.53*
−Ile	0.43*
−EAA	0.24*
SEM	0.19
P value	0.01

Figure 14. Addition of a complete mixture of essential amino acids (**EAA**) quadruples mTOR activity in vitro in mammary cells, but omitting arginine, leucine, or isoleucine from this mixture reduces the mTOR stimulation. Note these are not usually thought to be limiting amino acids for cows, and probably aren't as building blocks for milk protein, but may help other signals that increase the potential for milk protein yield. (Appuhamy et al., 2012)

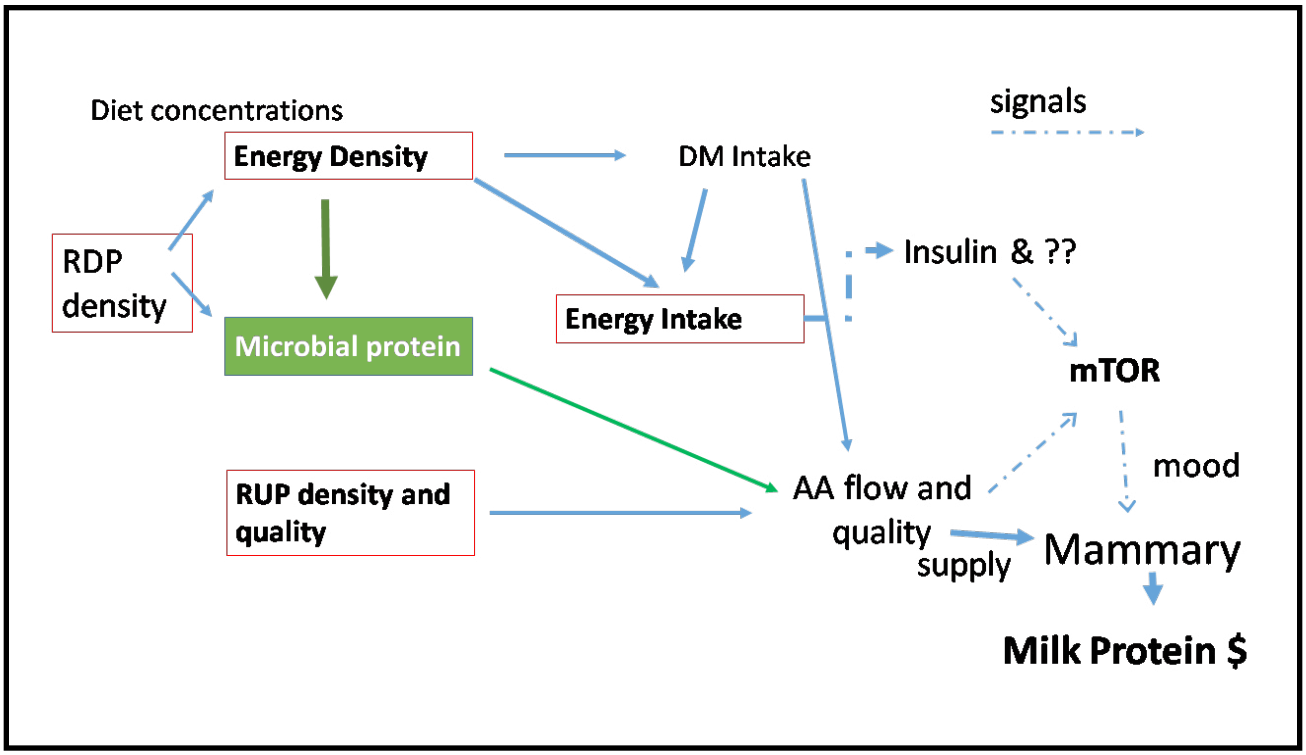

Figure 15. This figure shows how the interactions discussed in this paper tie together in a lactating cow. Supply of energy, amino acid supply and endocrine (insulin) and cellular control proteins (mTOR) play a part in getting the mammary gland in the "mood" to make milk protein while supplying the required energy and amino acid building blocks for protein synthesis (**RDP** = rumen degradable protein and **RUP** = rumen undegradable protein).

Can We Differentiate Supplemental Magnesium Sources Nutritionally?

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Abstract

A laboratory test to differentiate the apparent availability of Mg among supplemental sources would be useful. Evaluation directly with cattle to test the reactivity, solublization (dissolution), and apparent absorption of Mg from various Mg sources in the rumen is tedious, laborious, and expensive. The degree of reactivity in the rumen and release of soluble Mg in the primary absorption site (the rumen) is key to differentiating among various sources. In addition to their solubility, other primary factors that affect solubility include origin (source), specific chemical compound, proper calcining process of magnesium carbonate to yield magnesium oxide (**MgO**), particle size, and other chemical compounds (e.g., potassium, calcium) in the diet and rumen. When supplemental sources of Mg were tested in the laboratory for solubility, sometimes, but not always, improved lactational performance was detected. Unfortunately, determination and ranking of Mg sources by solubility as an indicator of apparent availability does not appear to be a very reliable test. The "vinegar test" proposed by Goff (2014) is a simple way to characterize the reactivity and alkalizing property of various MgO sources. Test sources that raise the pH in a solution of vinegar (5% acetic acid) are more alkalizing. This also might provide indirect evidence that some MgO sources are more reactive and yield more soluble Mg for absorption from the rumen than others. However, MgO sources ranking differently in the vinegar test have not been evaluated with dairy cows by measuring differences in apparent digestibility or lactational performance to verify that the test reliably differentiated sources for apparent Mg availability.

Introduction

Dairy cattle rely on a continuous dietary (and ruminal) supply of absorbable Mg to maintain optimal Mg concentrations and homeostasis in blood and extracellular fluids. There are neither specific regulatory (e.g., hormonal) mechanisms to maintain Mg homeostasis (Littledike and Goff, 1987; Schultz et al., 1988; Martens and Schweigle, 2000), nor is there much body storage (NRC, 2001). Therefore, dietary sources with potentially soluble and available Mg to be absorbed from the rumen and reticulum are required daily (Green et al., 1988; Meyer and Zentek, 1990; Martens and Schweigle, 2000; NRC, 2001).

The National Research Council (2001) listed Mg requirements based on estimates of absorbability of Mg. Amount of available Mg supplied by a particular diet is the product of the concentration of total dietary Mg times an absorption coefficient (**AC**). The NRC (2001) used an AC of 0.16 for Mg for all feed ingredients except supplemental sources. The estimated AC for Mg from MgO and magnesium

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hydroxide was 0.70, 0.90 for magnesium sulfate, and 0.30 to 0.35 for magnesium carbonate and dolomitic limestone (see Table 15-4, page 312; NRC, 2001).

However, some of these estimates are from non-ruminant animal studies and (or) using "reagent grade" Mg salts because no other information was available. Jittakhot et al. (2004) used MgO to increase dietary Mg from 0.39 to 0.64% (adding 7.6 g Mg to the diet from MgO). The increase in apparent absorption of dietary Mg was 3.6 g. This suggests their MgO had a coefficient of absorption of about 0.47, considerably lower than the 0.70 listed in NRC (2001). Additionally, with the lack of research results to make the AC estimations for most feedstuffs, the NRC subcommittee lowered the mean overall AC by 1 standard deviation for practical application to reduce the risk of Mg deficiency. In a meta-analysis of mass balance studies done in Ohio with feedstuffs typical of those in the TriState area, Weiss (2004) calculated an average apparent digestibility for dietary Mg of 0.24 when the dietary K was 1.0% (near the NRC K recommendation). Since released in 2001, many dairy nutritionists suspect that the NRC AC (0.16) is an over-estimation based on cases with relatively low total dietary Mg, suboptimal lactational performance, and (or) sub-clinical Mg deficiency. In most cases with lactating dairy cows some supplemental Mg source is needed to meet requirement for absorbed Mg.

A common question from the feed industry is: "Can we differentiate supplemental magnesium sources nutritionally?" This is asked because: 1) it is known or suspected that there are distinct differences in apparent availability of Mg from a fairly large list of choices for supplemental Mg and 2) it might be desired to provide the greatest apparently available Mg per unit price, or a differential price point based on apparent availability among sources. Because of the ever evolving number and origin of sources of feed grade Mg, the desire would be to have a relatively quick laboratory method that could: 1) at minimum, reliably, but indirectly, rank a set of sources from best to worst for apparent availability and 2) even better, provide a reasonably accurate value of apparent availability of each source that could be used in ration formulation. For this discussion "apparent availability" is used to define that proportion of Mg from a feed grade source that ultimately is presented in the animal's blood stream. It is "apparent" because there is some recycling of once-absorbed Mg back into the digestive tract where it can be absorbed again.

Differing apparent availability of various supplemental Mg sources may be influenced by several factors: source or origin; physical and chemical properties; the source's reactivity in the ruminal fluid; and absorption mechanisms in the rumen and factors influencing those mechanisms. Objectives of this paper are: 1) to characterize known factors that can affect the apparent availability of Mg; 2) summarize associated research to demonstrate effects of the aforementioned factors; and 3) comment on possible simple laboratory tests that might provide information about reactivity and the potential to predict apparent availability of various MgO sources.

Factors Affecting Apparent Availability of Mg from Supplemental Sources

Sources of supplemental Mg

In order to be absorbed from the rumen, the Mg from any basal feed ingredient or supplemental source must first be solubilized and exist in its ionized state (Mg^{+2}) in the fluid of the rumen and reticulum (henceforth called the "ruminal fluid").

Magnesium carbonate typically is obtained by mining the ores known as mineral magnesites. In rare occasions, these magnesites may be ground directly and offered as a feed source of Mg. However, their Mg availability is very low or non-existent. The Mg in magnesites and dolomite minerals (anhydrous carbonate minerals composed of calcium magnesium carbonate or dolomitic limestone) should be considered totally unavailable for absorption by dairy cattle; absorption coefficient of Mg equal to zero.

The primary use of magnesium carbonate is to produce magnesium oxide (**MgO**) via a calcining process (reduction, oxidization, and burning or roasting with strong heat). Some feed grade MgO sources are produced by calcination of magnesium carbonate. In Scotland, Wilson (1981) found that magnesites calcined for 3 hr at temperatures of 1,472 to 2,012°F resulted in MgO with greater availability for sheep compared with those burned at 1,202°F or less, or at greater than 2,372°F. In another Scottish study, MgO resulting from higher temperature calcination (1,472 to 2,012°F) had greater apparent Mg availability compared with MgO from lower temperature (932 to 1,202°F) calcination (Adam et al., 1996.). Higher temperatures result in greater surface area by breaking down the magnesium carbonate particles, thus increasing the potential for solublization and release of Mg into the ruminal fluid.

Magnesium oxides

Magnesium oxides are commonly used Mg salts in dairy diets typically with at Mg content ranging between about 51 to 59% (Urdaz et al., 2003). They are included in dairy rations to alkalize the rumeno-reticular ecosystem when rations are lower in forage than normal and when supplemental Mg is needed to meet requirements. The desire to differentiate supplemental MgO sources obviously is not new. Long ago Michigan State University researchers (Emery et al., 1965; Thomas et al., 1969) studied dietary and metabolic effects of magnesium oxide (an alkalizer) and sodium bicarbonate (a buffer) on milk fat concentrations in cows fed restricted-roughage rations. They found that milk fat concentration, milk yield, ruminal pH, and molar percentages of ruminal acetate, iso-butyrate, and iso-valerate were increased by feeding MgO and that some of the effects could be additive with the joint feeding of sodium bicarbonate. The authors speculated that beyond the alkalizing effects of MgO that Mg *per se* may act to increase uptake of plasma acetate and triglycerides at the mammary gland to affect milk fat concentration.

Other Mg sources, besides MgO, available for supplementation in dairy rations include magnesium sulfate • 7 H_2O (Epson salts; 9.8% Mg) and magnesium chloride • 2 H_2O (18% Mg); both are soluble in ruminal fluid and their Mg has relatively high availability for absorption; however, they are relatively low in Mg. These so-called anionic salts are included sometimes in pre-fresh supplements to provide an available source of Mg, as well as the respective anion to reduce dietary cation-anion difference and to help acidify close-up cows to aid in prevention of periparturient hypocalcemia. However, with their relatively low Mg concentration and risk to reduce feed intake (they are not very palatable), their inclusion in rations is typically fairly low. Also, unlike the potential of some of the more reactive MgO sources, magnesium sulfate and chloride provide no alkalizing action in the rumen. Magnesium phosphate (**MgP**) that was originally from Sweden and chelates of Mg were tested in the USA, but they never became viable commercial products, although MgP showed promise as a supplemental source of Mg and P for lactating dairy cows (O'Connor et al., 1988);

neither of these sources has alkalizing properties in the rumen.

Particle size

Following their early work characterizing the lactational responses to MgO as a ruminal alkalizer and Mg's metabolic influence to overcome "low-milk fat syndrome", Thomas et al. (1969) and Emery et al. (1965) delved more deeply into the apparent bioavailability of Mg from MgO (Jesse et al., 1981). They examined the effects of particle size from MgO (~56% Mg) using the same magnesium carbonate ore from the same calcining process on availability of Mg by 3 techniques. They used a loading technique in which cows consuming a Mg-adequate diet were given separately an excess load of 4 different particle sizes of MgO into the rumen and then they quantified the relative amount of Mg appearing in urine over time, which was a function of size of the load and the availability of the Mg treatments (varying in particle size). A second technique measured changes in milk fat production of cows fed a restricted-roughage diet. Cows fed the more readily available MgO treatments were expected to increase milk fat, indicating differences in relative Mg availability among particle size treatments. They demonstrated that MgO ground to pass through a 200-mesh screen size (-200) or a 20 mesh (-20) screen resulted in more Mg in urine of cows compared with the baseline (with no Mg treatment fed) Mg excretion. In another study, increased milk fat concentration, milk fat yield, and blood serum Mg concentration resulted when cows were fed MgO with -20 (finest), 30 to 100, or 12 to 40 mesh screen size compared with no MgO supplementation. Authors suggested that differences resulted from the greater solublization in ruminal fluid of MgO with finer particle size, as noted also in their *in vitro* incubation work (described below). MgO sources should be ground as fine as possible, while still meeting Occupational Safety and Health Administration standards, to increase potential for solublization and availability of the MgO for absorption of the Mg.

Solubility of the MgO at the varying particle sizes noted above also was characterized in an *in vitro* ruminal fermentation system (Jesse et al., 1981). Release of solubilized Mg after incubation (0, 3.5, 6, 12, and 24 hr) in strained, centrifuged rumen fluid (without added buffer) was characterized. Maximum concentration of soluble Mg occurred at 12 hr from the most finely ground (-20 screen mesh size) MgO; about 30% less soluble Mg (on a relative basis) was present with 12 to 40, or 30 to 100 screen mesh sizes at 12 and 24 hr of incubation. Ruminal fluid pH *in vitro* had similar patterns as soluble Mg relative to incubation time and MgO particle size. It was concluded that MgO with the finer particle size resulted in more soluble Mg potentially available for ruminal absorption. For the particular MgO source tested, even the unground coarse material was partially reactive with some solublization and apparent absorption of Mg using the 3 testing techniques (Jesse et al., 1981).

Following the work of Jesse et al. (1981), researchers at the University of Florida set about characterizing the *in vitro* solubility of 11 feed grade sources of Mg, 8 of which were MgO (Beede et al., 1992). The *in vitro* system was a modification of the techniques of Tilley and Terry (1963) and Jesse et al. (1981). The system included strained ruminal fluid from a ruimnally fistulated cow fed alfalfa plus trace mineralized salt, McDougall's artificial saliva buffer, and solublization of Mg in sample tubes (in triplicate) was characterized at 0, 6, 12, 24, 36 and 48 hr of incubation of 0.5 g of ground dietary concentrates containing the different Mg sources (Beede et al., 1989). The pH of the buffered *in vitro* rumen system was maintained

at an average ~ 6.78 and ranged from 6.94 (0 hr) to 6.64 (36 hr) across the 48-hr incubation. Average percentage of the total Mg from the supplemental Mg sources solubilized in the 48 hr rumen incubation was 13.9% and ranged from 1.4 to 27.9%. Average solublization percentages (in parentheses) for the different sources were: Min-Ad U.S.A. (1.4%); SuperMag-Greek (MgO) (6.5%); MagFeed-Greek (MgO) (7.6%); Mg phosphate-Swedish (11.2%); Chinese-MgO (11.4%); BayMag58-Canadian (MgO) (14.2%); Magal-Spanish (MgO) (14.5%); CoMag-Turkish (MgO) (14.6%); FeedOx-U.S.A. (MgO) (20.4%); MagOx-U.S.A. (MgO) (22.6%); and Rumen-Mate-U.S.A. (27.9%). There are 2 very important points to understand about these solublization percentages: 1) they were determined from Mg sources nearly 30 years ago and very likely are not representative of products today, even of the same name and origin; and 2) the values are not apparent absorption or availability values, but rather the percentage of the total Mg in the source that was found in the soluble fraction of the *in vitro* rumen incubation after 48 hr.

Subsequent to the assessment of Mg solubility using the *in vitro* rumen system, a lactation performance experiment was conducted using 4 of the MgO sources: MagFeed-Greek (7.6% soluble Mg from MgO in the in vitro system), Magal-Spanish (14.5% soluble Mg from MgO), BayMag58-Canadian (14.2% soluble Mg from MgO), and MagOx-U.S.A. (22.6% soluble Mg from MgO). Thus, MgO sources evaluated in the lactation experiment ranged from 7.6 to 22.6% in soluble Mg from the *in vitro* rumen system. Particle size distributions of each source are reported in Beede et al. (1992). On average, MagFeed-Greek had the largest particle size and MagOx-U.S.A. had the smallest particle size, with BayMag58-Canadian and Magal-Spanish having intermediate average particle sizes.

Eighty-six midlactaion Holstein cows were used in a randomized incomplete block design. The basal diet was 55% concentrate, 13% alfalfa hay, and 32% corn silage, dry basis. The basal TMR (Control) without Mg supplementation contained 0.21% total Mg. The 4 supplemental MgO sources were each supplemented in the basal diet to provide total dietary Mg concentrations of 0.27, 0.35, and 0.46%. Daily DMI was greater when cows were fed MagFeed-Greek vs. Magal-Spanish, BayMag58-Canadian, and MagOx-U.S.A. ($P < 0.02$) and DMI was greater with Magal-Spanish vs. BayMag58-Canadian and MagOx-U.S.A. ($P < 0.08$). Milk yield was greater with MagFeed-Greek vs. Magal-Spanish, BayMag58-Canadian, and MagOx-U.S.A. ($P < 0.12$). There was no effect on 3.5% FCM yield. Milk fat concentration (in parenthesis) was lower ($P < 0.05$) when cows were fed Control (3.50%) versus MagFeed-Greek (3.61%), Magal-Spanish (3.73%), BayMag58Canadian (3.70%), and MagOx-U.S.A (3.65%), respectively. There were no differences in milk protein percentages due to the 4 MgO supplemental sources.

When the effect of dietary Mg concentrations (pooled across MgO sources) was considered, there was significant lactational performance responses. Daily DMI declined linearly ($P < 0.001$) as total dietary Mg increased from 0.21% (Control) to 0.46%, about a 3% decline. Overall, 3.5% FCM yield increased linearly ($P < 0.05$) as total dietary Mg increased from 0.21 to 0.46%, with a 5.3% increase with 0.27% Mg compared with 0.21% (pooled across MgO sources). Mike fat percentage also increased ($P < 0.05$) from 3.5% (Control) to 3.72, 3.68 and 3.62% with 0.27, 0. 35, and 0.46% total Mg, respectively. Increasing dietary Mg did not affect milk protein percentage, and there were no MgO treatment by dietary Mg concentration interactions detected.

There was some lactational performance effects detected related with MgO source and its solubility in the *in vitro* rumen system. However, the source (MgO-Greek) with the lowest (7.6%) apparent *in vitro* solubility among the 4 MgO sources had the greatest numerical DMI, milk yield, 3.5 FCM yield, and milk fat percentage. Overall, it does not appear that the *in vitro* solubility test in a buffered system suggests anything about lactational responses one should expect.

Absorption of Mg in the rumen and interfering compounds

In adult ruminants, the rumen and reticulum are the principal locations of Mg absorption (Martens and Gabel, 1986). Thus, it is critical in adult dairy cattle that this divalent cation (Mg^{+2}) be soluble in ruminal fluid and presented at the ruminal epithelial cells for absorption. In pre-ruminant calves and non-ruminants, Mg absorption is primarily from the small intestine; Mg salts that are poorly soluble in neutral pH water can be solubilized by action with HCl in the abomasum or stomach. This facilitates absorption of Mg in the small intestine. However, in ruminants, Mg absorption is dependent on the concentration of Mg^{+2} in the ruminal fluid where pH typically is greater than 5.8. However, ruminal pH can be less than 5.5 for considerable lengths of time (e.g., 3.1 to 9.7 hr) in lactating dairy cows (Oba and Allen, 2000).

Once solubilized in the ruminal fluid, the ionized Mg^{+2} can be absorbed at the interface of the rumen epithelial cell apical membrane. Absorption of Mg^{+2} is either by an active transport system (transcellular system) or by a passive or paracellular transport system (Ebel, 1990; Martens and Schweigel, 2000; NRC, 2001). The concentration gradient of Mg between ruminal fluid and blood is the motive force for the transcellular system. This system is very effective, even when soluble Mg^{+2} concentrations in ruminal fluid are quite low. The presence of short chain fatty acids in the ruminal fluid can help promote Mg uptake by this mechanism.

Paracellular transport works based on the electrochemical gradient with high concentrations of Mg in ruminal fluid, forcing greater quantities of Mg through permeable tight junctions between epithelial cells into the extracellular space (Ebel, 1990; Martens and Schweigel, 2000). However, K inhibits this transporter because high K concentration promotes passive diffusion of K into the ruminal epithelial cells, causing a reduction in the potential difference across the apical membrane. Because the major negative charge inside the cells was the primary factor causing movement of Mg through these channels, the high K greatly reduces the effectiveness of the paracellular transport system for Mg. The effect of K was demonstrated in dairy cattle (see below). Sodium, ammonium, and Ca ions in the ruminal fluid can have similar effects on paracellular Mg absorption (Urdaz et al., 2003).

Dietary K and Ca effects on Mg absorption

Weiss (2004) used data from 8 experiments, 39 dietary treatments, and 162 individual cow mass balance collections to determine apparent digestibility of total dietary Mg. Basal diets had corn silage, corn grain, and soybean meal as predominant ingredients, along with alfalfa hay or silage, and orchardgrass silage in some studies. Original studies were designed to evaluate different feed byproducts, forages, and fat supplements, but the database allowed assessment of utilization of other mineral elements as well (Weiss and Wyatt, 2004). Supplemental dietary Mg came from MgO or magnesium sulfate, and total dietary

Mg ranged from 0.20 to 0.36% Mg, dry basis. Mean apparent digestibility of Mg was 18% with a range of -4 to 33%; this apparent mean digestibility was about 30% less than estimated by the NRC (2001) model. A very important factor in the analysis was the concentration of dietary K that averaged 1.60% (range = 1.07 to 2.65%). The authors stated that a main reason for the relatively low apparent Mg digestibility was the influence of high dietary K. At 1% dietary K, results agreed with NRC (2001); however, as dietary K concentration increased, the apparent digestibility of Mg declined 7.5-percentage units per each percentage increase in dietary K. To achieve the same amount of apparently digestible Mg at 1% K, cows had to consume an additional 18 g/day of Mg for every 1 percentage unit increase in dietary K above 1% to maintain the intake of apparently digestible Mg as consumed when fed a diet with 1% K.

Holtenius et al. (2008) studied the effects of 0.19, 0.28, and 0.37% dietary K factored with 0.19 and 0.43% dietary Mg on lactating cows fed a grass silage-based diet in Sweden. There was no effect of increasing dietary K (very low concentrations compared with those typically found in lactation rations in the TriState area and in the Weiss (2004) study) on apparent Mg absorption, urinary Mg absorption, or blood plasma Mg. Increasing dietary K or Mg did not improve milk yield. Research in the Netherlands explored effects of increasing dietary K (0.21, 0.48, and 0.75%, dry basis) on Mg absorption (Jittakhot et al., 2004). With high (~0.92% Mg of dietary DM) or low (~0.54% Mg) Mg absorption, urinary excretion of Mg was reduced with increasing dietary K and increased with increasing supplemental Mg intake. Their studies also demonstrated that increasing supplemental Mg (if from an available source) can effectively counteract the inhibitory effect of K on ruminal Mg absorption.

Work increasing dietary Ca prepartum (0.49, 0.93, and 1.36% of dietary DM) with 0.18% Mg across all treatments showed reduced apparent digestibility of Mg and daily urinary Mg excretion prepartum with 1.38% Ca (Kronqvist et al., 2011). Postpartum blood Mg was lowest at day 2, 4 and 7 for cows fed the 1.38% Ca diet prepartum. Varying prepartum dietary Ca did not affect Ca status, plasma Ca, parathyroid hormone, or marker of bone resorption (**CTx**) concentrations postpartum.

Vinegar Test of Reactivity of MgO Sources

Goff (2014) proposed a simple method to differentiate the reactivity and potential alkalizing properties of various MgO sources. Method is described as: *"If rumen alkalinizing activity is valued, then the reactivity of MgO with acetic acid could give the nutritionist a simple test of the relative reactivity of a MgO being considered for use in lactating rations. Place 3 g of a MgO source in a container and slowly add 40 ml 5% acetic acid (white vinegar). Cap container and shake well for 15 seconds and let sit. Shake again at the 15-minute mark and check the pH at 30 minutes. Vinegar alone has a pH of 2.6 to 2.8. The best MgO sources will bring the pH up to 8.2; the worst to just 3.8 (Goff, 2014). pH is a log scale so this represents > 10,000-fold difference in the number of hydrogen ions neutralized. In an experiment with four cows with rumen fistulas, the solubility of MgO in vitro (tested in several ways) was found to parallel their solubility in the rumen and their urinary excretion (Schonewille et al., 1992)."*

This procedure and the alkalizing effect are an indication of the reactivity and solublization of various MgO sources; it also could suggest that the Mg^{+2} ion is released to a greater extent and might be available for ruminal absorption. However, this idea has not been evaluated in experiments with dairy cattle.

Nonetheless, it offers a way to differentiate the reactivity of various MgO sources that could be easily done with a calibrated pH meter or even pH paper strips.

Conclusion

When supplemental sources of Mg were tested in the laboratory for solubility, sometimes, but not always, improved lactational performance was detected. Unfortunately, determination and ranking of Mg sources by solubility as an indicator of apparent availability does not appear to be a very reliable test. The "vinegar test" proposed by Goff (2014) is a simple way to characterize the reactivity and alkalizing property of various MgO sources. It also could suggest that the Mg^{+2} ion is released to a greater extent and might be available for ruminal absorption. Follow-up studies with animals are needed for proof of concept relative to apparent Mg availability using the vinegar test.

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Dairy Farming in the Midwest and USA in 2067

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Summary

Fifty years from now, 81% of the world's population will live in Africa and Asia and world dairy trade will depend on their demand for imported dairy products. Dairy production in North America will shift to areas with sufficient rainfall and adequate growing seasons, primarily migrating from the west and southwest to Great Lakes regions and into the Canadian prairies. Milk yield per cow will exceed 50,000 lb/year and the USA will have 4 to 5 million milk cows. Commercial cows will comprise genes from multiple breeds or from gene editing. New genetics will move into herds primarily through embryos that may carry proprietary genes. Dairy enterprises will share laterally-integrated business structures that include separate units for pre-weaned calves, replacement heifers, early-dry cows, transition cows, milk cows, dairy beef, and feed centers. Feed production will have a greater focus on agro-ecological systems and perennial crops, including perennial maize, sorghums, and energy-grasses that will replace annual row crops. Robotics, automation, and sensors will replace a majority of manual labor and will enhance reliability, consistency, and compliance with regulations. Major shifts in herd management will be driven through management of epigenetics and associated environmental regulation of gene expression, and management of microbiomes of cattle, soils, crops, and farmsteads. Knowledge systems will evaluate herds as independent superorganisms to understand why herds that have similar genetics and environments differ in performance.

Background

The motivation for addressing this topic was a 2015 invitation from Michigan State University to present the Tucker Endowed Lecture in 2016. The author sought independent feedback from colleagues in the USA (Mike Hutjens, IL; Gordie Jones, WI; Jeff Stevenson, KS; Pam Ruegg, WI; Chad Dechow, PA; George Seidel, CO; Bob Cushman, NB; Tony McNeel, MI) and Europe (Hilary Dobson, UK; Martin Sheldon, UK; Patrice Humblot; SE). Independent ideas and thoughts from each were shared with the entire group to generate discussion. After a few iterations, this was used as a primary basis for moving ahead. Over the last year, several modifications have been added based on discussions with other colleagues and new findings in scientific and technical literature.

Harvesting milk from cows has been practiced for more than 10,000 years or approximately 450 generations, so it is unlikely that it will disappear in the next 2 generations. Moreover, a dairy-based food production system will support greater populations per acre or hectare of arable land as estimated for the USA by Peters et al. (2016). Dairy's most sustainable component is high quality protein that meets human dietary needs.

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Data Driven Forecasts

World and country populations

Forecasts for populations in the future are driven by current populations, birth and fertility rates, and longevity. World population will reach 10.7 billion in 2067 with 81% of the population living in Africa and Asia (Figure 1). The United States' population will fall from 4th to 5th place as a country, being surpassed by Nigeria. Population data are updated regularly for each country based on United Nations data, and a user-friendly website is available (DeWulf, 2016).

For growth in world dairy trade, it will be important for the USA to develop products that are suitable and acceptable to customers in countries that have growing populations. In Africa and Asia, the types of products may need to be quite different from those marketed in Europe and Russia. For example, they may need to be lactose free, packaged to withstand long storage without refrigeration, and contain spices on ingredients not typical in today's products.

In recent years, the USA has exported about 12 to 15% of its milk equivalents, and USA per capita consumption has increased to 627 lb (285 kg) of milk equivalent per capita in 2015. Milk equivalent imports have been lower than exports. For future projections, estimates are that 10% of production will be exported – this is a conservative estimate.

Climate change

Forecasts for climatic changes have been derived from a number of sources, depending on the state or region of the country. For the upper Midwest, the Nelson Institute Center for Climatic Research at the University of Wisconsin has useful resources that include application of the 9 major global climate models developed by different agencies or research teams around the world (http://nelson.wisc.edu/ccr/resources/visualization-and-tools.php). Their downscaled illustrations of some climate changes in Michigan in the late century are illustrated in Figure 2. These trends are consistent with trends for other area in the Great Lakes region and the Canadian prairies.

Generally the upper Midwest and Northeast will have longer growing seasons and slightly-to-significantly more precipitation than today. All seasons will be warmer. Water demand will increase less in these regions than in almost any other parts of the country. The eastern Canadian prairies will also see warmer temperatures and more precipitation, so more dairy cattle could move into those regions.

Availability of water for dairy farms will be limited in the south and southwest dairy regions of the USA by late century. Our forecast is that dairy farms will relocate to regions that have ample rainfall and suitable climates. The upper Midwest is likely to see growth in dairy farms because it is projected to have ample rainfall and longer growing seasons (Figure 3).

Projected milk yield per cow

There was strong agreement among forecasters in amount of milk that cows will produce in 2067, especially those in high-input dairy farms where feed is not limited. The estimate was 55,700 lb (25,318 kg) per cow per year. The average cow in the USA today produces 2.65-times the amount that the average cow produced 50 years ago. If we multiply today's average by 2.65, it equals 59,341 lbs (26,973 kg) per year; therefore, forecasters feel comfortable with estimates.

With higher production, the question becomes how many milk cows will be needed in the USA in 50 years. To address this, US Census projections were used to estimate the population and annual consumption was set at 600 lb (273 kg) per capita of milk equivalent, lower than the 627 lb per capita consumption in the USA in 2015. To this was added a 10% overage for export. With these targets for milk equivalent demand, estimates were made to determine number of milk cows needed to meet the demand. The number ranges from about 7.5 million cows at lower levels of production and 3.8 million cows at higher levels of production (Figure 4).

Predicted Forecasts for Technology and Innovations

Genetics of the cow of the future

Genetics of commercial dairy cows will move from breed- to gene-based with movement of genes within breeds and between breeds. Gene editing will be used to change natural alleles from one form to another form, for example, from horned to polled phenotype or from A1 milk to A2 milk phenotype. Data mining of genomes will find many single-nucleotide polymorphisms (**SNP**) that are markers for important health and welfare traits and many will be proprietary and require a fee for identifying a cow or bull's genotype. Synthetic genes may be introduced if their value is important for protecting the nation's food supply and export markets. For example, synthetic genes that would protect against Foreign Animal Diseases (Transboundary Animal Diseases), such as Foot and Mouth Disease, would be of vital interest to the industry and the USA.

Cows of the future will have a smaller environmental footprint and will have higher feed efficiency than today. There will be more emphasis on animal welfare because genetic markers of animal welfare will have been identified and implemented into selection programs. Markers for animal health may the most important genes in genomic indexes.

Forecasters believe that most genetic introductions into herds in 50 years will be by embryo transfer rather than semen. Embryos will be produced by genetic companies that are the descendants of today's AI companies and embryos may carry proprietary genes, limiting sale of females or their daughters from dairy herds. Embryos will be produced using stem cells and cloning technologies.

Globally, milk-producing cows will represent phenotypes and their associated genotypes that fit into various climatic sectors -- generally characterized as temporal, subtropical, and tropical phenotypes. The northern and southern latitudes for these distributions will shift over time and genetics will shift with the climate. Today's global cooperation among dairy geneticists worldwide will make this transition simpler for farmers.

Robotics, sensors, and automation

Adoption of robotic systems, sensors, and automation will continue to escalate in North America and technologically-advanced dairy economies. These shifts will be driven by shortages of labor in rural areas, increased focus on knowledge systems for decision making, and consistency of automated systems. Dairy cows like consistency, and integrated systems will provide that more consistently than manual labor.

Milking, feed handling, mixing and delivery, waste handling, sanitation, vaccination, health monitoring and treatments, planting, harvesting, and storage will be automated

and will include driverless equipment, robotic delivery systems, and farmstead-wide sensors that inform enhanced agro-ecological systems that link soils, forages, feeds, wastewater, manure, workers, and other aspects of the dairy enterprise. At the animal level, metabolic profiling and gene activity monitoring will utilize biodegradable implanted sensors as part of the integrated systems.

Management of Epigenetics and Associated Regulation of Genetic Activity

Approximately 18% of the variation in important traits monitored in dairy cattle is heritable, meaning that differences among animals in these traits can be accounted for by ancestors in their pedigrees. Over 80% of variation in such traits is attributed to "Environment" in the classical equation: *Phenotype = Genetics + Environment*. We are beginning to understand that there is extensive regulation of gene expression that occurs in a temporal, predictable manner that can be managed in a beneficial way other than changing the genome. This fits into the "*Environment*" category in the equation and provides opportunities to manage more of the variation in traits.

Historically, epigenetic effects were defined by when changes within bases in a gene's deoxyribonucleic acid (**DNA**) sequence were methylated to prevent that gene from being "turned on". That concept was expanded to include situations in which the histone proteins in the nucleus were acetylated, therefore altering access of enzymes to sites for transcription of DNA. Some of these changes were transmitted to the next generation and sometimes for several generations.

There are a growing number of mechanisms that regulate gene expression in a predictable way and that are good candidates for active management. These mechanisms are expanding the definition of epigenetics in practice. In particular, mechanisms that act on mitotically-active cell lines, such as the mammary epithelial cells or ovarian germ cells, are a top priority. Animal scientists are learning to control some of these processes through developmental or metabolic programming, and this will grow the number of management tools that regulate gene activity without altering the genome (Sinclair et al., 2016).

Examples of epigenetic and related effects

Feeding pre-weaned calves. It is generally accepted that feeding calves greater amounts of milk to produce greater weight gains before weaning leads to enhanced yield of milk during first lactation about 670 days later (Soberon et al., 2014). This is a repeatable phenomenon with a temporal relationship such that a management action (feeding more milk) results in a biological response in a predictable way. This is a classic example of an epigenetic or related effect that is not associated with a change in the animal's genome.

Early postpartum milking frequency and higher yields. Experimental trials have shown that milking or suckling cows 4- to 6-times daily during the first 3 to 4 weeks of lactation boosts milk yield during the remaining lactation when cows are milked twice daily. This appears to be an effect on the mammary epithelial cells caused by the higher milking frequency in early lactation (Bar Peled et al., 1995; Hale et al., 2003).

Fertility of oocytes developing under adverse conditions. Britt (1992) hypothesized that the developing bovine oocyte could be affected adversely by environmental conditions, particularly negative energy balance, that would affect its viability 2 to 3 months later. It has

taken about 25 years for this hypothesis to be fully verified and for potential epigenetic or related mechanisms to be identified. As we now understand, the oocyte that is ovulated at around 80 days postpartum begins development around 21 days prepartum (Figure 5). Consequently, this oocyte is subjected to impacts of negative energy balance, metabolic disturbances, and clinical diseases that are elevated during the transition period. Recently, Carvalho et al. (2014) demonstrated that change in body condition score during 3 wk postpartum could have a profound effect on pregnancy rate to timed AI at 82 days postpartum (Figure 6).

We are just beginning to understand how developmental or metabolic programming can influence temporal actions and subsequent responses in dairy cattle. In the future, we will utilize a broad array of management practices to regulate gene expression in beneficial ways and to avoid undesirable environmental effects.

Managing Microbiomes on Dairy Farms

Dairy cattle are role models for interactions between an animal and its microbiome, and dairy farms may be equally appropriate models for an enterprise and its microbiome. Cows have complex microbial populations that occupy the rumen, gut, udder, uterus, urinary tract, skin, feet, and other body components. Dairy farms have complex microbial populations in feeds, manure, farmsteads, equipment, personnel, soils, crops, and water resources.

Too often, we have sought to kill microorganisms without understanding that most are beneficial. Broad use of antibiotics, sterilants, fungicides, and other microbial agents have been effective in many ways, but their perceived effectiveness mislead us from understanding roles that the microbiome plays in animal health and resilience of agro-ecological systems. In the future, we will manage microbiomes in ways that are beneficial (Deusch et al., 2015).

Microbial ecology is challenging to study, but progress in high-throughput DNA sequencing and data mining is leading to clearer understanding of relationships that are targets for management. Shanks et al. (2011) measured over 600,000 high-quality DNA sequences in rectal fecal samples from feedlots to show that microbial populations differ significantly among locations and among primary feed constituents.

In the future, it is likely that mixed cultures of microorganisms will be used routinely to manage and treat diseases and sustain health. For example, calves will be inoculated with mixed cultures around the time of weaning to ensure optimal rumen function. Pubertal heifers will have their mammary quarters and uteri populated with beneficial organisms to limit infections. These are a few of many examples of how management of the microbiome will be implemented (Figure 7).

Feeding the Herd

Energy feeds will shift to a greater emphasis on perennial crops in the future because of development of perennial maize, sorghums, and energy grasses. Perennial maize is under development and is expected to be available on a commercial scale in about 30 years (Murray and Jessup, 2014). It is being produced through selective breeding with related plants that are perennials. Perennial sorghum is closer to development and will be particularly suitable for more arid climates (Paterson et al., 2014). Energy grasses are being developed genetically with a focus on reducing recalcitrance – making them more suitable for producing fuels. These grasses are much less dependent on nitrogen fertilization than maize and may yield 30 to 40 tons of dry matter per acre at maturity (Moore,

2009). Such crops may produce for up to 20 years without being re-planted and their ability to sequester carbon in the soil will be a valuable feature.

Lateral Integration of Herds

Vertical integration is common in other livestock enterprises (swine, broilers, layers, turkeys, farmed seafood, and crickets). Beef feedlots provide partial integration in that sector. The future will see broader lateral integration in the dairy industry, and there will be some specialized vertical integration. The simplest form of dairy lateral integration will comprise sharing of resources for stage-specific animals (Figure 8).

Herds as Superorganisms

Animal scientists tend to study animals, organ systems, cells, or genes. None of these tell us much about herds and why herds differ in health and performance. In contrast, scientists that study bee hives, termite colonies, and similar superorganisms see the hive or colony as the experimental unit, not the individual bee or termite (Seely, 2010). Should we adopt some of their practices in understanding herds?

The USA has many counties or micro-regions that are home to multiple herds that share common precipitation, ambient temperature ,and growing conditions. Yet, herds often differ significantly in health and performance. To understand how management makes a difference, there is a need for collaboration among several disciplines to ask the right questions and collect the right information to understand why herds differ. This is an undertaking that would not be prohibitively costly in terms of agricultural research and it would provide new insights.

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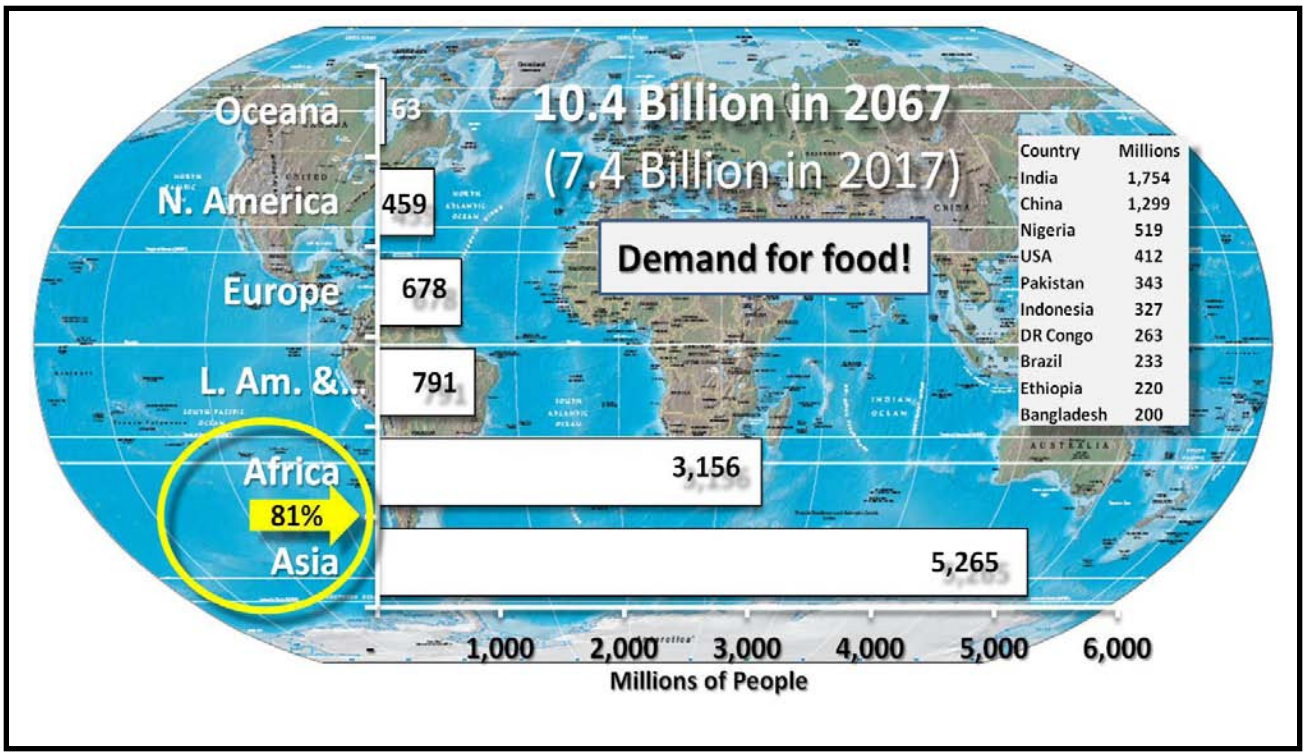

Figure 1. Estimated population of the world and its top 10 countries in 2067, updated January 2017 from https://populationpyramid.net/world/2065/.

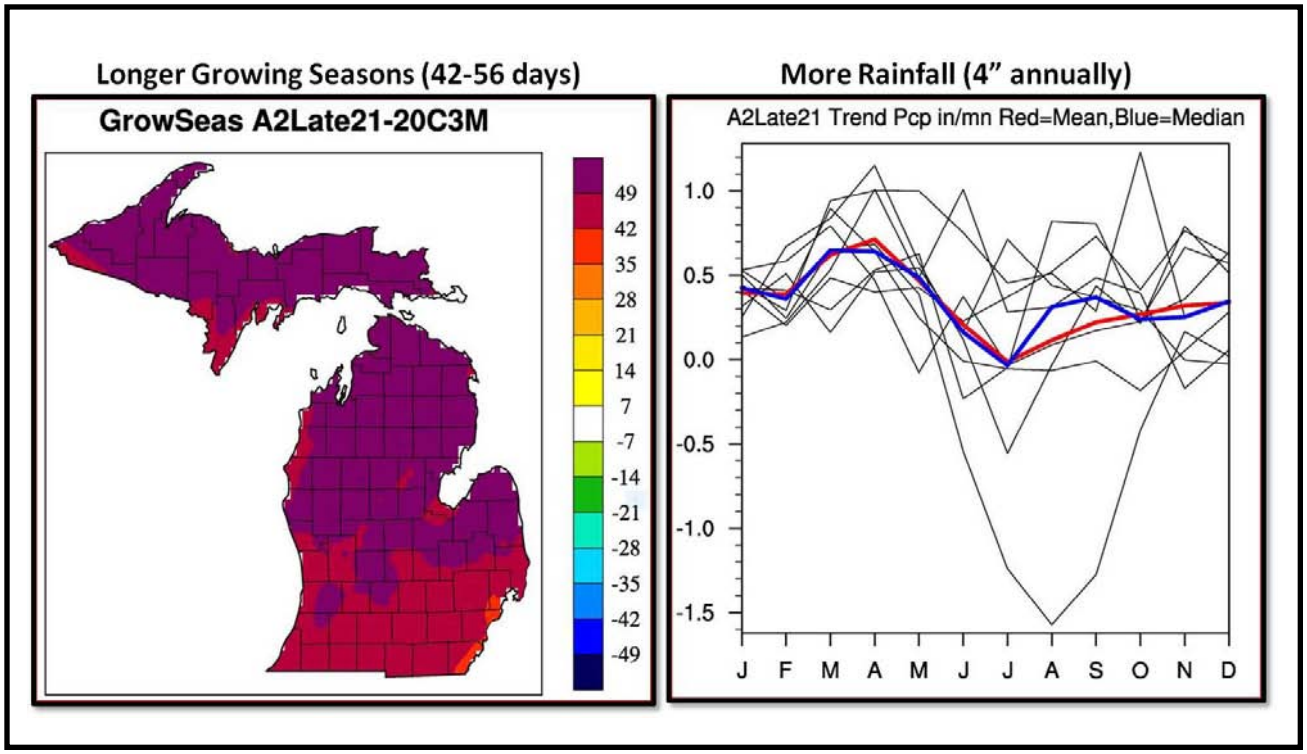

Figure 2. Forecasts for growing season and rainfall in the late 21st century in Michigan. Downscale data from the Nelson Institute Center for Climate Research at the University of Wisconsin. http://nelson.wisc.edu/ccr/resources/visualization-and-tools.php.

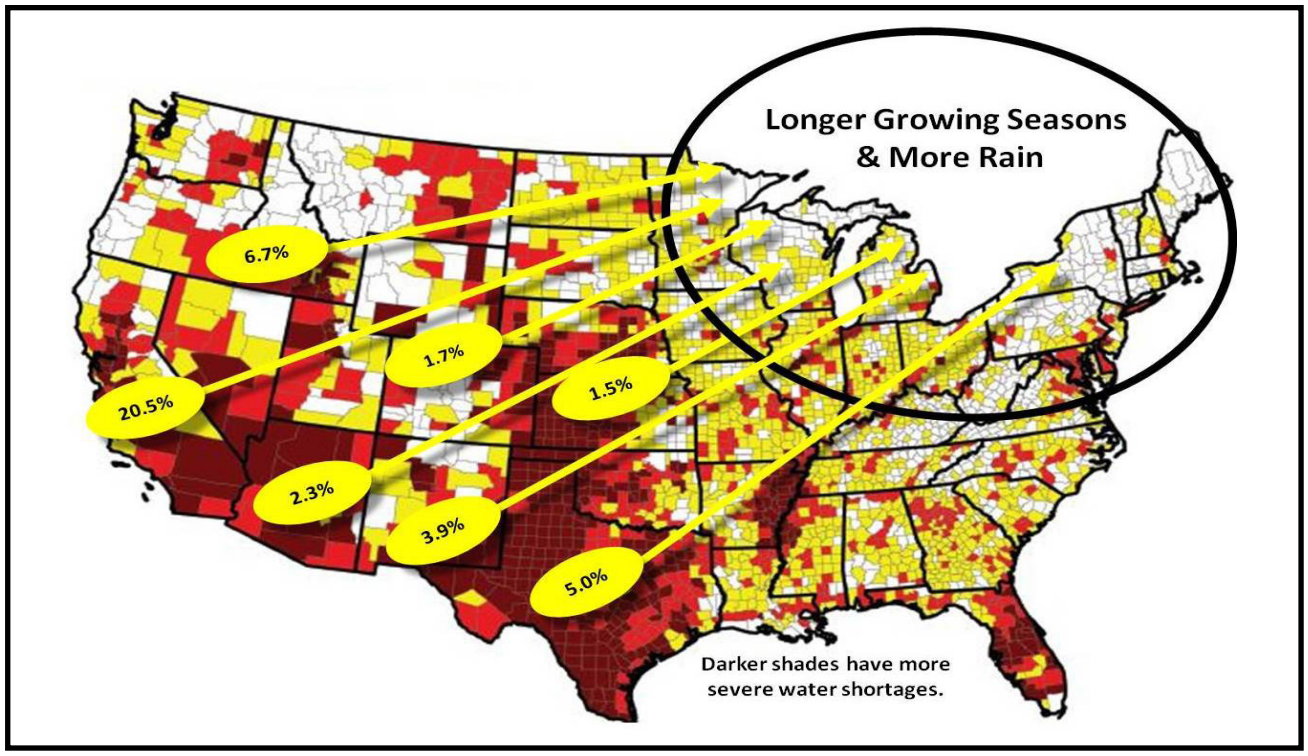

Figure 3. Forecast of movement of dairy cows from southwest and west to regions that will have more rainfall by late century. Map source: Spencer and Altman, 2010.

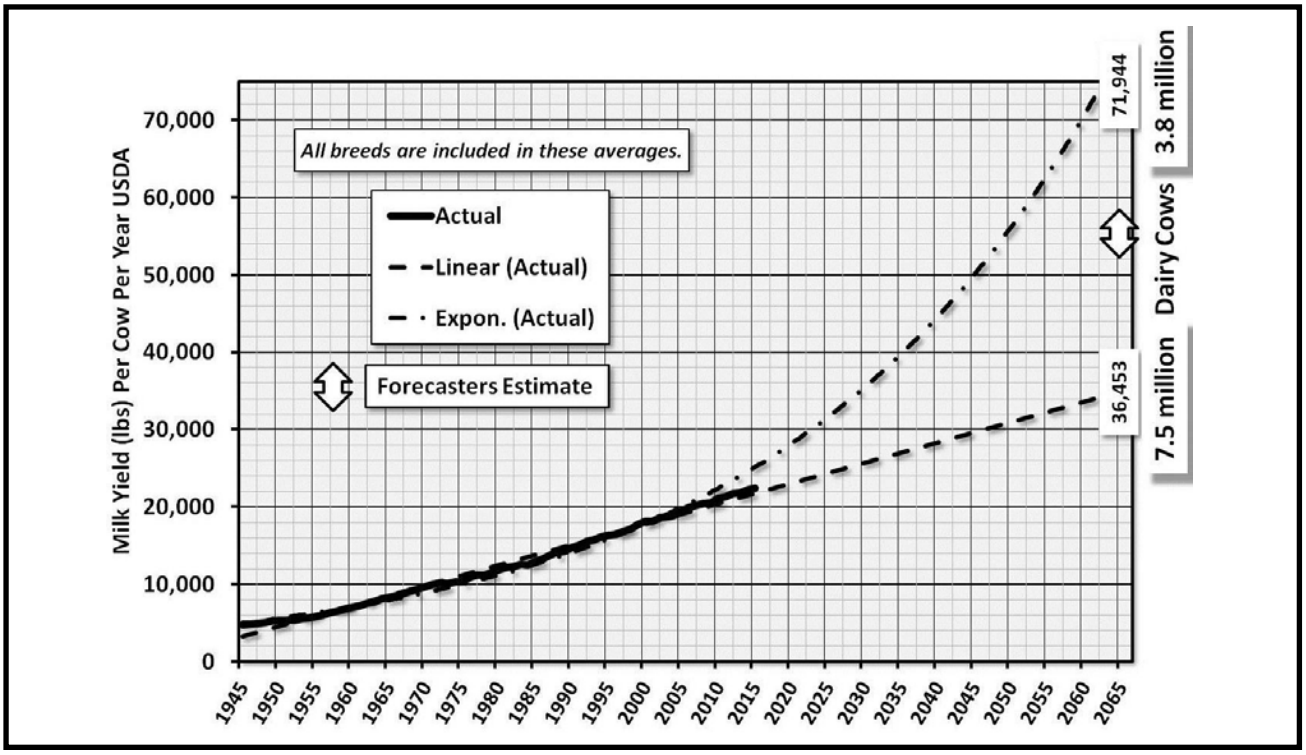

Figure 4. Projected milk yield and number of cows needed to meet USA needs plus 10% export in 2067.

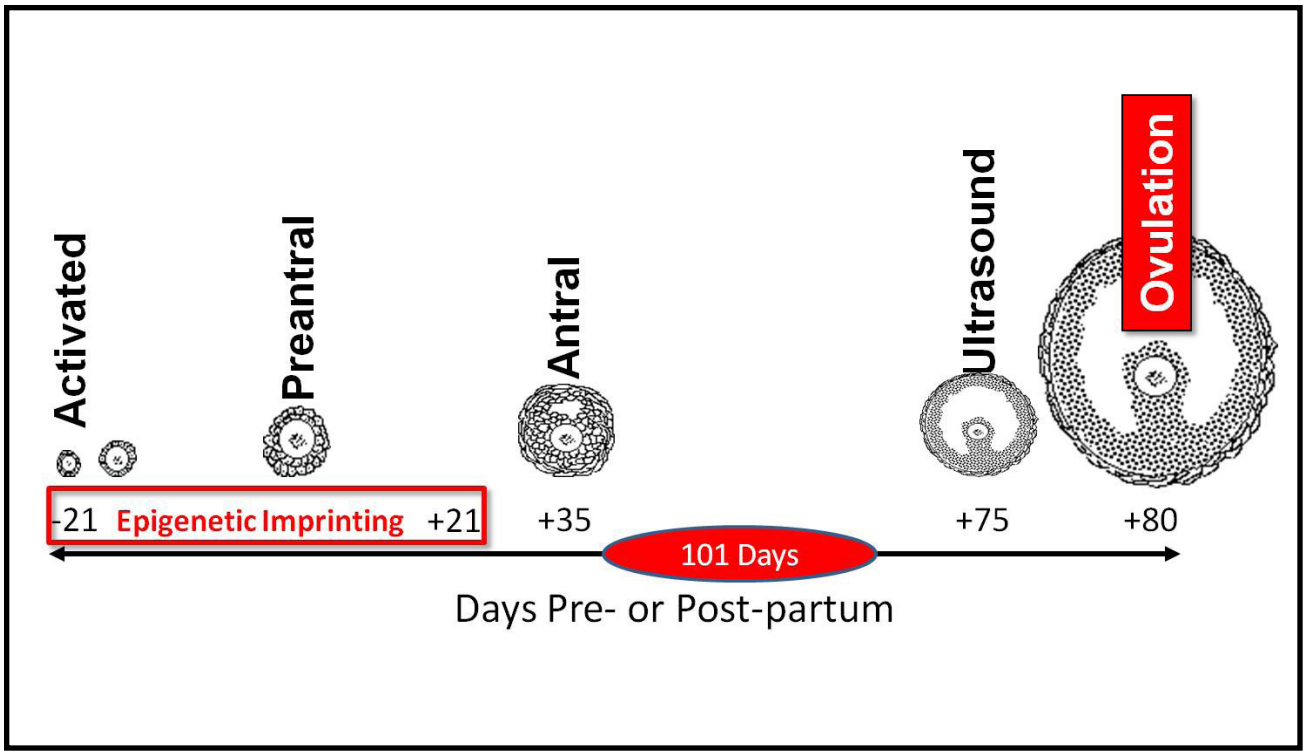

Figure 5. Model for Britt (1992) Hypothesis illustrating temporal relationship between an oocyte's activation about 21 days prepartum and its subsequent ovulation about 80 days postpartum.

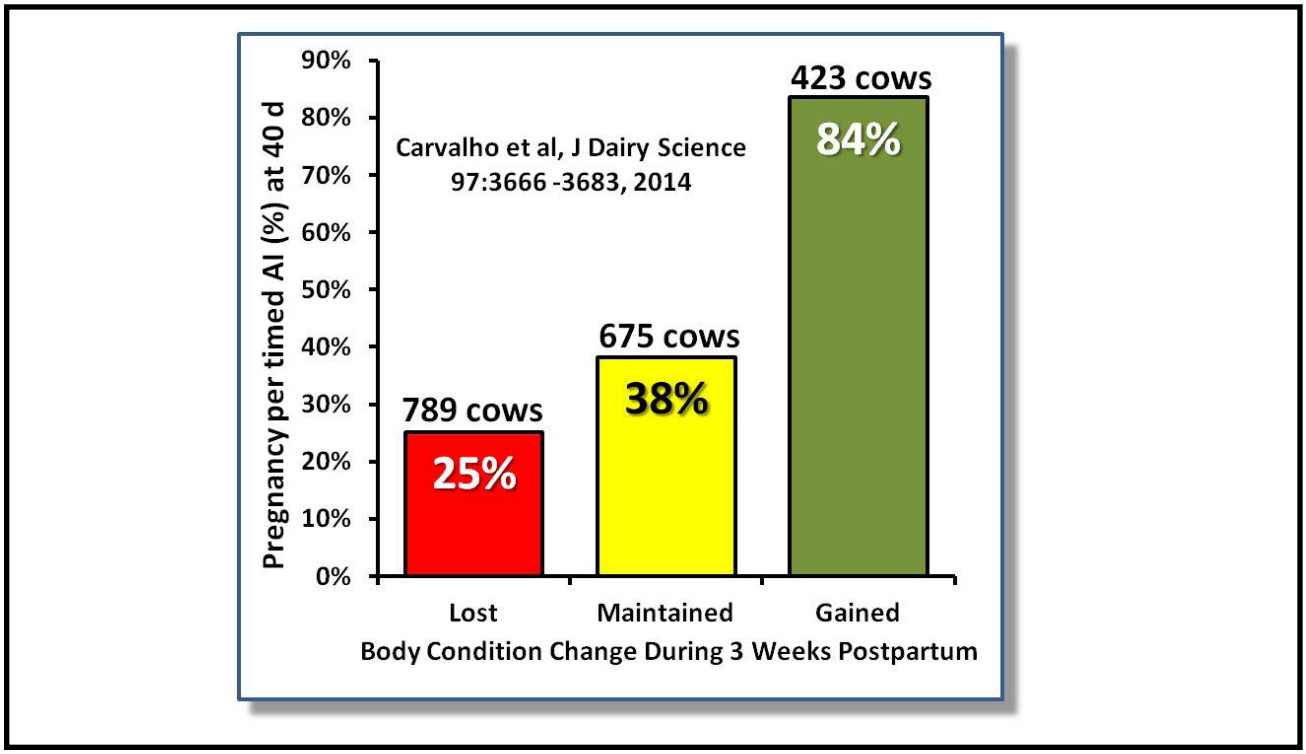

Figure 6. Pregnancy rate to timed AI among cows that lost, maintained, or gained body condition during 3 wk postpartum (Carvalho et al., 2014).

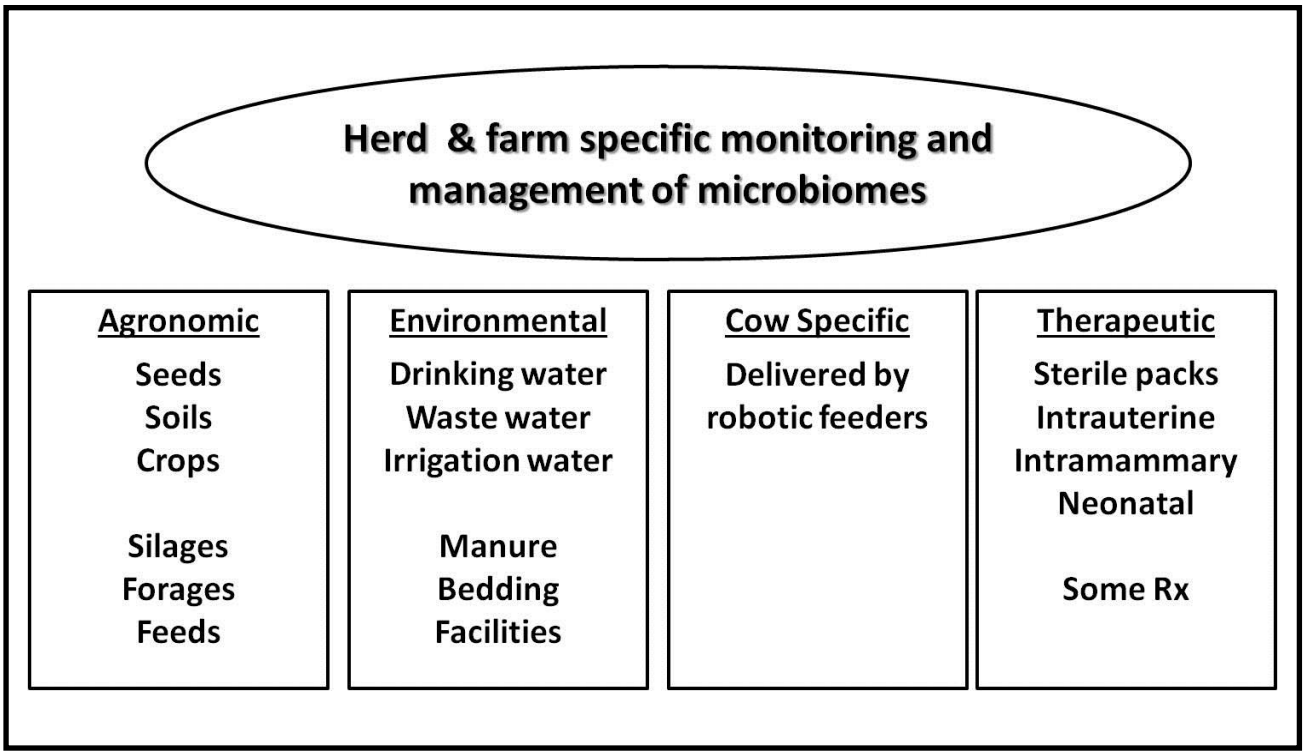

Figure 7. Examples of microbiome management on future dairy farms.

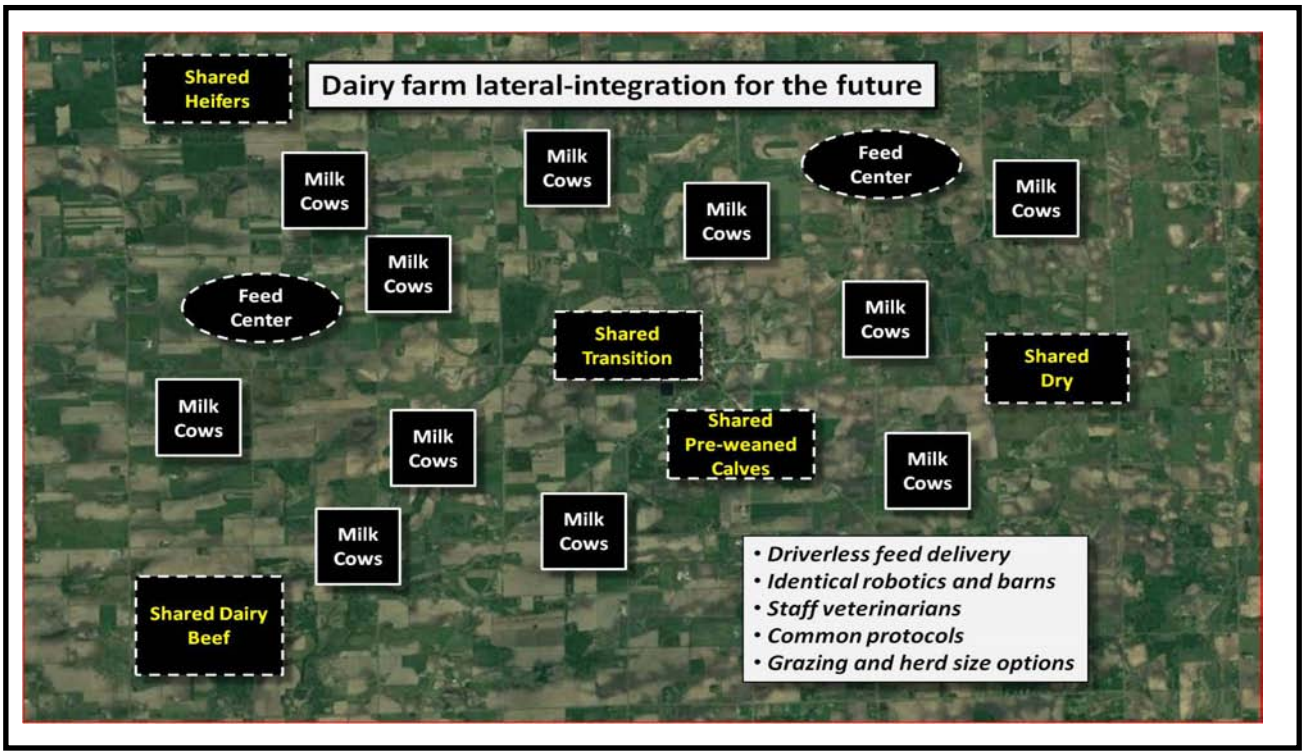

Figure 8. Examples of lateral integration of dairy animal units for efficient production with different scales of enterprises.

Feeding Cows in a Robotic Milking System

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Summary

There has been a rapid growth on the number of farms using robotic milking systems (**RMS**) in the USA. This growth is expected to continue. It is more challenging to feed cows in RMS as the complexity of balancing the ration that is offered in the feed bunk (a partially mixed ration, PMR) and the pelleted feed offered in the milking station can be a difficult task. Additional challenges exist for pasture-based systems as it is necessary to entice cows from pasture to the milking station barn. Important factors affecting feeding success in RMS include feeding a high quality pellet and achieving excellent feeding management. Research shows that pellets are better than meal and that a very hard pellet made from highly palatable ingredients will minimize fetch cows. It is important to balance energy in the PMR with pellets fed through the milking station to optimize visits and minimize the number of fetch cows. A focus should be on optimizing milking station visits and health of early lactation cows and heifers. It is also important to have adequate cow comfort and good hoof health.

Introduction

Dairy producers choose to install RMS for a variety of reasons, but surveys have shown that one of most common reasons relates to labor (flexibility maybe more than labor cost) and lifestyle or quality of life. de Jong et al. (2003) conducted a survey of North American dairy producers who had implemented RMS. They reported that for many smaller farms, using RMS improved flexibility of their schedule and reduced the physical intensity of labor, which was primarily provided by the family owning the farm. In fact, 84% of the producers surveyed mentioned having a more flexible work schedule as a reason for making the decision to install RMS. However, producers did not report a reduction in hours of work on the farm, but they did have a reduction in physical labor, and decreased cost of hired labor was reported by 70% of farms. We found similar results in our survey of RMS dairy farms in Minnesota and Wisconsin. For larger farms, RMS may be a means to reduce hired labor and to provide an improved quality of life to the employees they hire. There are signs that larger farms will adopt RMS, as some have done so already. Notable recent announcements from TDI Farms in Michigan to install 24 DeLaval (Tumba, Sweden) VMS units to milk 1,500 cows; and Chilean Dairy, Fundo El Risquillo, planning to milk 4,500 cows with 64 DeLaval VMS units (http://www.delaval.com). Other examples include Hemdale Farms in New York with 19 Lely (Maassluis, Netherlands) RMS and Corner's Pride in British Columbia with 30 Lely RMS (to be installed by June 2017; http://www.Lely.com).

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It appears that growth in RMS in the USA is a given fact, and one of the most important factors for success in these systems is how cows are fed. When we feed dairy cows, we aim to develop a low cost diet that meets the nutritional requirements of cows while optimizing milk production and cow health. In most conventional confinement herds, this is accomplished by feeding a totally mixed ration (**TMR**) where all the ingredients are mixed together and delivered to the cows. For RMS herds, a PMR containing all the forage and some of the concentrate is offered in the feed bunk. An additional amount of concentrate is fed through the RMS milking station; this amount varies according to the cow's stage of lactation. This appears on the surface to be a simple concept, but achieving the optimal combination of nutrients from the PMR and the concentrate pellet is not necessarily an easy task and it takes some trial and error in some instances.

Enticing Cows to the RMS Milking Station is a Key for Success

The major motivating factor to attract cows to consistently visit the RMS milking station is the pelleted concentrate that is offered in the RMS milking station, not the fact that cows 'feel' they need to be milked at that time. However, cow's attendance to the milking station is not only dependent on the PMR delivered in the feed bunk and pellets offered in the RMS, but also on feeding management, cow comfort, cow health, and social interactions among cows. In a survey we conducted with RMS herds, nutritionists indicated that quality of the pellet offered in the milking station and consistency of the PMR were the 2 most important feeding factors contributing to RMS success.

Rodenburg and Wheeler (2002) showed that in a free flow RMS, feeding a high quality pellet (hard pellet with few fines made from palatable ingredients) increased the number of voluntary milkings from 1.7 to 2.1/cow per day compared with feeding a low quality pellet. We observed that at start-up of a new RMS, nutritionists and farmers focused on developing a pellet formula that encouraged milking station visits. Once they had a pellet that worked well, other factors became more important. Many producers commented that even minor changes in the PMR moisture, consistency of the mix (i.e., long hay that is difficult to process to a consistent length), and changes in forage quality affected visits. Visits may drop if forage moisture changes and rations are not adjusted promptly. The drop in visits will result in a decrease in milk production and an increase in the number of fetch cows. The increase in fetch cows may disrupt other cow behaviors, resulting in even greater decreases in visits and milk production, leading to a downward spiral that creates much frustration for the producer. It is crucial to have consistent feeding in order to maintain high production and minimize the number of fetch cows.

Differences Between Free Flow and Guided Flow RMS Barns

In barns with free flow traffic, cows can access all areas of the barn without restriction. In guided flow traffic, one-way gates and selection gates are used to guide cows to milking, feeding, and resting areas. Free flow traffic was associated with greater milk yield per cow per day (Tremblay et al., 2016) compared to guided flow; their study included only Lely RMS farms. Guided flow was associated with increased number of milkings per day and reduced number of cows being overdue for milking and needing to be fetched (Bach et al., 2009). Cows managed in a guided flow system consumed less meals per day but larger meals with longer meal duration when they visited the feed bunk, resulting in no difference in total eating time, eating rate, or average daily DM intake (Bach et al., 2009).

There are two types of guided flow traffic - milk first and feed first. In the milk first system, cows leaving the resting area must pass through a pre-selection gate that determines if she is eligible for milking. If she meets the requirement to be milked, she is guided to a commitment pen that contains the RMS milking station. If she is not eligible for milking, she is allowed to enter the feed bunk area and can only enter the resting area through a one-way gate. In the feed first system, cow traffic is the reversal of the milk first system. After eating the PMR, cows enter a selection gate that determines if she is eligible for milking. The gate either guides her to the commitment pen for milking or to the resting area. Farmer comments and our observations indicate that the milk first system is superior with the US style of dairying where economics demand high milk production. In feed first systems, cows consume the PMR and tend to stand in the feed alley or commitment pen ruminating without visiting the RMS milking station.

Independent of type of flow used in the RMS, efficient cow flow through the RMS milking station is an important factor influencing the availability of the RMS for milking. This can be inhibited by cows hesitating to leave the RMS milking station, cows remaining in the exit lane, and cows blocking the exit lane outlet. Jacobs and Siegford (2012) reported that cows exited the milking station slower when they were not milked (sufficient time from the previous milking had not lapsed) compared to cows who were successfully milked. Cows were more hesitant in the exit lane if another cow was blocking her exit from the lane on the other side of the exit lane one-way gates, or if other cows were in the area at the exit of the milking station. Later lactation and mid lactation cows were also more likely to hesitate in the exit lane than cows in early lactation. Interestingly, heifers were more often the cause of blocking events than mature cows. Additionally, lighter heifers were more often the cause of blocking events than heavier heifers.

Free flow system feeding strategies

Our survey indicated that the amount of pellets offered through the milking station in free flow system farms averaged 11 lb/cow per day and ranged from 2 to 25 lb/cow per day. The PMR was balanced for milk production levels of 10 to 30 lb less than the herd's bulk tank average milk production.

Lead feeding is generally used in early lactation. To 14 to 28 days in milk, cows are fed for 75 to 90 lb/day of milk. From 14 to 28 days in milk through peak lactation, cows continue to be fed nutrients that support 75 to 90 lb/day of milk or for actual milk production, whichever is higher. After this time, the feed delivery changes to feed cows for actual milk production and regaining body condition. Some farms with very high producing late lactation cows close to dry-off develop a feed table for late lactation cows that decreases RMS station feed so cows drop in production before dry off. One challenge of free flow systems is that late lactation cows can become fetch cows. A key to preventing this is to have an excellent reproductive program that maintains high milk production through the end of lactation.

Guided flow system feeding strategies

Feed first and milk first guided flow RMS use different feeding strategies. Feed first systems use a feeding strategy that is very similar to free flow milking systems and will not be discussed further.

Our survey indicated that most milk first guided flow system dairy producers have a different feeding philosophy than free flow. The

amount of feed offered in the milking station is minimal and only used to entice cows to attend the milking station. A higher percentage of the cow's feed intake is delivered through the PMR. One main reason farmers install guided flow RMS is the desire to feed less of the more expensive pelleted feed in the milking station. Farmers with milk first guided flow systems were feeding from 2 to 12 lb of pellets/cow per day. The average amount fed across all herds was approximately 8 lb/cow per day. Commonly, 1.5 to 3 lb of pellets was fed at every milking visit. Because earlier lactation, higher producing cows are guided to the milking station more frequently, they receive more RMS pelleted concentrate.

The PMR in guided flow systems tended to be slightly higher in energy (0.015 Mcal net energy for lactation/lb DM) and lower in neutral detergent fiber (2.1% of DM) than the PMR in free flow systems. For guided flow herds, the PMR was balanced for 9 to 20 lb less milk production than the average of the herd. This difference should be expected between free flow and guided flow systems. Using a high energy density PMR in free flow barns may lead to more fetch cows or decreased milking frequency, resulting in less milk production per cow, whereas in guided flow barns, cows are guided to the milking station using selection gates.

Other Feeding Considerations

PMR composition and physical characteristics

Table 1 summarizes key PMR nutrient concentrations from our Minnesota/Wisconsin survey and a 2013 Ontario survey (T. Wright, Ontario Ministry of Agriculture, personal communication). Wright also evaluated the PMR particle size using the Penn State Particle Separator and reported a higher percentage of particles on the top screen and a lower percentage on the bottom screen than recommended in a TMR (average 13.1% on the top sieve). This is expected considering some of the concentrate is fed in the milking station separate from the PMR.

Pellet composition and physical characteristics

Pellets that are made from high quality, palatable ingredients and with a very hard sheer force promote increased visits and more rapid feed consumption. Nutritionists need to pay special attention to manufacturing processes to produce a consistent pellet with a high sheer force. Milking station pellets should be designed to complement the farms' forages and other ingredients in the PMR. For example, if the PMR is high in corn silage and thus high in starch, a pellet with highly digestible NDF from by-products should be considered to minimize the risk of sub-acute ruminal acidosis.

Using pelleted feed of different ingredient inclusion rates could be beneficial to more precisely feed individual cows. Halachmi et al. (2006) found that both pellets high in starch (high inclusion of ground barley, corn, sorghum, and wheat bran) and pellets high in digestible neutral detergent fiber (high inclusion of soy hulls, corn gluten feed, and soybean meal) could be used successfully to attract cows to the RMS. The 2 pellets resulted in similar daily milk visits, milk yield, and fat-corrected milk yield. However, concentrate allowance was kept low. Miron et al. (2004) reported a difference in milk components with a higher concentrate allowance - concentrates high in starch resulted in greater milk protein percentage; whereas, concentrates high in digestible fiber resulted in greater milk fat percentage. However, results of these studies may indicate that palatability can be maintained even when significant changes

are made to the ingredient composition of the pelleted concentrate.

Precision Feeding

One potential advantage of RMS is the opportunity to feed each cow closer to her nutrient requirements by providing nutrients through a combination of the PMR and milking station pellet. Even though RMS allow for feeding more than one concentrate feed in the milking station, many producers in our survey only used one feed. Some producers are more recently using more than one feed to better target cows' nutrient requirements. Feeding a combination of concentrates in the milking station at different proportions and amounts according to milk yield, body weight, stage of lactation, and potentially milk components may maximize returns from RMS (Bach and Cabrera, 2017). These authors suggested that concentrate meal sizes should be limited to about 3 lb or less per visit so that cows consume all the feed that is allocated to them at each visit (Bach and Cabrera, 2017).

Fresh Cow Management

Most RMS facilities do not have a separate fresh/early lactation group. Suggestions to consider that may increase the likelihood that all cows have a successful transition and high milk production include:

1. Use of multiple feeds through the milking station which allows the producer to use feed additives specifically targeted to fresh cows. As mentioned earlier, this will allow more precise targeting of nutrients to meet the cow's needs.

2. Special observation and monitoring of fresh cows. Fresh cows that are not feeling well may continue to consume all the milking station pellet but decrease intake of the PMR. This can potentially lead to sub-acute rumen acidosis, digestive upsets, and increase the risk for other diseases.

3. Rumination and activity on all fresh cows should be observed daily. The RMS software (depending on the system) creates a daily list of cows that are not meeting rumination and activity goals compared to herd mates. If these metrics are deteriorating, producers need to intervene rapidly and consider making adjustments to the milking station feed offered.

4. It is important to have a high quality PMR to encourage intake at the feed bunk.

5. Frequent fetching of fresh cows should be a priority. Research has shown that high milking frequency in early lactation increases milk production throughout lactation.

Feeding Consistency

Cows like consistency. This is even more important in a RMS herd. Farmers that achieve consistently high milk production achieve these goals:

1. Consistent PMR (PMR is adjusted to maintain nutrient concentration as forage DM changes) that is well balanced and composed of high quality ingredients.

2. Consistent mixing and delivery of the PMR.

3. Consistent feed push ups.

4. Consistent, high quality RMS milking station pellet.

Considerations for RMS in Grazing Herds

When RMS is used in grazing herds, there is an additional challenge of enticing cows to leave the pasture and voluntarily attend the RMS milking station. In pasture-based systems, there appears to be a relatively large percentage of cows with long milking intervals (defined as greater than 16 hours). Lyons et al. (2013) found 47 and 38% of milking intervals exceeded the 16-hour threshold in groups of cows fed a PMR and concentrate pre and post milking, respectively. Cows fed pre milking returned from pasture to the milking barn sooner (11.9 hours) than cows fed post milking (13.3 hours); however, the cows fed pre milking spent more time in the feeding and waiting areas before entering the RMS platform (voluntary rotary RMS), resulting in a decreased average milking frequency compared to those fed post milking (1.6 vs. 1.7 milkings per day for groups fed pre and post milking, respectively). It is important to note that while there were differences in cow behavior, no differences were found in daily milk yield between the 2 feeding management systems. Davis et al. (2005) also reported a low milking frequency per cow in a pasture-based system with an average of 1.1 milkings per day (range of 0.9 to 1.9).

Conclusions

Feeding cows in RMS requires adjustments on ration formulation to address the need to entice cows to the milking station. Many factors affect attendance to the RMS and influence milk production. Along with balancing the PMR and concentrate pellet for the targeted milk production goal of the farm, factors related to feeding management, cow comfort, and transition cow programs also play a major role. The use of multiple feeds at the milking station (both amount and composition) to more closely match the nutrient needs of individual cows is an area that has not yet been extensively implemented in US herds and could be beneficial to the success of RMS.

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Table 1. Range of select partially mixed ration nutrient values on two surveys of RMS farms.

Item	Univ. of MN Survey	Ontario Survey[1]
Net energy for lactation, Mcal/lb	0.60 to 0.78	0.63 to 0.81
Neutral detergent fiber, % of DM	28 to 40	30 to 50
Crude protein, % of DM	12.0 to 17.7	13 to 18

[1]Tom Wright, Ontario Ministry of Agriculture, personal communication.

DCAD: It's Not Just for Dry Cows

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Abstract

Dietary cation anion difference (**DCAD**) is an index of the relative proportions of the strong cations (potassium and sodium) and anions (chloride) in the diet. The dietary strong ions are virtually 100% absorbed from the diet and play a critical role in regulation of osmotic balance and electrochemical charge in rumen and digestive system, blood, and intracellular fluids, and urinary acid-base excretion in the dairy cow. Low and negative DCAD diets in dry cow diets have been used to prevent milk fever for more than 20 years. However, the importance of DCAD in the lactating dairy cow cannot be underemphasized. Inadequate DCAD in the milking cow diet can lead to impaired acid-base balance and reduced feed intake, milk production, and milk fat content. There is no minimum NRC requirement for DCAD. Meta-analysis of published literature on DCAD suggested that increasing DCAD from 0 to 400 mEq/kg diet dry matter (**DM**) would increase DM intake, milk production, and milk fat yield by 3.3, 2.2, and 0.33 lb/cow/day, respectively. Increasing DCAD from 0 to 400 mEq/kg increased DM digestibility by 3 percentage units, with the majority of the increase due to improved fiber digestibility. The manipulation of DCAD through ingredient selection and supplementation of mineral salts is discussed. The primary economic response to DCAD is milk fat yield and a practical suggested minimum DCAD appears to be about 300 mEq/kg.

Introduction

For more than 20 years, dairy producers have been using low DCAD diets in their transition cow feeding programs to prevent milk fever and subclinical hypocalcemia. The use of low DCAD diets in dry cows has virtually eliminated the incidence of clinical milk fever in most dairy herds. While dairy producers are well aware of the importance of proper DCAD concentrations in the dry period, relatively little attention has been paid to the effect of DCAD in lactating cows. We will review the principles of the strong ions in physiology and calculating and formulating for DCAD and then highlight the responses of lactating cows to DCAD.

What is DCAD?

The term DCAD stands for Dietary Cation Anion Difference. DCAD is an index of the relative balance between the principle cations (potassium; K and sodium; Na) and the principle anions (chloride; Cl and sometimes sulfur; S) in the cow's diet. Na, K, and Cl fall into a class of dietary minerals that are sometimes referred to as the "osmoregulators" because of the critical role that they play in maintaining osmotic balance in various body tissues (Table 2).

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In blood, Na is the primary cation and Cl, and to a lesser extent bicarbonate, ions are the primary anions. In the cell, K is the principal cation, while amino acids and proteins with a negative charge serve as the principle anions. Finally, in rumen fluid, a combination of Na and K are the principal cations, whereas volatile fatty acids (**VFA**) that are produced during rumen fermentation serve as the primary anions. These minerals are absorbed from the diet with nearly 100% efficiency and can readily move across the intestinal wall, blood, and cell membranes. Their relative content in these tissues is maintained by a Na-K-ATP pump. They are also important for maintaining osmotic balance in milk and the relatively consistent moisture content (85%) of feces in the cow. Na and K are the primary drivers of urine output. Thus, added intake of these minerals will also increase water intake in the cow. Finally, surpluses of these ions (Na, K, and Cl) in excess of the cow's requirements are regulated through urinary excretion.

There are 2 important principles with respect to the cations and anions: 1) the sum of the cations and anions (equivalent weight basis) should add up to about 300 to maintain a consistent osmotic pressure and maintain water balance between tissues; and 2) the sum of the cations should equal the sum of the anions to maintain neutral electrical charge. These 2 principles are important in understanding the role of DCAD in acid-base balance and urinary excretion of these minerals.

The Strong Ion Theory

Na, K, and Cl are also referred to as the "Strong Ions" because they are absorbed from the diet with nearly 100% efficiency, they remain completely dissociated in solution and physiologically, and any surplus intake from the diet above and beyond the animal's needs will be excreted in the urine. The "Strong Ion Theory of Acid-Base Balance", first proposed by the Canadian physiologist Peter Stewart (Stewart, 1978) applies to virtually every mammal, including humans. Stewart (1978) referred to the sum of the strong cations minus the sum of the anions as the Strong Ion Difference (**SID**):

$$SID = Na^+ + K^+ - Cl^-$$

The SID equation is in fact identical to the simplest DCAD equation that was first developed for poultry and swine that is also referred to as the Mongin (1981) equation. Excretion of strong ions in the urine can be summarized by the following equation where the sum of the cations (Na^+, K^+, H^+) must equal the sum of the anions (Cl^-, OH^-) to maintain electrochemical neutrality:

$$Na^+ + K^+ + H^+ = Cl^- + OH^-$$

If an animal consumes a diet that is high in cations in relation to anions, (SID or DCAD is positive), its urine must contain additional anions to maintain electrochemical neutrality. Cattle routinely consume diets that are high in K, and the additional base (anion) excreted in the urine is usually the bicarbonate ion. In contrast, cattle consuming diets that are high in Cl relative to K and Na (DCAD or SID is negative), additional cations such as ammonium (**$NH4^+$**) and other titratable acids are needed to balance the negative charge of Cl. Because of this relationship, animals such as cattle which are typically are fed diets high in cations, will have an alkaline urine (pH > 7); whereas, animals that are fed diets that are low in cations will have acid urine (pH < 7). This concept is illustrated in Table 3 that compares lactating sows and dairy cows. Pigs, because they consume a low K diet, have an acidic urine; whereas, cows that consume a high K diet have an alkaline urine.

How Does DCAD Work in Preventing Milk Fever?

The initial work on use of DCAD was based on the observation by Scandinavian researchers that cows fed diets that were low in ash content resulted in reduced incidence of milk fever (Ender et al.,1971; Dishington, 1975). Since potassium is a major factor that affects dietary ash content (low ash diets were also low in K), it was found that diets with low DCAD (low K and Na, relative to Cl) reduced not only milk fever but also subclinical hypocalcemia. Since excess dietary Cl is excreted in urine, it requires a corresponding cation to maintain a neutral charge. Low K diets stimulated hydrogen ion (low pH) secretion and the "spilling of calcium" (Ca^{++}) in the urine. In turn, that increased loss of calcium in the urine also increased the cow's metabolic mechanisms for resorption of calcium from bone and intestinal absorption of Ca from the diet such that the cow was able to regulate blood calcium more effectively when the increased demand for Ca in milk production kicked in at the time of calving.

These observations stimulated numerous studies on the use of DCAD to prevent milk fever by Elliott Block (1984) at McGill University in Canada, Jesse Goff and Ron Horst (1997) at the USDA Animal Disease Laboratory in Iowa, and several others. The key points from their work were: 1) diets that were negative in DCAD were effective in preventing milk fever and subclinical hypocalcemia 2) selection of feeds that were low in K and Na along with addition of Cl and sulfate salts were required to achieve a low or negative DCAD diet, and 3) low urine pH was a very useful indicator of the cow's DCAD status.

Probably the most pivotal experiment was a study using Jersey cows by Goff and Horst (1997) where cows were fed diets containing 1.1, 2.1, and 3.1% K with either 0.5 or 1.5% Ca during the dry period. The DCAD across Ca levels was increased from -75 to 430 mEq/kg diet DM with increasing K. Incidence of milk fever increased from 0% in the 1.1% K, 0.5% Ca diet to 80% in the 3.1% K with either 0.5 or 1.5% Ca. It was clear that the low DCAD (low K) diets had a profound effect on incidence of milk fever. Subsequent work looked at the effectiveness of various Cl and sulfate salts to reduce urine pH and it was determined that dietary sulfur was about 60% as effective as Cl in reducing urine pH and preventing hypocalcemia (Goff et al., 2004).

The DCAD Equations

The simplest calculation of DCAD is referred to as the Mongin (1981) equation that was originally developed for formulation of poultry and swine diets. The formula includes the Na, K, and Cl contents of the diet and an example of DCAD calculations for a diet that meets the minimum (NRC, 2001) requirements for K, Na, and Cl in lactating dairy cows is in Table 1. DCAD is most frequently expressed as either mEq/kg or mEq/100 g feed DM. The difference in magnitude is a factor of 10.

Table 4 shows the various DCAD equations that have been used by dairy nutritionists in diet formulation programs. Each equation is very similar in that they all account for the strong ion (K, Na, and Cl) contents of the diet. The first equation suggested for use in formulating dry cow diets was proposed by Ender (1971). This equation includes dietary sulfur (**S**), which has a +2 valence and therefore in this equation, the sulfur content divided by the atomic weight is multiplied by 2. The inclusion of S in the DCAD formula is only important when dietary S varies. Typically, this is not an issue unless distillers grains (**DDGS**) are a major component of the cow's diet. As stated earlier, the Mongin (1981) equation is the simplest

equation and is equally effective as long as dietary S does not vary substantially. The NRC (2001) equation is perhaps the most precise and is based on the relative rates of absorption of each of the minerals in the equation. However, very few nutritionists utilize that equation. Finally, the Goff et al. (2004) equation with a 0.6 coefficient for S is based on the relative effectiveness of sulfate salts in reducing urine pH compared to Cl salts. In our opinion, this is probably the most precise of all of the DCAD equations. However, the Ender (1971) DCAD equation still remains the most commonly used one, in spite of the fact that it probably overemphasizes the role of dietary sulfur.

DCAD in Lactating Dairy Cow Diets

Although negative DCAD diets have been fed to dry cows for many years, relatively little work was done on the effect of DCAD in lactating dairy cows until the late 1980's and early 1990's. Work by Tucker et al. (1988) demonstrated that in contrast to dry cows, negative DCAD diets should not be fed to lactating cows and negative DCAD diets resulted in reduced feed intake and milk production. A series of experiments at Georgia (West et al., 1992) and Florida (Sanchez and Beede, 1996) examined the effects DCAD during heat stress. They suggested that increasing DCAD improved feed intake, milk production, and milk fat concentration during heat stress. The importance of DCAD was extensively discussed in the 2001 NRC publication, but no minimal DCAD requirement was established. There simply had not been enough experiments conducted with varying DCAD concentrations to establish a requirement at the time of publication. If one were to feed diets at the minimal requirements for K, Na, Cl, and S, the implied requirement would be around 179 mEq/kg DM using the Ender (1971) equation that includes dietary S and about 304 mEq/kg DM using the Mongin (1981) equation that does not include S in the formula.

The first meta-analysis of DCAD studies in lactating dairy cows was published by Hu and Murphy (2004), where the results of 12 papers involving 17 experiments and 54 treatment means were summarized. Hu and Murphy (2004) estimated that maximum feed intake, milk production, and 4% fat-corrected milk (**FCM**) production occurred at DCAD of 40, 34, and 49 mEq/100 g of feed DM, respectively using the Mongin (1981) equation to calculate DCAD. This study conclusively demonstrated the importance of feeding positive DCAD diets to lactating cows. However, the number of experiments and treatment means available for the analysis were limited. Further, many of the diets in that summary were DCAD negative, with more than 50% of the treatment means from cows fed diets containing less than 304 mEq/kg DM, the theoretical requirement for cows fed diets with the minimum requirements for K, Na, and Cl. Because Hu and Murphy (2004) had chosen to use a quadratic equation to explain the data, only a maximal response to DCAD rather than an optimal response could be determined.

Dietary buffers containing bicarbonate and carbonate salts of K and Na will increase DCAD, and they have been common feed additives in dairy cow diets for more than 50 years. We reasoned that the numerous feeding studies on the use of buffers in the early lactation period and to increase milk fat in low forage diets (Erdman, 1988), along with studies published since 2004 could be used to augment the dataset of Hu and Murphy (2004). Although some of the older publications did not have complete mineral analysis to calculate DCAD, we were able to show that book values from the 2001 NRC software could be used to fill in the missing mineral concentrations and accurately predict DCAD (Iwaniuk and Erdman, 2015).

The calculated DCAD from those publications was the basis for our recent meta-analysis of DCAD effects in lactating dairy cows (Iwaniuk and Erdman, 2015). A total of 43 articles published between 1965 and 2011 that included 196 treatment means and 89 DCAD treatment comparisons were included in the analysis. The range in DCAD was from −68 to +811 mEq/kg of diet DM (Ender equation), but the vast majority of diets contained between 0 and 500 mEq/kg of diet DM, which we considered to be the practical range of inference.

Figure 1 (A to D) shows a summary of the dry matter intake (**DMI**), milk production, and milk composition responses to DCAD from that analysis that were fitted to curvilinear and linear response equations. For DMI (Figure 1A), the maximum response was 1.92 kg/day (4.2 lb/day) and 66% and 80% of the maximum DMI responses were achieved at DCAD concentrations of 290 and 425, respectively. Maximum milk production responses (Figure 1B) were small (1.1 kg/day; 2.4 lb/day) with very little response to DCAD above 300 mEq/kg diet DM. For milk fat percentage and yield (Figures 1C and 1D, respectively), the responses were linear. Every 100 mEq/kg increase in DCAD resulted in a 1 point (0.1 percentage unit) increase in milk fat percent and a 38 g/day (0.08 lb/day) increase in fat yield. This suggests that fat yield will be the primary economic response to DCAD. Consequently, the 3.5% FCM response was much greater than for milk production alone, and 66% and 80% of the maximum FCM response (4.8 kg/day, 10.8 lb/day) occurred at DCAD concentrations of 450 and 675 mEq/kg DM, respectively. We consider the 675 mEq/kg DCAD to be outside of the range of inference of this data set. There were no effects of DCAD on milk protein percent or yield (data not shown). In summary, clearly there are intake, milk production, and milk composition responses to DCAD, and these effects need to be accounted for in diet formulation for lactating dairy cows.

We also looked at the effects of DCAD on rumen pH (data not shown). A 100 mEq/kg DM increase in DCAD resulted in a linear 0.003 unit in rumen pH, such that increasing DCAD from 0 to 500 mEq/kg DM was projected to increase mean rumen pH from 6.31 to 6.46. These results are very consistent with earlier studies on the use of buffers to increase rumen pH and correspond to changes in milk fat percent (Iwaniuk and Erdman, 2015).

With respect to digestibility, increasing DCAD from 0 to 500 mEq/kg DM resulted in a 3.5 percentage unit increase in DM digestibility and a 7.5 percentage unit increase in NDF digestibility (Figure, 2A and B). About two thirds of the increase in DM digestibility was due to increased NDF digestibility. Changes in NDF digestibility of this magnitude are huge and exceed those expected with substitution of brown midrib corn silage for traditional corn silage. Oba and Allen (1999) suggested that a 1-percentage unit increase in NDF digestibility resulted in 0.17 and 0.25 kg/day increases in DMI and 4.0% FCM, respectively. Using Oba and Allen (1999) coefficients and assuming a 7.5-percentage-unit increase in NDF digestibility by increasing DCAD from 0 to 500 mEq/kg, the expected increase in DMI and 3.5% FCM would be 1.3 and 1.9 kg/day (2.9 and 4.2 lb/day), respectively and would account for 75% of the expected increase in DMI and 55% of the expected increase in 3.5% FCM. We concluded that one of the primary modes of action of DCAD is the increase in rumen pH and NDF digestibility.

What is the Optimal DCAD for Lactating Dairy Cows?

There is no NRC requirement for DCAD, but feeding at the minimal requirements for Na, K, Cl, and S would result in a DCAD of 304 and 179 mEq/kg DM using the Mongin (1981) and Ender (1971) equations, respectively. The difference being the incorporation of S in the DCAD calculation.Table 5 shows a comparison of the maximum DMI milk, and FCM responses from our summary (Iwaniuk and Erdman, 2015) and the earlier analysis of Hu and Murphy (2004). First, the primary economic response to DCAD is milk fat yield, which in combination with a slight increase in milk production drives increased FCM. Secondly, an optimal DCAD concentration is not necessarily the concentration at the maximal response. We prefer to look at DCAD concentrations somewhat below maximum because there is a cost of added mineral supplements to increase DCAD and the cost of increased feed intake caused by increased DCAD. We view a practical minimum as a DCAD of 300 mEq/kg DM (Ender, 1971 equation). This corresponds to two-thirds of the maximum response in DMI and will garner nearly all the added milk production and achieve the majority of the increase in FCM production. After that point, the decision to feed higher DCAD will depend on the cost of supplementation and the added value of the extra milk fat produced.

Formulating for DCAD

Diet formulation for DCAD begins with feed ingredient selection. Table 6 shows a comparison of selected feed ingredients and their relative mineral and DCAD concentrations. The first thing that is apparent is that most feeds have a relatively low Na content and vary substantially in K, and to a lesser extent, Cl and S. Feeds that are high in DCAD, where the cations (K and Na) are greater than the anions (Cl and S), are usually feeds that are high in K. Feeds like soybean meal, alfalfa haylage, barley, and grass silages that are high in K are also high DCAD feeds. Corn silage, because it is a mixture of the corn plant (stalk and leaves) and grain, is intermediate in DCAD content. Protein supplement, such as DDGS and canola meal are intermediate in K content and are low DCAD feeds because of their relatively high S content. Thus, in selection of feed ingredients for high DCAD, you will normally look for feeds that are high in K content. Feeds like soybean meal and forages, especially alfalfa and small grain silages, will increase DCAD.

Generally, high NDF feeds (forages) are also high DCAD feeds because of their K content. One side benefit of increasing fiber (**NDF**) in the diet to increase milk fat is that this also indirectly increases DCAD. While dairy producers frequently attribute the increase in milk fat when NDF is increased to the added NDF, part of the response is likely due to increased DCAD caused by substitution of low fiber and low DCAD feeds like corn for high fiber and high DCAD feeds like grass or small grain silages.

Supplements that can be Used to Increase DCAD

Once DCAD has been increased through feed ingredient selection, further increases can be achieved by use of mineral supplements. There are a variety of Na and K carbonate and bicarbonate salts that can be used to raise DCAD. Table 7 shows some commonly supplemented K and Na mineral salts used in dairy cattle diets. Please note that common salt (**NaCl**) and potassium chloride (**KCl**) are DCAD neutral since the cation (Na or K) is balanced by a corresponding anion (**Cl**). While salt and KCl are highly available sources of Na,

K, and Cl, supplementing with these minerals will have no effect on DCAD. In order to raise DCAD, nutritionists must select from mineral supplements, such as potassium carbonate, sodium bicarbonate, or sodium sesquicarbonate. Surprisingly, there is very little difference among these in their relative DCAD content (Table 7). Adding 0.75, 0.83, or 0.75% of commercially available potassium carbonate, sodium bicarbonate, or sodium sesquicarbonate, respectively, to the diet DM will increase DCAD by 100 mEq/kg diet DM. At that point, the choice of supplement is based on cost unless the minimum requirements for sodium and potassium have not been met.

Summary

DCAD is not only important in dry cows but also lactating cows. Optimal DCAD for dry cow diets is typically zero or negative, while feeding low DCAD diets to lactating cows will depress feed intake, milk production, and milk fat concentration. A suggested minimal DCAD for lactating cows is most likely about 300 mEq/kg feed DM (30 mEq/100 g DM). However, the optimal DCAD will be dependent on the value of the increased milk and milk fat yields, including the primary economic responses to DCAD, the cost of increased feed intake, and the cost of increasing DCAD above the diet's inherent DCAD concentration using mineral supplements.

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Table 1. Calculation of dietary cation anion difference using K, Na, and Cl.[1]

Element	% of DM	g/kg	Atomic Wt., g	Eq./kg	Eq/kg
K	1.06	12	39.1	0.271	271
Na	0.23	2.3	23.0	0.100	100
Cl	0.24	2.5	35.5	0.067	67

[1]DCAD = mEq K + mEq Na – mEq Cl; DCAD = 271 + 100 – 67; DCAD = 304 mEq per kg DM = 30.4 mEq per 100 g DM.

Table 2. Principle cations and anions (mEq/L) in body fluids.

Ion(charge)	Blood	Intracellular	Rumen Fluid
Sodium (Na^+)	145	12	84
Potassium (K^+)	4	139	27
Chloride (Cl^-)	116	4	8
Bicarbonate($HCO3^-$)	29	12	6
Amino acids and proteins$^-$	9	138	(VFA's) 105
Magnesium (Mg^{++})	1.5	0.8	4.2[1]
(Ca^{++})	1.8	<0.0002	3.5[1]
Milliosmoles/L	290	290	315[1]

[1]From Bennink et al., 1978.

Table 3. Comparison of strong ion requirements for lactating dairy cows and sows using the 2001 Dairy NRC and 2012 Swine NRC.

Mineral	Lactating Sow Requirement, % As Fed	Lactating Cow Requirement, % of DM
Na	0.20	0.23
K	0.20	1.06
Cl	0.16	0.24
DCAD[1], mEq/kg	93	303
Expected urine pH	6.5	7.5 to 8.0

[1]DCAD = Dietary cation anion difference.

Table 4. Examples of various DCAD equations used in dairy cattle feeding programs when minerals are fed at NRC (2001) minimum requirements.[1]

Equation	Elements Included:	DCAD, mEq/kg DM
Ender (1971)	Na + K - Cl - S	179
Mongin (1981)	Na + K - Cl	304
2001 Dairy NRC	(Na + K + 0.15 Ca + 0.15 Mg) − (Cl + 0.6 S + 0.5 P)	284
Goff et al. (2004)	Na + K - Cl - 0.6 S	228

[1]DCAD = Dietary cation anion difference.

Table 5. Comparisons of maximum responses to dietary cation anion difference (**DCAD**); (Ender 1971 equation) from the meta analyses conducted by Iwaniuk and Erdman (2015) and Hu and Murphy (2004).

Item	Maximum Response, kg/day	66% of Maximum	80% of Maximum	Hu and Murphy (2004)
		DCAD mEq/kg DM Required		
DMI	1.92	290	425	275
Milk	1.11	150	225	215
FCM	4.82	450	675	No Maximum

Table 6. Comparison of cation (K, Na) anion (Cl, S), and dietary cation anion difference (**DCAD**) concentrations (mEq/kg DM), along with crude protein (**CP**), and NDF of feed ingredients. DCAD was calculated using the Ender (1971) equation that includes dietary S.

Feed Ingredient	K	Na	Cl	S	DCAD	CP, %	NDF, %
Shelled corn	107	9	-23	-63	31	9.4	9.5
Dried distillers grains	281	130	-28	-275	109	29.7	38.8
Soybean meal	775	13	-155	-244	389	53.8	9.8
Canola meal	361	30	-11	-456	-76	37.8	29.8
Corn silage	307	4	-82	-88	142	8.8	45
Alfalfa haylage	775	13	-155	-188	445	22.8	36.3
Grass silage	795	22	-181	-131	505	18	49.9
Barley silage	621	57	-203	-106	369	12	56.3

Table 7. Composition of sodium and potassium mineral supplements.

Mineral Supplement	K, %	Na, %	Cl, %	DCAD,[1] Eq/lb	DCAD, Eq/kg	DCAD
Salt (NaCl)	0.0	39.3	60.7	0	0	Neutral
Potassium Chloride (KCl)	52.4	0.0	47.6	0	0	Neutral
Potassium Carbonate (K_2CO_3)	52.4	0.0	0.0	609	1340	Positive
Sodium Bicarbonate ($NaHCO_3$)	0.0	27.7	0.0	547	1203	Positive
Sodium Sesquicarbonate ($Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$)	0.0	30.5	0.0	602	1325	Positive

[1]DCAD - Dietary cation anion difference.

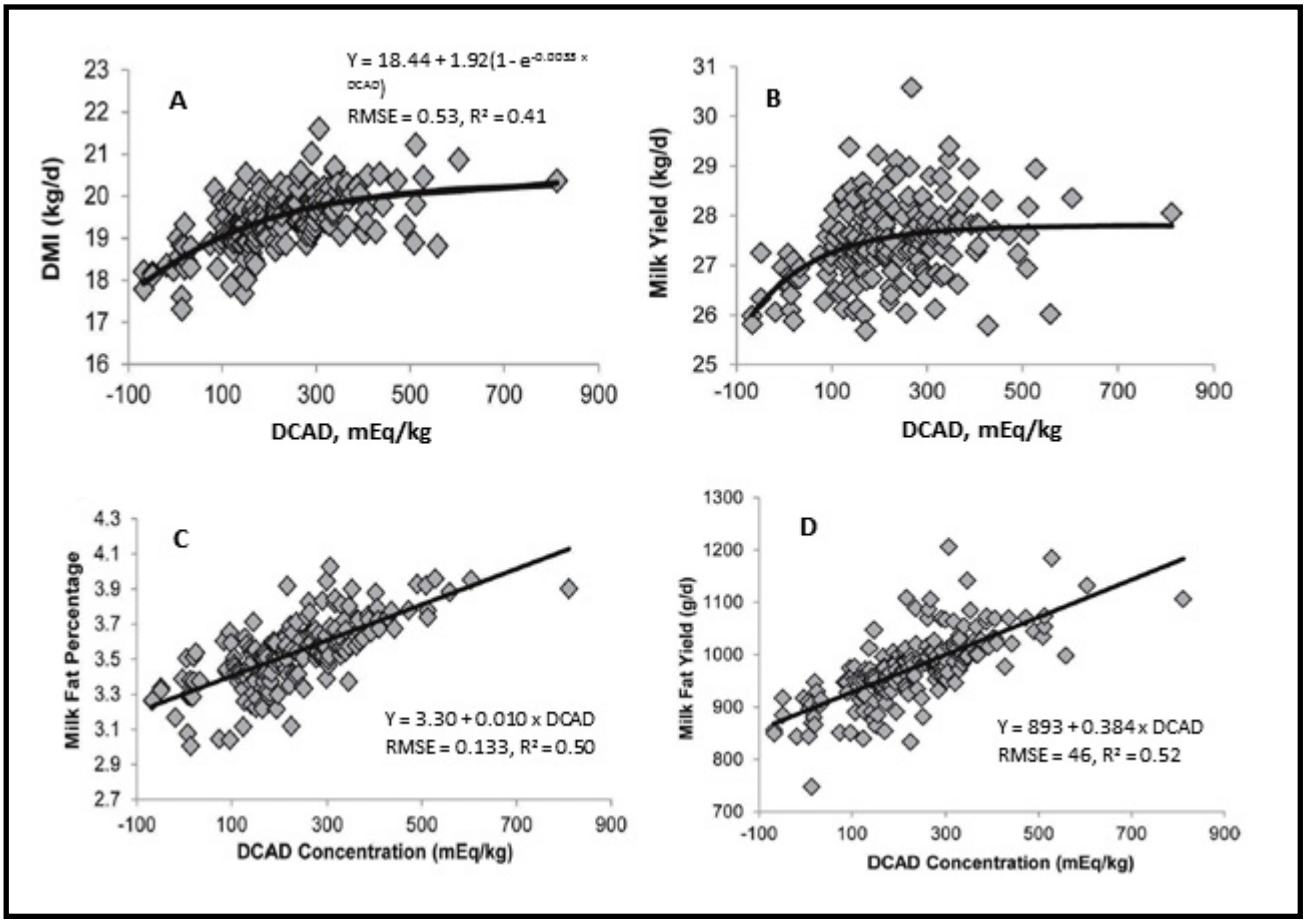

Figure 1. Dry matter intake (A), milk production (B), milk fat percent (C) and fat yield responses (D) to increasing dietary cation anion difference (**DCAD**: Iwaniuk and Erdman, 2015; RMSE = root mean square error).

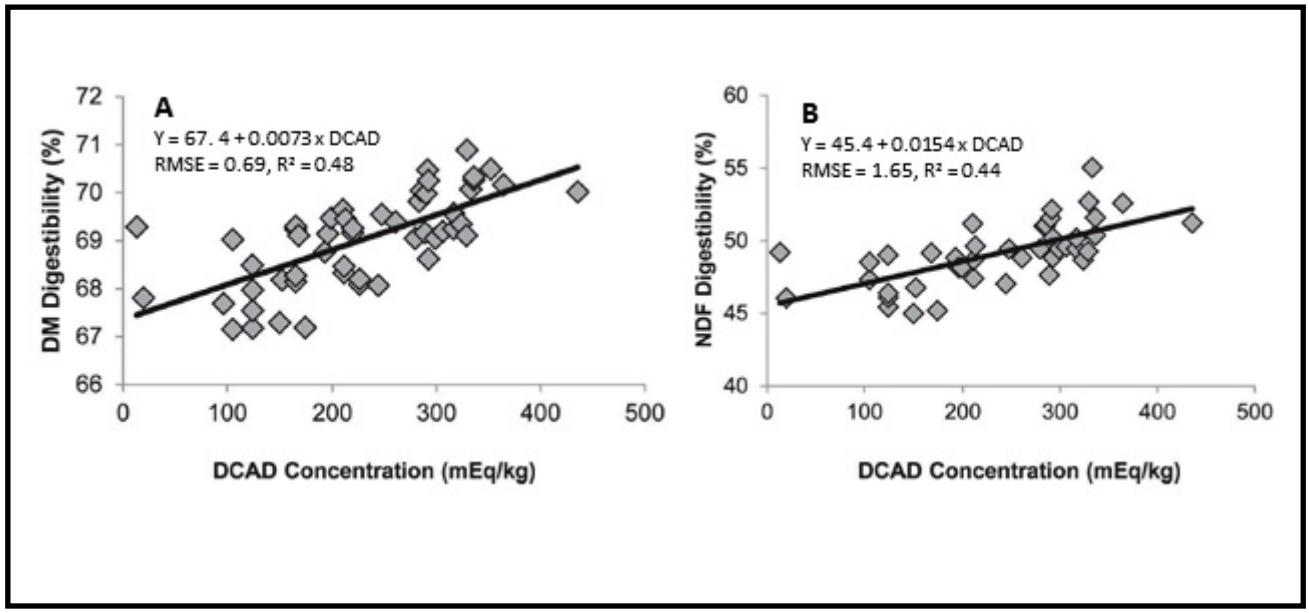

Figure 2. Effect of dietary cation anion difference (**DCAD**) on dry matter (**DM**) (A) and NDF digestibilities (B). (Figures from Iwaniuk and Erdman, 2015; RMSE = root mean square error).

Sugars in Dairy Cattle Rations

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Abstract

Sugars found in animal feeds include the monosaccharides glucose and fructose and the disaccharides sucrose and lactose. They are part of the larger commonly analyzed fractions of water- and 80% ethanol-soluble carbohydrates. Ruminal microbes convert sugars to organic acids, gases, microbial cells, and glycogen. Fermentation of sugars can produce a greater molar percentage of butyrate than is seen with starch. Glycogen is an internal storage polysaccharide with a structure similar to starch that is produced by ruminal bacteria and protozoa; the sugars other than lactose may be more prone to be converted to glycogen than is starch. Production of glycogen slows the fermentation rate of sugars, potentially helping to maintain higher ruminal pH. Glycogen production can also reduce energy available for microbial growth, but this may be counterbalanced by the rapid rate of microbial growth on some sugars. When substituted for starch or starchy feeds, increasing the amounts of sugars in diets for lactating cows have had varied effects -- not affecting (most studies), increasing, or decreasing milk and milk protein production. A more common effect of sugars is to increase milk fat production. This may be related to production of butyrate or the role of glucose-utilizing microbes in the biohydrogenation of fatty acids. In order to more reliably predict animal performance as we modify sugar content of rations, we need a better understanding of how the impact of sugars on nutrient supply and rumen function are affected by the levels of sugars fed and other feeds and components in the rations.

Introduction

"Sugars" include the monosaccharides or simple sugars glucose and fructose, and the disaccharides sucrose and lactose (Figure 1). These water-soluble, readily available carbohydrates have digestion characteristics that differ from the starch and fiber carbohydrates in the diet, particularly in how they behave in the rumen. Understanding how ruminal microbes and the cow utilize sugars can help us to understand the basis for the effects we see on animal performance.

Sources and Measurement

There is sufficient variation in the sugar contents of feeds that they can be used to modify the sugar content of diets. Glucose, fructose, and sucrose are found in fresh forage and hays and are affected by stage of maturity and growing conditions of the crop and preservation conditions (2 to 6% of DM in legumes and warm season grasses, up to 8 to 15% in some cool season grasses; Smith, 1973). Silages tend to have little residual sugar after fermentation, but this can increase to a few percent in well preserved

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forages with higher DM concentrations (M.B. Hall, unpublished), or up to 40% (measured as nonstructural carbohydrate) in high sugar silages such as that made with sugar cane (Sousa et al., 2014). Fruit and vegetable pulps, such as citrus and beet pulps, can contain substantial amounts of sugars that vary with the amount of citrus or beet molasses applied (citrus pulp: 12 to 40% as ethanol-soluble carbohydrates; Hall, 2001). Cane or beet molasses vary in sugar content depending upon the blends of ingredients present in the final product. Almond hulls (20 to 29%; Aguilar et al., 1984), and even soybean meal (6 to 7%; Choct et al., 2010) can contribute sugars to the diet. Lactose is found only in milk products, such as whey (70%; Defrain et al., 2004) and whey permeate (76 to 85%; American Dairy Products Institute, 2016).

Commonly used feed analyses do not measure sugars alone, but include them in larger fractions. Water-soluble carbohydrates (**WSC**) and 80% ethanol-soluble carbohydrates (**ESC**) include sugars but also contain other carbohydrates. The WSC include simple sugars, both sucrose and lactose, short chain carbohydrates (oligosaccharides), and possibly some of the polysaccharides. such as long and short chain fructans. The ESC contains the same carbohydrates as WSC except that it does not fully solubilize lactose (Machado et al., 2000) or long chain polysaccharides (Asp, 1993), including the long chain fructans. Based on our present understanding, the ruminal fates of the WSC are sufficiently similar, except for rates of fermentation, to keep them as a group…. but don't call them "sugars".

An assay used on molasses that does measure sugar content is "total sugars as invert". This analysis provides a value for the sum of sucrose, glucose, and fructose in molasses. If whey was added to the molasses to help it flow, the value may or may not include lactose, or may count only half of the lactose, depending on the analysis used.

Utilization of Sugars in The Gut

Cattle themselves have the capacity to digest starch, lactose, and the microbial storage carbohydrates glycogen and the disaccharide trehalose, based on enzymes present in the pancreatic secretions and the membrane lining the small intestine (Kreikemeier et al., 1990). All other carbohydrates, including sucrose, fructans, pectins and those in neutral detergent fiber, must be degraded and utilized by ruminal or other gastrointestinal microbes for them to provide nutrients to the animal. Based on their solubility, sugars likely flow with liquid in the gut.

Microbial products

Sugars disappear very rapidly from the rumen, with rates of glucose disappearance of 422 to 738% per hour (Weisbjerg et al., 1998). Microbial fermentation of sugars is generally reported to give greater molar percentages of butyrate and lactate than does starch (Strobel and Russell, 1986; DeFrain et al., 2004; Hall et al., 2010). But the yield of microbial nitrogen from sugars like sucrose has been reported to be lower than from starch (Hall and Herejk, 2001; Sannes et al., 2002). However, organic acid and microbial cell growth do not tell the whole story.

We've traditionally thought of ruminal disappearance of carbohydrates in terms of microbes converting them into organic acids (lactate, acetate, propionate, butyrate, valerate), gases (carbon dioxide and methane), and microbial cells, or having the carbohydrates pass undegraded through the rumen. But, there are other products that ruminal microbes can make in appreciable quantities, and one of them is glycogen (Figure 2). Glycogen is a

polysaccharide with a structure very similar to starch. It is made and stored internally by both protozoa and bacteria and may be fermented by the host microbe. Glycogen may pass from the rumen with the passage of microbes, such that there can be a significant flow of glycogen (with potential to digest like starch) to the small intestine, even on all forage rations (Branco et al., 1999). Glycogen production essentially slows down fermentation and acid production, relative to the rate of the readily available carbohydrate from which it was formed. But, a hidden cost of glycogen production is that it costs 1 ATP to add a glucose to the glycogen chain (Ball and Morell, 2003). To put this in perspective, if rumen microbes obtain 3 to 4 ATP from fermenting a carbohydrate (Russell and Wallace, 1988), transiently storing glucose as glycogen effectively decreases the ATP yield by 25 to 33%, reducing the amount of energy available to drive microbial cell production. The facts that not all of the carbohydrate that microbes took up has yet been fermented to energy that drives microbial cell growth, and that the available ATP has been reduced may be the basis for reported reductions in microbial nitrogen production with sugars as compared to starch (Hall and Herejk, 2001; Sannes et al., 2002).

Sugars may be more prone to be converted to glycogen than many other carbohydrates because of how rapidly available they are in the rumen. More microbial glycogen is made when greater amounts of rapidly available carbohydrate are present (Prins and Van Hoven, 1977), particularly if there is more available relative to the microbes' need for energy (Ball and Morell, 2003). In this light, glycogen this may be an alternative strategy to energy spilling where microbes produce ATP from fermenting carbohydrate, but then waste the energy as heat. Increased availability of ruminally degradable protein (**RDP**) can decrease glycogen production (McAllan and Smith, 1974) and increase the flux of carbohydrate through fermentation, which can also increase ruminal lactate production (Counotte and Prins, 1981; Malestein et al., 1984). Given glucose as a substrate, ruminal microbes prefer to use amino nitrogen (amino acids, peptides) rather than ammonia or urea (Hristov et al. 2005) and may produce more microbial protein with peptides than urea (Figure 3; Hall, 2017).

Effects of sugars on ruminal fiber digestion have varied among studies. Supplementation of cattle diets with feeds high in sugar have depressed fiber digestion, even when ruminal pH is not greatly reduced (Pate, 1983). Sugar supplements can depress fiber digestion through effects of pH (Khalili and Huhtanen, 1991), inhibitors produced by the microbes (Piwonka and Firkins, 1996), and if RDP is limiting (Heldt et al., 1999). In the latter case, it may be a matter of the sugar-utilizers outcompeting fiber-users for scarce nutrients (Jones et al., 1998). However, sugars may not be all bad: there is some evidence that they may increase fiber digestion if protein is not limiting (Heldt et al., 1999) (Figure 4).

Sugar-utilizing microbes also have a role in the biohydrogenation of fatty acids in the rumen which may affect milk fat production. Some species of glucose-utilizing microbes perform biohydrogenation on fatty acids in the rumen (e.g., *Butyrivibrio fibrosolvens*; McKain et al., 2010). The trans-10 isomer of the 18:1 fatty acid has been implicated in milk fat depression. When sucrose was supplemented as 4.7% of ration DM, the concentration in the milk of total trans 18:1 fatty acids declined and milk yield had a tendency to increase (Penner and Oba, 2009). In one study, addition of 2.6% molasses blend product that added 1.5% invert sugars to the diet was associated with an increase in the trans-10 18:1 concentration in milk, but it

was questioned as to whether this was a molasses product effect, or related to urea feeding on some diets containing the molasses product (Oelker et al., 2008).

Another difference between sugars and other carbohydrates like starch is strictly a matter of how much sugar is actually there in terms of hexoses, or single 6-carbon sugars. Glucose, fructose, and galactose are hexoses. One glucose = 1 hexose that is not bound to another sugar, so 1 lb of glucose = 1 lb of free hexose. Sucrose or lactose contain 2 hexoses that are bound to each other. To put them on the same free hexose basis as glucose, the molecules have to be hydrolyzed to release the free sugars, which means you have to add the weight of water used to hydrolyze them, which nets 1.05 lb free hexose per pound of disaccharide. In polysaccharides like starch, there are many bonds that need to be hydrolyzed by the addition of water, and so 1 lb of starch = 1.11 lb of free hexose. So, the same DM weight of starch has more total free hexose than sugars. Does this matter? If the microbes can use sugars more efficiently than starch because they can ferment them more rapidly (think dilution of maintenance), then maybe not, but it is another piece that can factor into the value of carbohydrates to the microbes or cow.

Lactose different than other sugars?

The way microbes handle lactose seems to be different from other sugars, possibly because of its slower rate of utilization. In fermentations using ruminal inoculum from cows that had been fed glucose and lactose for 2 weeks so that the microbes were adapted to using the sugars, there was slower carbohydrate disappearance and organic acid production with lactose than with glucose (Figure 5; Hall, 2016). There was much more glycogen production with glucose, though lactose fermentations produced enough to maintain the initial level of glycogen. Microbial nitrogen yield was lower with lactose. Lower microbial nitrogen and glycogen production for lactose may have been related to its much slower rate of use by the microbes.

Animal Performance

Based on microbial use of sugars, how might sugars affect animal performance? The results we see in research studies are affected by how much and what type of sugar was included, what the background level of WSC was in the diet, and what the other ration ingredients were. At this point, we do not have sufficient information to state exactly how sugars will affect performance under different circumstances. However, with an understanding of how sugars are processed in the gut, we may hazard some ideas on what factors can affect cow performance.

Milk production

In research studies, supplementation with sugars or sugar sources did not affect milk production when substituted for starch or starch sources (Nombekela and Murphy, 1995; McCormick et al., 2001; Sannes et al., 2002; DeFrain et al., 2004; Broderick et al., 2008; Oelker et al., 2008; Hall et al., 2010), or increased production to a point then declined above 5 to 6% total sugars as ESC in the diet (Broderick and Radloff, 2004), or depressed milk production in late lactation cows (Oelker et al., 2008). A key element here may be simply making sure that enough digestible carbohydrate is provided to the animal to meet energy needs.

Milk fat

Sugars have been reported to increase milk fat production (lb/day; Nombekela and Murphy, 1995; Broderick and Radloff, 2004; Broderick et al., 2008; Penner and Oba, 2009),

but that response is not always seen (McCormick et al., 2001; Cherney et al., 2003; DeFrain et al., 2004; Oelker et al., 2008). Milk fat production was depressed when sucrose addition in late lactation cows also depressed milk production (Sannes et al., 2002). One way that sugars could have a positive impact on milk fat is through biohydrogenation of fatty acids to reduce availability of those that can cause milk fat depression. That would require that unsaturated fatty acids that could become a problem are present in the diet in sufficient amounts to potentially be an issue. It could also require that the rate of liquid passage is at a rate that allows the microbes and fatty acids to remain in the rumen long enough for biohydrogenation to occur. Another potential option to affect milk fat is through production of butyrate. Ruminal infusions of butyrate or acetate were shown to increase the milk fat percentage and not depress milk yield, but milk production of animals on the studies were quite low (Rook and Balch, 1961; Rook et al., 1965). Although butyrate makes up a small proportion of the fatty acids in milk, it constitutes approximately 30% of the fatty acids in the sn-3 position in milk triglycerides (Jensen, 2002) and can be used to make other short chain fatty acids that are secreted in milk.

Milk protein

Milk protein production (lb/day) has been reported to increase and then decrease with increasing sugar addition (maximum response at ~added 3 to 6% sugars then declined; Broderick and Radloff, 2004), be unaffected by sugar addition as a substitution for starchy feeds (Nombekela and Murphy, 1995; McCormick et al., 2001; Cherney et al., 2003; DeFrain et al., 2004; Broderick et al., 2008; Oelker et al., 2008), decrease with sucrose addition (Sannes et al., 2002; milk production depressed), or be equivalent to starch when more undegradable protein was increased in the diet or less than starch with more dietary RDP (Hall et al., 2010). The effect of sugar inclusion will likely be a matter of how rapidly the microbes are grown and the degree to which they pass from the rumen to where the cow can digest them, and whether the amino acids that the microbes provide are a limiting nutrient for milk protein production. We may be able to get more microbial protein produced from sugars if we provide true protein / peptides rather than urea. That could also result in less glycogen production and the associated reduction in energy available for microbial growth. Another thing to consider is shown in Figure 5. Compared to slowly used lactose, even though the microbes made much more glycogen when given glucose, they still made more microbial protein. That could be a function of dilution of maintenance – even with the glycogen drain on ATP, the microbes were using the glucose so quickly that the amount of the energy that they spent on maintenance was a smaller proportion than they spent on growth; just like the feed efficiency of energy spent on milk production vs. maintenance for a high producing cow vs. a low producer. Delivery of protein from sugar-utilizing microbes to the cow may also have the advantage that those microbes have potential to pass from the rumen more quickly as they move with the liquid, rather than the much slower passage with the solids.

Ruminal pH

Generally, sugars have not had the negative impact on ruminal pH that one might expect from a potentially rapidly fermenting carbohydrate that can ferment to lactic acid. When comparing sugars or sugar sources vs. starch or starch sources in lactating dairy cows, ruminal pH was unaffected (McCormick et al., 2001; Sannes et al., 2002; Broderick and Radloff, 2004; DeFrain et al., 2004; Broderick et al., 2008; Oelker et al., 2008) or increased (Penner and Oba, 2009) as sugars in the

diets were increased. Lactating cows given a molasses + sucrose-containing diet with more undegradable protein had a similar rumen pH to diets containing ground corn or citrus pulp as the main nonfiber carbohydrate source (average pH in 6 hours after feeding = 6.0). But, a molasses + sucrose diet with more RDP had an average ruminal pH of 5.7 in the same time frame (Hall et al., 2010). When beef steers were fed low-quality tallgrass-prairie hay supplemented with 0.122% of BW as supplemental RDP and 0.30% of BW as glucose, fructose, or sucrose, ruminal pH reached its lowest point at 3 hours post-feeding, the earliest sampling point for the sugars; whereas, ruminal pH of cattle receiving starch reached the lowest point at 9 hours post-feeding (Heldt et al., 1999); the average ruminal pH of the starch-fed animals was lower than those receiving one of the sugar treatments which did not differ. A study on induced ruminal acidosis showed that ruminal pH declined more rapidly with the molasses treatment, but also began to recover after 24 hours, whereas the pH declined for 120 hours in animals given crushed wheat (Randhawa et al., 1982). This could be related to molasses and microbes flowing from the rumen with the liquid fraction, whereas wheat grain might be more likely to remain in the rumen with the solid fraction. How could a potentially rapidly fermented carbohydrate like sugars be having these effects? Slowing fermentation through production of glycogen or passage with the liquid fraction may temper the impact of sugar on ruminal pH. Increasing RDP may decrease glycogen production and increase the rate of fermentation and impact on ruminal pH – is RDP a governor for the effect of carbohydrates on pH? So, paying attention to the overall rate of fermentation/availability of the sugars and starch portions of the diet may dictate modifying the amounts of RDP that is fed to maintain a healthy rumen and supply nutrients to the cow.

How much sugar can we feed?

This is an open question because the work has not been done to test it adequately with high producing cows on the variety of rations that are fed commercially. And, we need to remember that including FEEDS that contain sugars may have different results than feeding sugars by themselves because there are other fractions in real feeds that could affect results. The highest levels of "sugars" as sugar proper or as ESC that have been fed to cows on research studies are 7.5% sucrose / 10% ESC (Broderick et al., 2008), 12% ESC from sucrose, molasses, and citrus pulp (Hall et al., 2010), and 13% lactose (DeFrain et al., 2004). In these studies, the main substitutions were sugar sources for starch sources. The most extreme feeding approach was 21% of diet DM as nonstructural carbohydrates from freshly cut sugarcane fed in addition to a concentrate mix to growing Nellore steers (Sousa et al., 2014). The 18 month old 606 lb steers consumed 10 to 13 lb of the total diet and had ruminal pH of 6.4 to 6.7.

Conclusions

Research on sugars substituted for starch have shown a variety of effects on ruminal microbe and animal performance. Increases in milk fat production and unchanged or increased ruminal pH are more common results that are in line with our understanding of how ruminal microbes process sugars, but the responses are not always seen. In order to know how best to incorporate sugars into diets for lactating dairy cows to reliably get the desired results, we need to understand what variables may be altering the picture. As we modify sugar content of rations, we need a better understanding of how the impact of these carbohydrates on nutrient supply and rumen function are affected by the levels of sugars fed and the other feeds and components in the rations, perhaps particularly including ruminally degradable protein and fatty acids.

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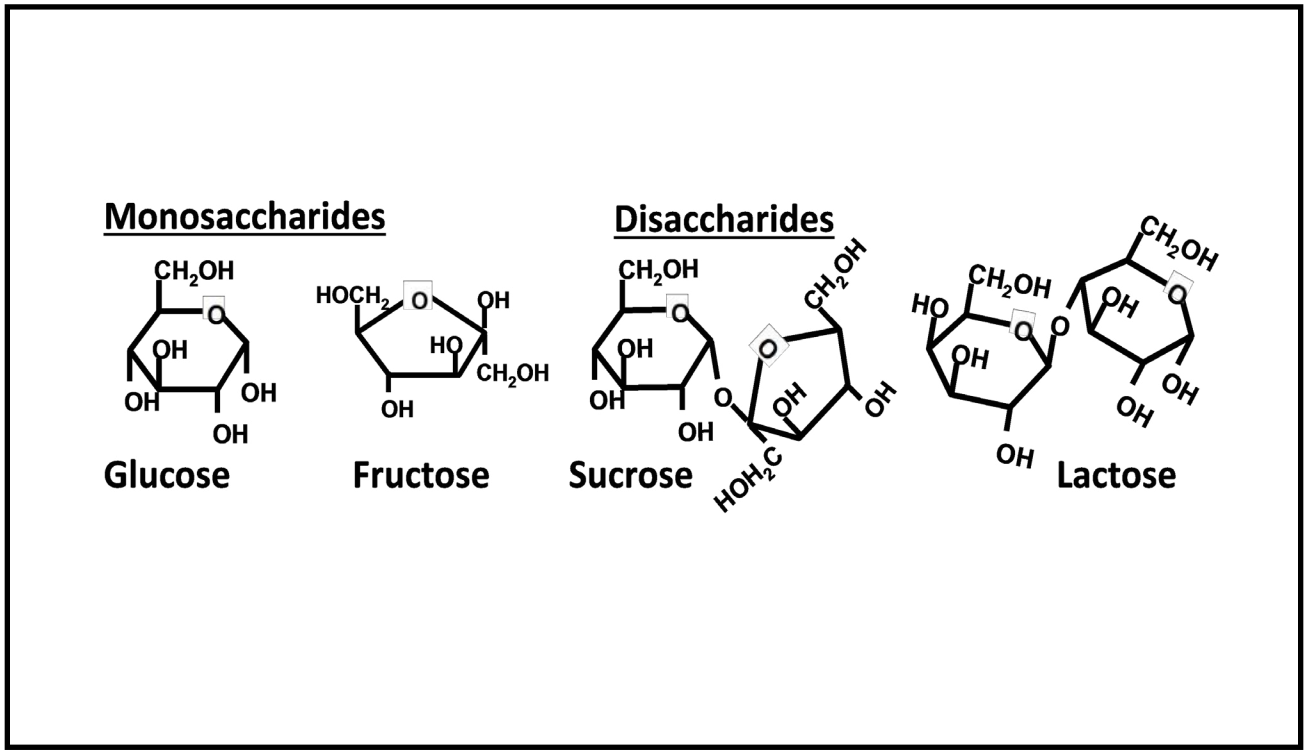

Figure 1. Chemical structure of sugars. Sucrose = glucose + fructose, Lactose = glucose + galactose.

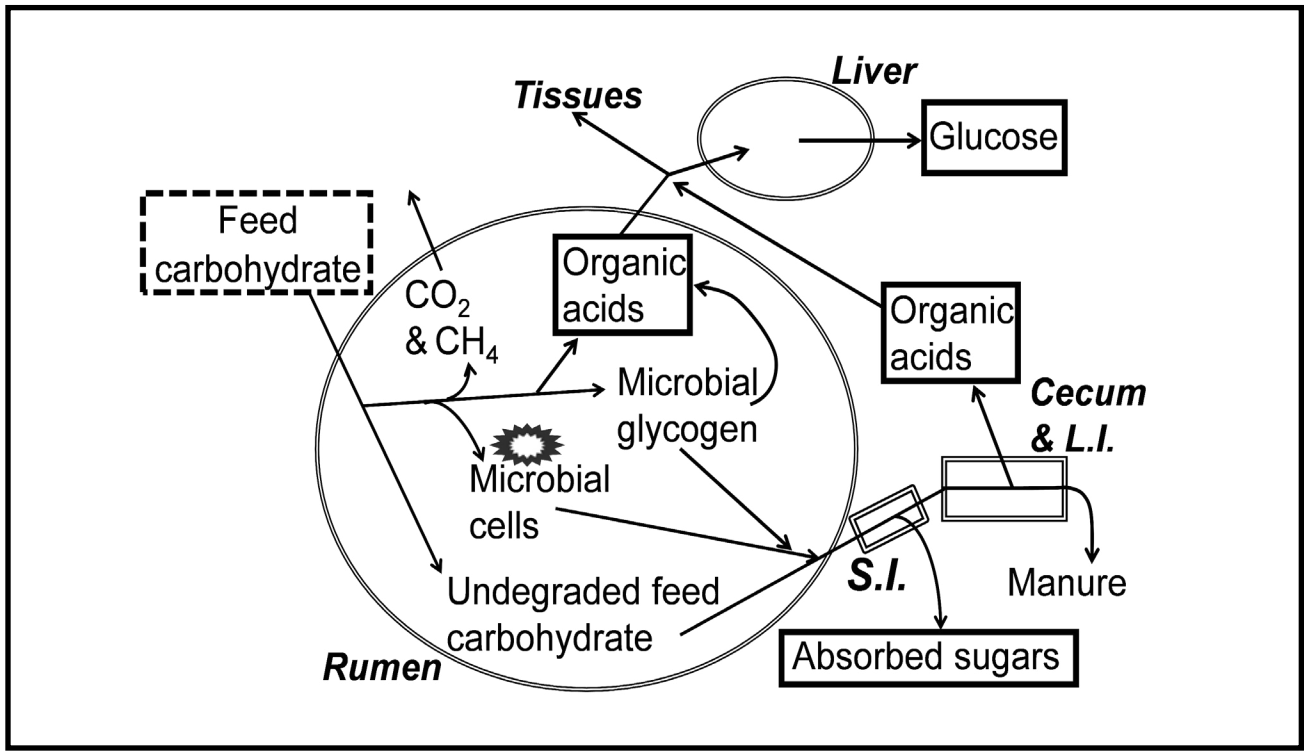

Figure 2. Fates of carbohydrates. SI = small intestine, LI = large intestine.

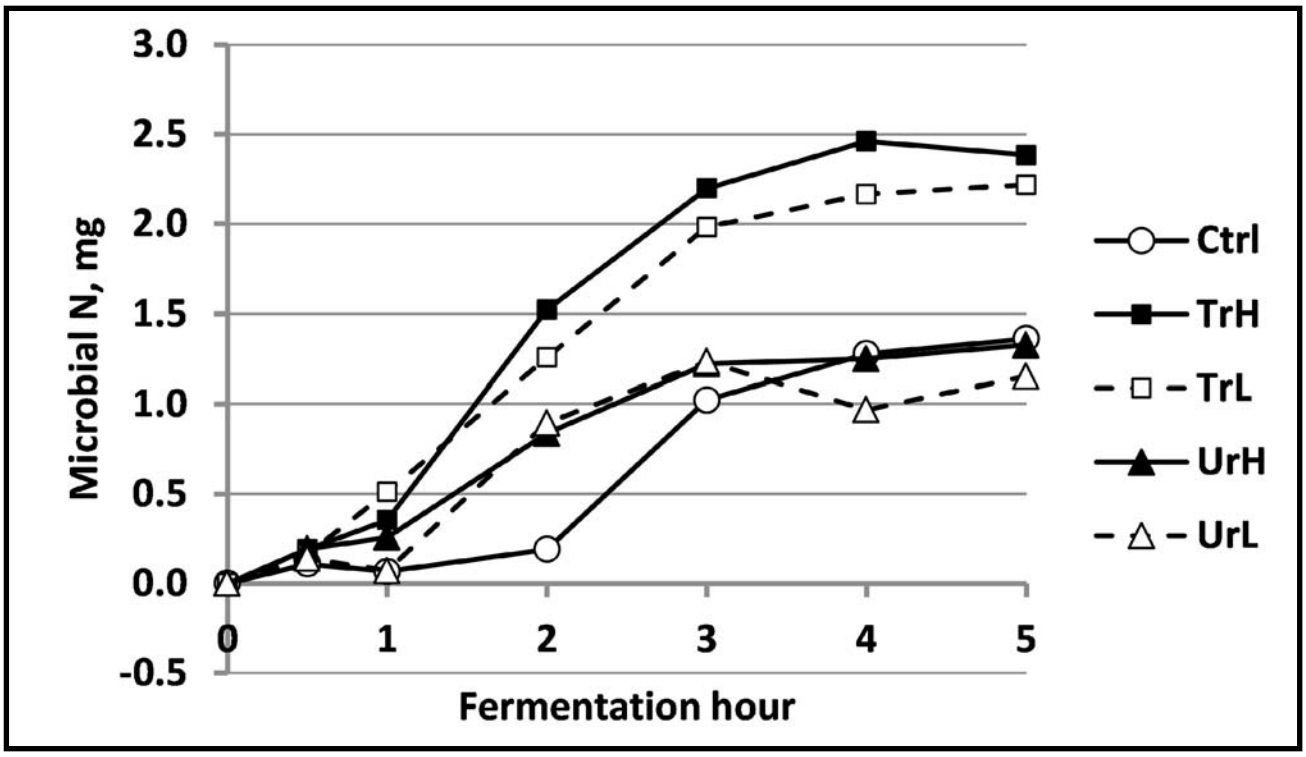

Figure 3. Responses in microbial nitrogen (**N**) production with glucose as a substrate and different concentrations of N, peptides (**Tr**) and urea (**Ur**) in the fermentation media. Ctrl = lowest N, L = Increased low level of N, and H = Increased highest level of N. (Hall, 2017).

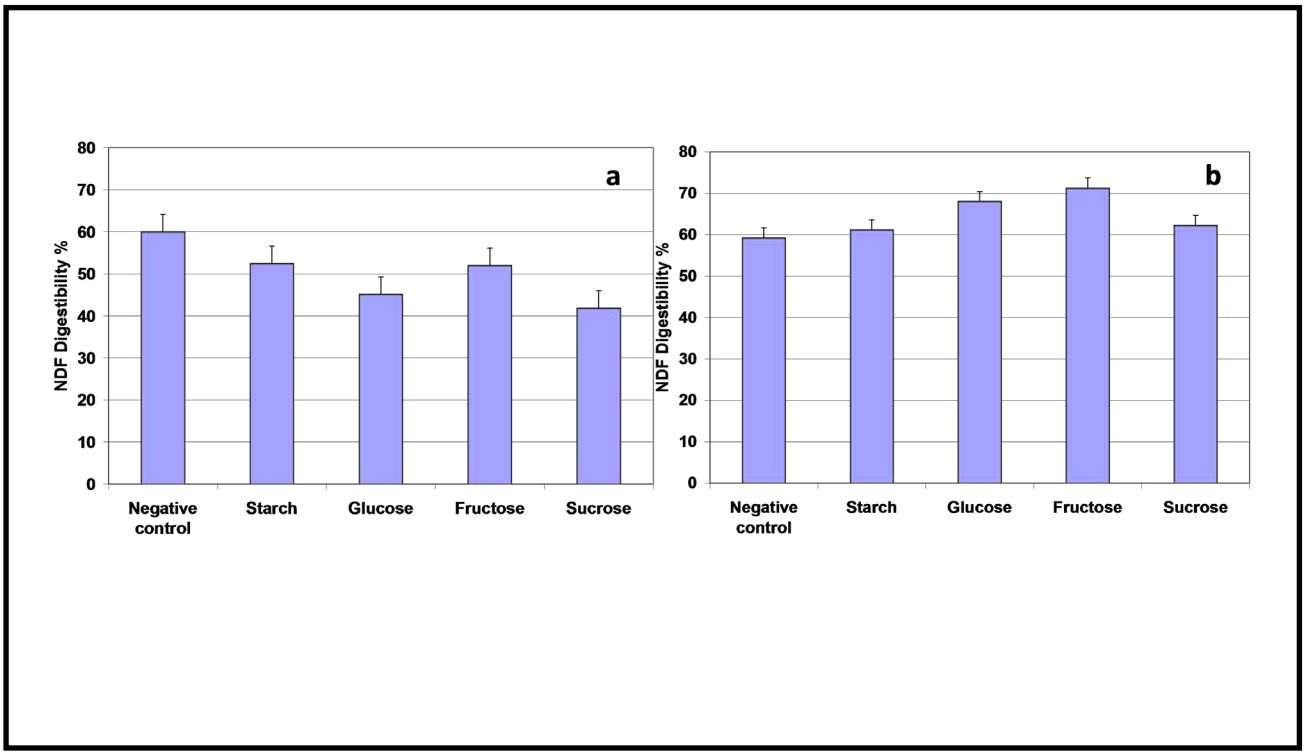

Figure 4. Total tract digestibility of NDF with different nonfiber carbohydrates and ruminally degradable protein (**RDP**) supplementation. Graph a: RDP supplemented at the lower level of 0.031% of body weight; Graph b: RDP supplemented at the higher level of 0.122% of body weight (Heldt et al., 1999).

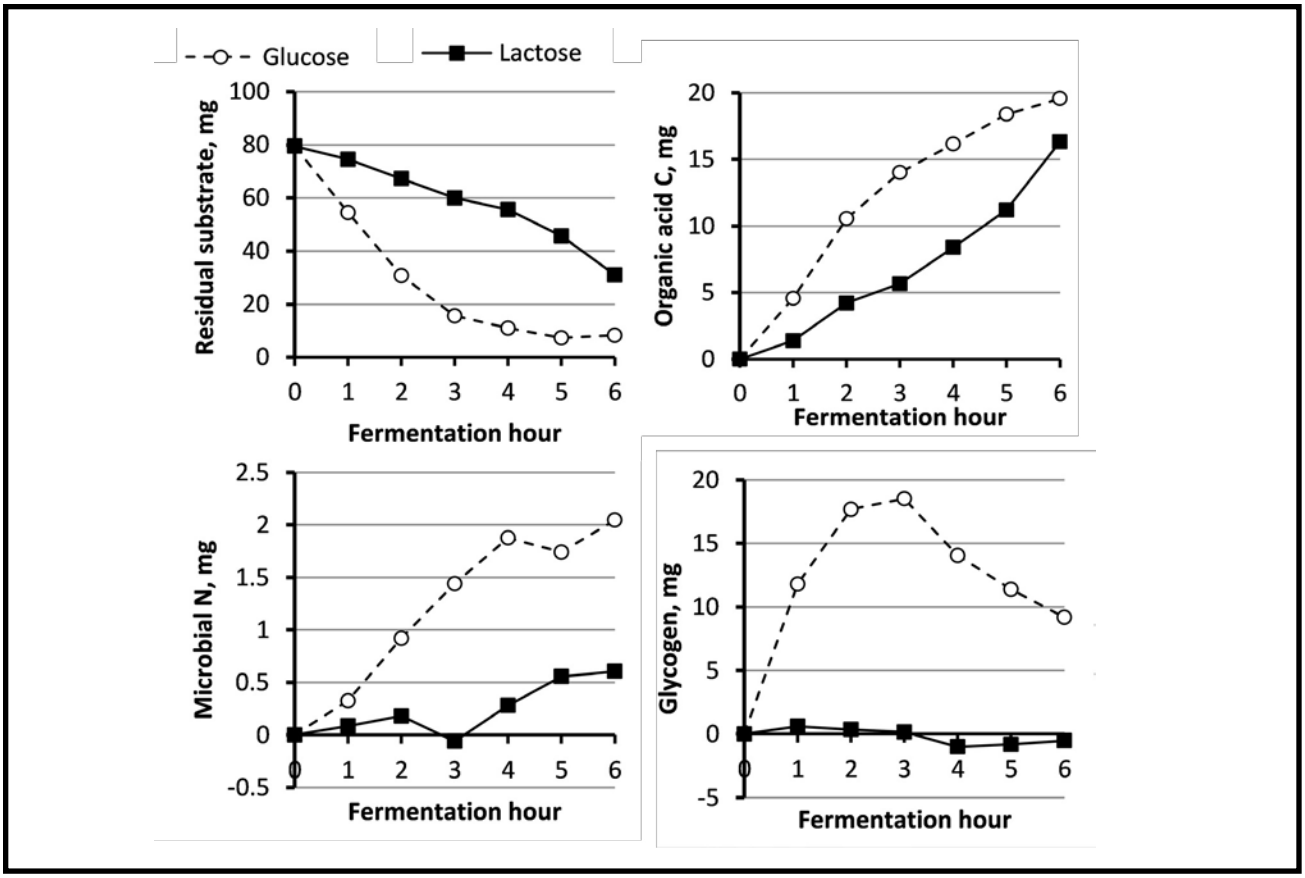

Figure 5. Use of glucose and lactose by mixed ruminal microbes in vitro (treatments with 300 mg nitrogen / L fermentation medium, including both ammonia and peptides; Hall, 2016).

Novel Concepts Regarding Calcium Homeostasis During the Transition Period

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Introduction

The transition period (3 weeks pre-calving through 3 weeks post-calving) is a critical time period in the life of the dairy cow. At this time, animals are highly susceptible to a variety of disorders that negatively impact their health, and hence, their overall production. Of particular concern during this time is the inability of the animal to maintain adequate blood calcium concentrations due to increased demand for calcium at the onset of lactation by the mammary gland. This increase in calcium results in decreased circulating calcium concentrations and can lead to the development of periparturient hypocalcemia (milk fever). Parturient paresis is one of the most common metabolic diseases of dairy cattle, with Jersey cows being more susceptible than Holstein (Oetzel, 1988; NRC, 2001). In fact, hypocalcemia is considered a gateway metabolic disorder that leads to increased risks of other periparturient diseases (Figure 1; DeGaris and Lean, 2008). Due to inadequate blood calcium concentrations at the onset of lactation, animals experience a range of clinical symptoms, depending on the extent of the decrease in calcium concentrations (Adams et al., 1996). Clinical hypocalcemia (**CH**) is clinically defined as a total blood calcium concentration of less than 1.4 mmol/L, and subclinical hypocalcemia (**SCH**) defined as total blood calcium of 1.4 to 2.0 mmol/L (DeGaris and Lean, 2008). Approximately 25% of heifers and 50% of older cows will succumb to SCH, and between 5 to 10% of animals will develop CH in the United States (Goff, 2008). Cattle that are afflicted with periparturient hypocalcemia exhibit a 14% decrease in milk production and are more susceptible to other transition disorders, such as ketosis, retained placenta, displaced abomasum, and muscle weakness, with the average cost of incidence of milk fever being $334/animal (Oetzel, 1988). However, should an animal succumb to additional issues due to suffering from milk fever, costs increase substantially. Subclinical hypocalcemia affects about 50% of second lactation and greater dairy cattle, and costs approximately $125/animal to treat. Overall, prevalence of milk fever and SCH are more common in Jersey cattle, likely due to their higher milk production per unit body weight (Oetzel, 1988). With a U.S. dairy cow population of approximately 10 million, an estimate for total loss due to symptomatic clinical milk fever is $240 million per year, and industry losses due to SCH are 4 times higher than that of clinical milk fever (Oetzel, 2013). Typically, in order to compensate for decreased blood calcium, increased intestinal calcium absorption and/or reduced calcium excretion from the kidney must occur; however, calcium resorption from the bone is the primary mode used during this time frame. Dairy cattle, in particular, exhibit a delay in calcium resorption from bone, causing circulating calcium concentrations to fall behind the demand from the mammary gland.

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The current working hypothesis in dairy cows is that increasing the interaction of parathyroid hormone (**PTH**) with its receptor on the bone tissue during late pregnancy can improve the dairy cow's ability to mobilize bone tissue at the onset of lactation (Goff, 2008). However, in other mammalian species, it has been elegantly demonstrated that a different hormone, parathyroid hormone related-protein (**PTHrP**), produced by the mammary gland during lactation is critical for increasing bone resorption during lactation (Wysolmerski, 2010). Recently, we have demonstrated that mammary serotonin (5-hydroxytryptamine) regulates induction of PTHrP (Hernandez et al., 2012). Manipulation of serotonin-induced PTHrP synthesis near the end of the pregnancy period could be critical in preventing the onset of hypocalcemia during the early lactation period. This is important because the early symptoms of milk fever often go undetected because they are short-lived. Data indicate that prevention of milk fever, rather than treatment, would save the dairy industry approximately $140 million per year (http://www.animate-dairy.com/dcalciumd-nutrition/index.html).

The Onset of Milk Production Drains Calcium Pools in Dairy Cows

Colostrum and milk synthesis rapidly deplete calcium from the maternal circulation, and therefore, calcium must be mobilized from maternal bone to maintain adequate circulating concentrations. Circulating calcium concentrations are tightly regulated and controlled by several hormones including: Vitamin D, calcitonin, PTH, and PTHrP (Figure 2). Liberation of calcium from bone stores can only be triggered when circulating calcium concentrations dip below the animal's minimal threshold for calcium, via a classic negative feedback loop. Dietary calcium is insufficient to maintain maternal calcium homeostasis during milk synthesis. This is demonstrated by the fact that a dairy cow will lose 9 to 13% of her bone mass during the first 30 days of lactation. Bone loss during lactation is an evolutionary strategy of mammals used to support the cow, as well as the mammary glands' demand for calcium for milk synthesis (Wysolmerski et al., 1995; Wysolmerksi, 2010; Goff, 2014).

The Mammary Gland Functions as an "Accessory Parathyroid Gland" During Lactation

The mammary gland produces the hormone PTHrP, which binds to receptors on bone to drive bone resorption and liberate calcium into the systemic circulation (Wysolmerski et al., 1995; Wysolmerski, 2010). PTHrP is only produced by the mammary gland during lactation. The calcium sensing receptor (**CaSR**) present in the mammary epithelium plays a crucial role in controlling maternal calcium concentrations during lactation. CaSR is highly expressed in the mammary gland during lactation, compared to virgin and pregnant time periods (VanHouten et al., 2003). Mammary PTHrP production is responsible for the mobilization of calcium from the bone during lactation, rather than the typical endocrine regulator of bone, PTH (Wysolmerski et al., 1995; VanHouten, 2005; Wysolmerski, 2010; Wysolmerski, 2012). Our lab made a novel discovery that serotonin is essential for the liberation of calcium from bone during lactation to sustain maternal calcium homeostasis in rodent models. Specifically, serotonin induces PTHrP synthesis by the mammary gland (Hernandez et al., 2012; Laporta et al., 2014a, 2014b). Furthermore, we demonstrated that serotonin is critical for the expression of CaSR. This finding indicates that serotonin is crucial for mammary gland sensing of systemic calcium concentrations.

Mammary Gland Coordination With the Skeletal System Liberates Calcium During Lactation

The skeletal system maintains its structural and functional roles via communication between two cell types, osteoblasts (**OB**), which are responsible for bone formation, and osteoclasts (**OC**), which are responsible for bone resorption, and thus calcium mobilization. PTH regulates this mechanism under non-lactating conditions. Research in humans and rodents has suggested that PTH action on bone is uncoupled during lactation (Wysolmerski, 2010; VanHouten and Wysolmerski, 2013). PTHrP signals through the same G-protein coupled receptor (**PTH1R**) as PTH on the OB to decrease OB cell proliferation and up-regulate genes responsible for OC differentiation during lactation. In rodents and humans, the mammary gland is the main source of PTHrP found in the circulation (Thiede, 1994; Wysolmerski et al., 1995; Wysolmerski, 2010; VanHouten and Wysolmerski, 2013). Mammary-derived PTHrP, not PTH, is the critical hormone responsible for induction of bone calcium mobilization during lactation (Wysolmerski et al., 1995).

Serotonin Regulates Mammary Gland Physiology During Lactation

Serotonin is synthesized in numerous tissues throughout the body and brain and is incapable of crossing the blood-brain barrier. Serotonin is synthesized from the amino acid L-tryptophan in a 2-step process. The first step is production of 5-hydroxytryptophan (**5-HTP**) via the rate-limiting enzyme, tryptophan hydroxylase (**TPH**). The second step is the conversion of 5-HTP to serotonin by aromatic amino acid decarboxylase (Wang et al., 2002). TPH1 is the rate-limiting enzyme for serotonin production in non-neuronal tissues, while TPH2 is used to produce serotonin in neuronal tissues. Our laboratory and others have shown that serotonin regulates milk protein gene expression, as well as the disassembly of tight junctions that occurs during the involution process (Matsuda et al., 2004; Stull et al., 2007; Hernandez et al., 2008; Pai and Horseman, 2008). Furthermore, we have shown that the mammary gland expresses a unique pattern of serotonin receptors in rodent, bovine, and human mammary epithelium (Hernandez et al., 2009; Pai et al., 2009). The epithelial component of the bovine mammary gland expresses at least 5 serotonin receptor isoforms (5-HT1B, 2A, 2B, 4, and 7; Hernandez et al., 2009). Our lab determined that the 5-HT2B receptor subtype modulates serotonin's regulation of PTHrP production within the mammary gland in a rodent model (Hernandez et al., 2012; Laporta et al., 2013a; Laporta et al., 2014a,b). We also confirmed that circulating serotonin concentrations postpartum are positively correlated with circulating calcium concentrations on the first day of lactation in dairy cows (Laporta et al., 2013b). Furthermore, we showed that serotonin activates expression of various calcium pumps and transporters in the mammary gland to stimulate transport of calcium from blood to milk during mouse lactation (Laporta et al., 2014a). Calcium transport into the mammary gland is thought to occur through the calcium influx channel (**ORAI1**) and subsequent pumping into the milk by the apical plasma membrane calcium ATPase (**PMCA2**; Cross et al., 2014).

Current research in humans and rodents implicates PTHrP in the regulation of maternal calcium homeostasis during lactation. Our laboratory has demonstrated the necessity of serotonin for regulation of calcium transport in the mammary gland during lactation. Furthermore, we have demonstrated that serotonin is necessary for the production of mammary PTHrP during lactation. Mammary PTHrP is critical to the mobilization of calcium

from bone tissue to support lactation. Therefore, delineation of the mechanisms regulating the mammary gland serotonin-PTHrP axis in the dairy cow could lead to development of novel therapeutic interventions to reduce the incidence of SCH and CH in the U.S. dairy cow population.

Can We Use Serotonin to Improve Calcium Homeostasis During Lactation?

Our laboratory recently demonstrated that serotonin is necessary for mammary PTHrP synthesis in lactating rodents and mammary epithelial cells grown in lactogenic culture (Hernandez et al., 2012; Laporta et al., 2013a; Horseman and Hernandez, 2014). We also demonstrated that supplementation of a serotonin precursor, 5-HTP, to rats during the transition from pregnancy to lactation increased postpartum circulating serotonin, PTHrP, and calcium concentrations, and also increased total calcium content in milk (Laporta et al., 2013a). Furthermore, we observed increased osteocyte numbers in the femurs collected from rats supplemented with 5-HTP, indicating this response was due to bone calcium mobilization. These findings led us to perform several experiments in dairy cows in order to evaluate the utility of these findings in rodents to dairy cows.

In order to evaluate the utility of the mammary serotonin-PTHrP axis in Holstein dairy cows, we performed several observational studies. We have observed that serotonin concentrations are dynamic over the course of a given lactation and decrease around the time of calving (day 0 to 2 of lactation), rebounding by approximately 10 days into lactation (Moore et al., 2015). The overall average serotonin concentration in dairy cows is approximately 1700 ng/ml. However, it should be noted that the concentrations fluctuate depending on stage of lactation. These results combined with our rodent data support our hypothesis that serotonin and PTHrP are critical players in the regulation of calcium homeostasis in Holstein dairy cows.

Intravenous (Iv) Infusion Of 5-Htp in Late Lactation, Non-Pregnant, Multiparous Holstein Dairy Cows Increases Circulating Serotonin Concentrations and Alters Calcium Dynamics

In order to demonstrate the role of serotonin in calcium homeostasis in dairy cows, we performed a preliminary experiment in which we infused 5-HTP intravenously for one hour daily for 4 days in late-lactation dairy cows at varying doses (0, 0.5, 1.0, or 1.5 mg/kg) to determine an optimum dose of 5-HTP necessary to produce significant changes in calcium. All 3 doses of 5-HTP increased circulating serotonin concentrations (Laporta et al., 2015) to a similar extent in the two hours after dosing, with concentrations returning to baseline concentrations observed in the saline controls by two hours after infusion. In addition to serotonin concentrations, we measured circulating total calcium concentrations following the same time course post-infusion. While initially counter-intuitive, our data demonstrated that total calcium concentrations decreased in immediate response to 5-HTP treatments (Laporta et al., 2015). In order to determine where the circulating calcium was going after 5-HTP infusion, we measured urine calcium concentrations prior to the start of infusion and 2 hours after the end of the infusion. Our results indicate that there was a decrease in urine calcium output with higher doses of 5-HTP treatment.This suggests that calcium is not being lost into the urine. Therefore, we measured total calcium concentrations in the milk during the infusion periods and observed that the highest dose of 5-HTP increased total milk calcium concentrations. This supports the hypothesis that 5-HTP infusion causes transient hypocalcemia by increased calcium transport

into the mammary gland and subsequently into milk. Increased calcium transport into the mammary gland during lactation is critical for the stimulation of calcium mobilization from bone by PTHrP.

Use of 5-Htp Before Calving to Prevent Hypocalcemia: Is it Possible and are Breed Differences Present?

In order to determine if elevating serotonin concentrations in pre-fresh dairy cows would result in increased post-calving calcium concentrations, we treated multiparous Holstein cows with daily IV infusions of 1.0 mg/kg of 5-HTP beginning 7 days before the estimated calving date until calving. Our data demonstrates that intravenous infusions of 5-HTP pre-calving increased post-calving total calcium concentrations compared to saline treated controls (Weaver et al., 2016). Furthermore, we measured deoxypyridinoline (**DPD**), a marker of OC activity and therefore bone resorption, in the urine. These data demonstrate that cows receiving 5-HTP before calving have increased bone resorption at calving. In other words, 5-HTP treatment pre-calving may improve post-calving calcium concentrations by increasing bone calcium resorption.We performed a similar study, using multiparous Holstein cows only, with our collaborator Dr. Rupert Bruckmaier in Switzerland using the common Swiss system for raising dairy cows, and the effects of 5-HTP on total calcium concentrations post-calving were similar to those seen in our Holstein cows (Hernandez-Castellano et al., 2017). Unpublished results from the study in Switzerland have also revealed that PTH is unaffected by 5-HTP during the transition period, which supports our working hypothesis that serotonin and PTHrP are responsible for coordinating bone mobilization during lactation (Hernandez-Castellano et al., unpublished results).

In order to examine if the serotonin-PTHrP-calcium was conserved across breeds, we tested the same hypothesis in multiparous Jersey cows in the same experiment on our research farm in order to be able to make breed comparisons. Interestingly, Jersey cows responded to 5-HTP differently than the Holstein cows. Jersey cows infused with 5-HTP had significantly decreased calcium concentrations prepartum, and then began to increase calcium concentrations at calving. This was in contrast to the control Jersey cows who did not reach their total calcium concentration nadir until 1 day postpartum (Weaver et al., 2016). Furthermore, Jersey cows treated with 5-HTP had higher concentrations of calcium in their milk compared to the saline treated cows, which was opposite to what was seen in the Holstein cows. These data indicate that serotonin positively impacts calcium homeostasis in both Holstein and Jersey cows, but the underlying mechanisms appear to be different and should be further investigated.

Interrelationship of a Negative Dietary Cation-Anion Difference (DCAD) Diet and serotonin

Given that 5-HTP treatment pre-calving was capable of increasing post-calving calcium concentrations in Holstein cows, we wanted to determine if a common preventative treatment for SCH and CH, negative DCAD, controls calcium homeostasis via a serotonergic mechanism. To this end, we fed Holstein dairy cows a positive DCAD (+130 mEq/kg) or negative DCAD (-130 mEq/kg) diet for 21 days pre-calving. Upon analysis of circulating serotonin concentrations from 9 days pre-calving through 6 days post-calving, we determined that a negative DCAD diet increased circulating serotonin concentrations pre-calving, resulting in an improvement in post-calving calcium concentrations. Preliminary results from a study testing the hypothesis that 5-HTP and negative

DCAD diets have a synergistic effect on post-calving calcium concentrations indicate that the combination of 5-HTP treatment with a negative DCAD diet results in a large increase in post-calving ionized calcium concentrations.

Serotonin and Calcium: Which is the Cart or the Horse? Or are They in Their Own Feedback Loop?

Recent efforts in our laboratory have focused on determining if serotonin is responsible for shuttling calcium into the mammary gland and other tissues during early lactation, or if decreased blood calcium concentrations are responsible for increasing serotonin concentrations to help restore calcium homeostasis in the circulation. We performed an experiment in dry, non-lactating dairy cows that were all fed a negative DCAD diet, but they were receiving 3 different levels of calcium in their diet (0.45%, 1.13%, and 2.02%) for 21 days. After the feeding periods were completed, all cows were subjected to a 5% ethylene glycol tetraacetic acid (**EGTA**) challenge. Our objective was to determine how cows responded to induction of a simulated hypocalcemia, and how quickly they recovered from the insult. Ionized calcium and serotonin concentrations were measured every 15 minutes until cows reached 60% of their initial ionized calcium (**Ca2+**) concentrations and at 0, 2.5, 5, 10, 15, 30, and every 30 minutes thereafter until 90% of initial Ca2+ was achieved. Our preliminary data analysis indicates that cows on the 2.02% calcium diet were more resistant to the hypocalcemic challenge, took longer to achieve the 60% target value, and recovered at the same rate as the cows on the 0.45% diet. Interestingly, the cows consuming 1.13% calcium reached 60% the fastest and took the longest to recover to 90%. Cows on the 0.45% diet reached the 60% induction at the same rate as the cows on the 1.13% calcium diet. Upon initial analysis of the serotonin concentrations during the challenge period in these cows, we observed that cows fed 1.13% calcium had the highest concentrations of serotonin compared to the other 2 treatment groups. The cows on the lowest level of calcium had the lowest serotonin concentrations, and the cows in the high group were intermediate between the other 2 during the challenge. Additionally, all serotonin concentrations in these animals were elevated compared to those in the study by Moore et al. (2015). This is in line with the unpublished studies that feeding negative DCAD diets increase serotonin concentrations as well; however, these cows are also dry and non-pregnant. Finally, these data suggest that serotonin and calcium are potentially acting in a negative feedback loop to regulate blood calcium homeostasis, rather than one or the other driving the system. We have further evidence that this may be the case in vitro in a bovine mammary epithelial cell model where we have observed that PTHrP mRNA expression is increased by both serotonin and EGTA, but the combination results in the highest level of expression. Further research will be aimed at elucidating these mechanisms of action.

Conclusion

In conclusion, we have demonstrated that serotonin plays a critical role in regulation of maternal calcium transport, maternal calcium homeostasis, and mammary PTHrP production in the rodent. Furthermore, our rodent models indicate that the mammary gland is a significant source of serotonin during lactation. Our observational data in Holstein cows suggest that serotonin, PTHrP, and calcium are interrelated during the early days postpartum. Furthermore, our initial experiment exploring the effects of 5-HTP on maternal calcium homeostasis in late-lactation dairy cows supports the hypothesis that serotonin induces transient hypocalcemia by shuttling calcium into the mammary gland

in order to stimulate mammary production of PTHrP, and the elevated PTHrP is critical to stimulate bone calcium resorption. Treating prepartum Holstein dairy cows with 5-HTP resulted in improvement of post-partum calcium concentrations both on our research farm, as well as at the University of Bern in Switzerland, suggesting that the manipulation of the serotonergic axis is conserved across management styles. It also appears that Jersey cows respond differently to 5-HTP treatment, and further research should be directed to understanding their physiology as compared to Holstein cows. Using a current therapeutic intervention for prevention of SCH and CH in the dairy industry, feeding of a negative DCAD diet prepartum, resulted in increased circulating serotonin concentrations. Our preliminary data examining the interaction of 5-HTP and negative DCAD suggests that the 2 treatments together have a synergistic effect on increasing post-calving ionized calcium concentrations. Finally, our most recent data suggest the possibility that serotonin and calcium may be acting in a classic negative feedback loop to maintain blood calcium homeostasis. Together, these findings support the possibility that serotonin is a key player in the search for prevention and treatment of periparturient hypocalcemia in the transition dairy cow.

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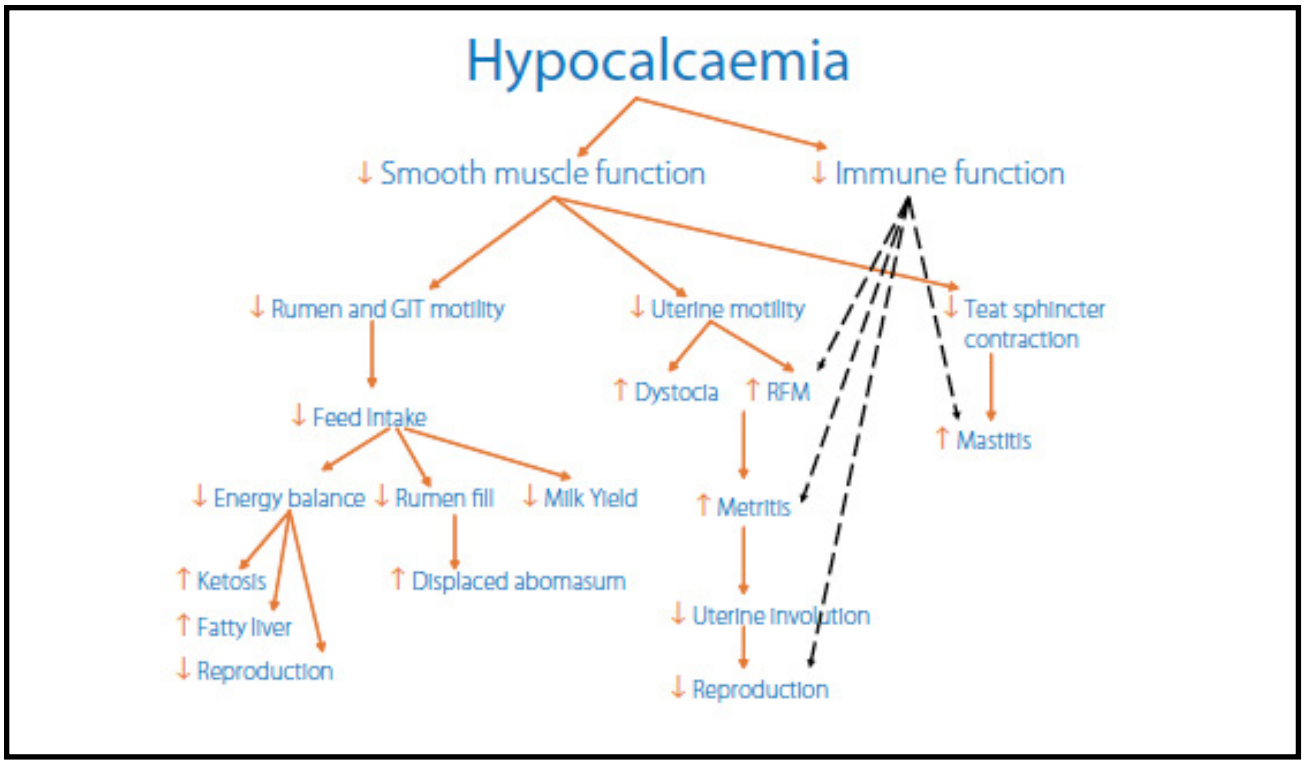

Figure 1. Hypocalcemia is a 'gateway' disease that leads to increased risks of other periparturient diseases (DeGaris and Lean, 2008).

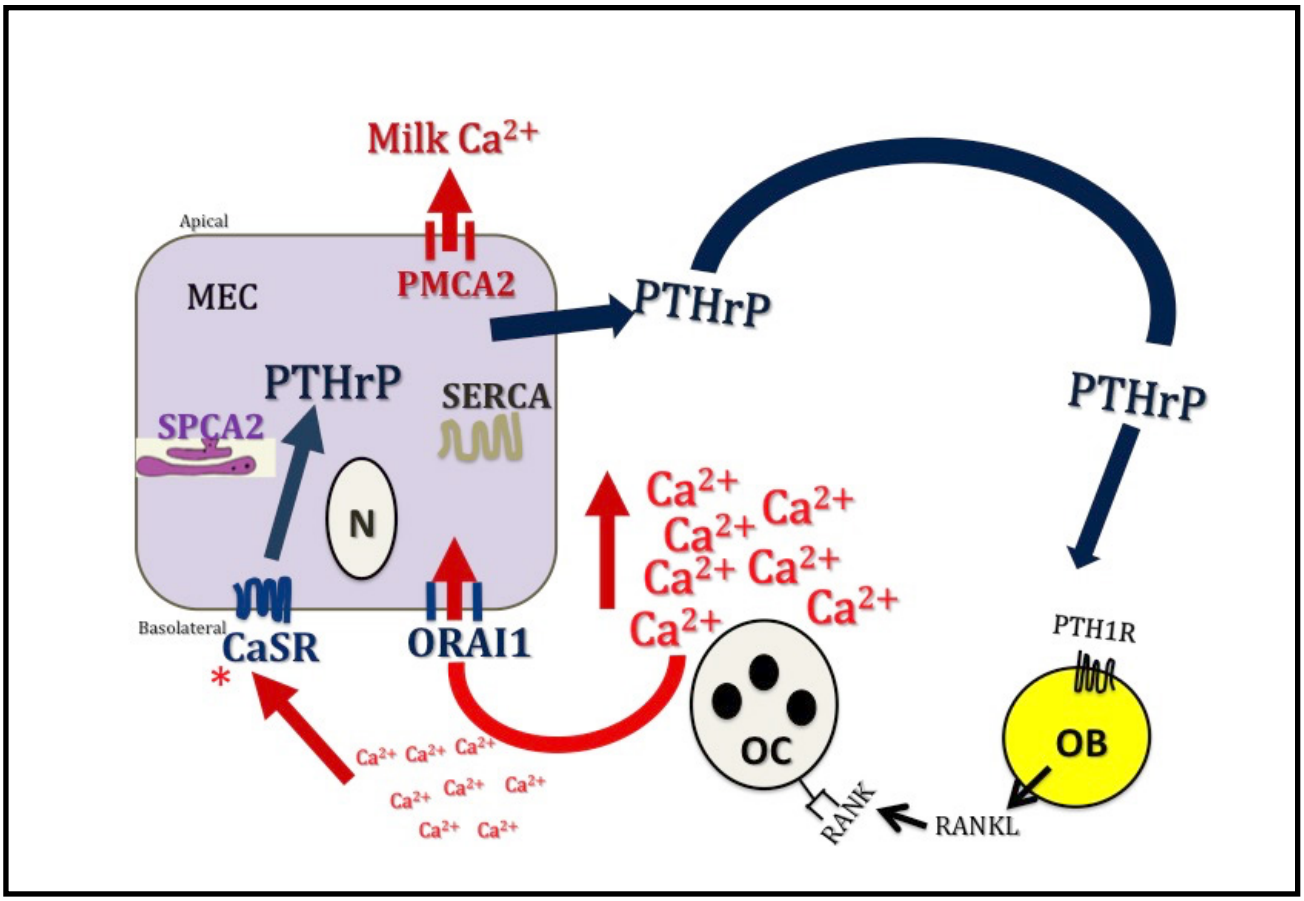

Figure 2. Maternal calcium homeostasis is regulated by the mammary gland-bone axis. During lactation, the calcium sensing receptor (**CaSR**) on the basolateral side of the mammary epithelial cell (**MEC**) during lactation detects low blood calcium concentrations due to the increased transport of calcium into the MEC by calcium release-activated calcium channel protein 1 (**ORAI1**). Calcium is either secreted into the milk through the apical plasma membrane Calcium ATPase 2 (**PMCA2**) or sequestered in the Golgi apparatus by secretory pathways Calcium ATPase 2 (**SPCA2**) or endoplasmic reticulum by the sarco(endo)plasmic reticulum Calcium ATPase (**SERCA**). Detection of systemic decreased calcium by CaSR results in parathyroid hormone related-protein (**PTHrP**) production. PTHrP is secreted into the circulation and will bind its receptor PTH1R on the osteoblast (**OB**) cell in the bone increasing production of receptor activated nuclear factor kappa B (**RANKL**), which binds its receptor (**RANK**) on the osteoclast (**OC**) cell in the bone tissue, activating calcium liberation from bone.

Impact of the Tri-State Dairy Nutrition Conference

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~ CELEBRATING 26 YEARS ~

The Tri-State Dairy Nutrition Conference, Fort Wayne, IN is a yearly conference for feed industry personnel, nutrition consultants, university personnel, veterinarians, and interested dairy producers. The conference began in 1992 as a spin-off from the 1991 Ohio Dairy Nutrition Conference. In September 1991, a meeting to discuss planning a tri-state conference was held with faculty and Extension staff from Purdue, Michigan State, and The Ohio State Universities. The first Conference was held May 20 - 21, 1992 on the Purdue campus in Fort Wayne, IN. A Planning Committee was formed after the 1992 Conference. Due to a continuous expansion of attendance, the conference moved in 1996 from the Purdue campus to the Grand Wayne Convention Center. Because of renovation of the Grand Wayne Center, the Conference was held for one year (2005) at the Allen County War Memorial Coliseum in Ft. Wayne. An abstract about the success of the Conference was presented at ADSA in 1999 (J. Dairy Sci. 82 (Suppl. 1):56) and was listed among successful dairy nutrition conferences in the special centennial issue of the Journal of Dairy Science published in 2006 (J. Dairy Sci. 89:1121-1368). The success of the Tri-State Dairy Nutrition Conference continues to be demonstrated by attendance (Figure 1) and citation or reprinting of proceedings manuscripts in the scientific, international, and popular press literature. The Proceedings are ordered by many people within and outside the U.S., placed on reserve in the USDA National Agricultural Library, and indexed by the Institute for Scientific Information.

Presentations and proceedings papers are oriented to timely, in-depth, and practical dairy nutrition topics to meet on-farm nutritionists' needs and provide the results of recent research findings. A tradeshow and rotating industry-sponsored pre-conference have been a part of the annual Conference for many years. In 2016, a hot topics breakfast was initiated and a post-conference program was offered in 2016 and 2017. A workshop program was began in 2013 on Monday afternoon with the focus the first year on nutrition formulation computer programs and has been continued since (2014 – dairy records management software; 2015 – TMR management software; 2016 – animal monitoring technology; and 2017 – feed analysis). A conference web page was launched in 1997, with the current site being http://tristatedairy.org. The attendance by students at the Conference has continued to grow, and we presently provide an undergraduate presentation program (original research or literature review) and separate MS and PhD research presentation categories. We offer free registration and lodging to all students attending the Conference. In 2017, a specialized undergraduate program is being offered on Tuesday morning. The Conference has been contributing annually $1,000 to the North American Intercollegiate Dairy Challenge because of its value to students and the dairy industry. Continuing education credit is offered to veterinarians and members of the American Registry of Professional Animal Scientists (ARPAS). ARPAS exams also are administered at the Conference.

The Planning Committee has consisted of five feed industry personnel, one nutrition consultant, one veterinarian, one Extension staff from one of the three host universities, and a faculty member from each of the three universities. An ad hoc member who represents the company hosting the pre-conference and an OSU conference assistant also met with the Planning Committee. The faculty members from the three universities have provided continuous

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Committee membership, but the other eight members have served 3-year staggered terms. The Committee has been meeting twice each year; once in September to plan the next Conference and it meets during the Conference.

Another milestone for the Conference occurred in 2015 when it was removed for accounting purposes from The Ohio State University to a non-profit organization 501 (c) (3) status. The purpose of this was to sustain the future of the Conference through changing staff at universities and policy changes at universities. A constitution and bylaws were developed and an outside firm is providing the accounting services. The Conference now operates with a Board of Directors, with a somewhat similar structure to the previous Planning Committee.

Multi-state programs similar to the Tri-State Dairy Nutrition Conference can serve a vital role in bringing research and Extension faculty from different universities and allied-industry professionals together to meet the educational needs of a rapidly changing dairy industry. The Conference has resulted in major impacts to the feed industry and dairy producers, and influenced students seeking careers in animal nutrition and the direction of some research programs. ***Your continued support of this Conference is much appreciated.***

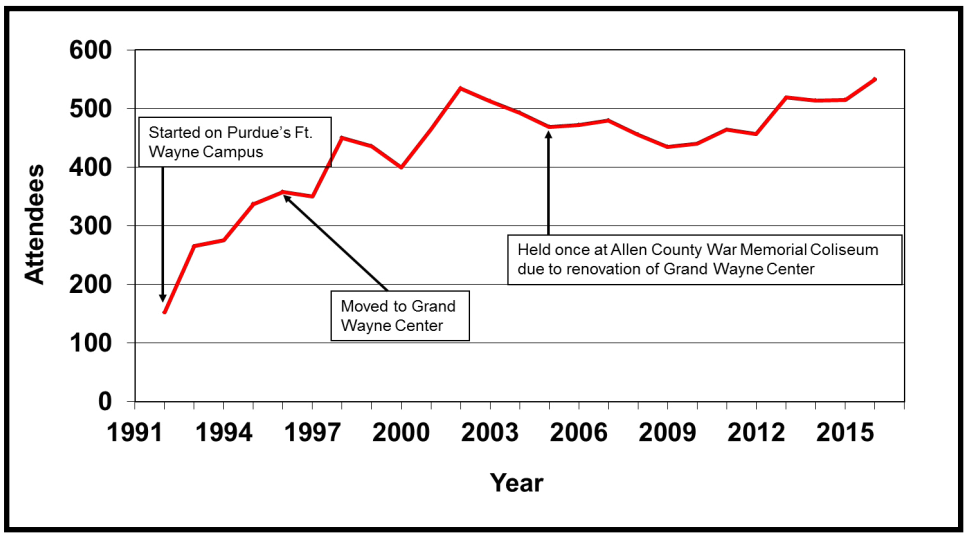

Figure 1. Attendance at the Tri-State Dairy Nutrition Conference

Abbreviations that may be found in this publication include:

AA = amino acids	FCM = fat-corrected milk	r = correlation coefficient
ADF = acid detergent fiber	ME = metabolizable energy	R^2 = coefficient of determination
BCS = body condition score	MCP = microbial crude protein	RDP = rumen degradable protein
BW = body weight	MP = metabolizable protein	RFV = relative feed value
CP = crude protein	NEFA = non-esterified fatty acids	RMSE = root mean square error
CV = coefficient of variation	NE_g = net energy for gain	RUP = rumen undegradable protein
DE = digestible energy	NE_m = net energy for maintenance	SCC = somatic cell count
DIM = days in milk	NE_L = net energy for lactation	SD = standard deviation
DHI = dairy herd improvement	NDF = neutral detergent fiber	SE = standard error
DM = dry matter	NFC = nonfiber carbohydrates	SEM = standard error of the mean
DMI = dry matter intake	NRC = National Research Council	TDN = total digestible nutrients
ECM = energy corrected milk	NSC = nonstructural carbohydrates	TMR = total mixed ration
FA = fatty acids	OM = organic matter	VFA = volatile fatty acids

Note: Most of the units of measure in this publication are expressed in U.S. equivalents; however, in some cases, metric units are used. Use the following to make conversions:

1.0 lb = 0.454 kg = 454 g
1.0 ft = 0.3 m = 30 cm
°F = (°C x 1.8) + 32
1 U.S. ton = 2000 lb = 909 kg
1 metric ton = 1000 kg = 1.1 U.S. ton (2200 lb)
1 acre = 0.4 hectare

Abbreviations for metric units are:

ppm = parts per million
mg = milligrams
g = grams
kg = kilograms
cm = centimeters
mm = millimeters
m = meters

Group Housing Systems for Calves, Facilities, Equipment, Protocols, and Personnel

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Introduction

I was fortunate to be invited to make a similar presentation to Western Dairy Management Conference in 2013. It is four years later. What have we learned? According to the most recent NAHMS Survey, (USDA, 2017) the majority of calves in the U.S. continue to be raised in some type of individual housing. We have commonly associated individual housing with the ability to control disease better and to more easily monitor and controls calves' appetites. However, recent research and changes within our industry are causing calf growers to reexamine commonly accepted calf feeding practices.

Feeding Management

Feeding management is evolving on many farms from a system that limit fed milk to encourage early weaning. Although this system may have resulted in lower costs per day, there are significant penalties to this practice. Milk or milk replacer intake of less than 1 lb (500 g) of solids per day (one gallon) is frequently inadequate to meet the maintenance requirements, and as a result, there is little energy and protein left to support any weight gain. At 32°F, a 100 lb calf must consume 1.2 gallons of whole milk just to maintain body weight. Even this modest level of intake of milk or milk replacer solids is a problem for calves during the first 3 weeks of life when starter intake is limited. However, feeding larger quantities of a liquid diet (2+ gallons) twice daily presents challenges for the young calf. Frequently, they will consume the morning feeding but may not be able to consume the evening one. If the milk or milk replacer can be fed in 3 or more equally spaced meals, the calves will gain more weight and height from the same amount of liquid fed twice daily. In addition, there is a reduction in morbidity and mortality. Unfortunately, increasing feeding frequency on most dairy farms is not feasible given the labor situation.

Labor Management

Labor management is and will continue to be a growing challenge on dairy farms. Although hutch housing systems may provide a perceived better environment for calves, these systems are not conducive to labor comfort during inclement hot, cold, or wet weather. Feeding calves their liquid diet individually is a labor intensive practice. Delivery of adequate supplies of clean, fresh water and calf starter grain and cleaning these housing systems is labor intensive and tedious work.

Animal Welfare

Animal welfare is a growing concern in animal agriculture. We, in the dairy industry,

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may believe that individual housing systems provide desirable conditions and comfort for calves, but the consumer seeing the same conditions may have an entirely different interpretation. Research conducted at various universities in North America and Europe have demonstrated distinct behavioral differences in calves housed in groups and individually. Housing calves in groups prior to weaning in well managed systems results in improved nutrient intake throughout the first few months of life and avoids the "post weaning" slump commonly observed in weaned calves when they are first placed in groups.

As a result of these considerations, group housing of preweaned calves is gaining in popularity in the U.S. Successful adoption and management of group housing systems requires:

- An effective colostrum management program such that more than 85% of calves receive adequate colostrum as evidenced by serum proteins above 5.2 g/ 100 mL.
- Accommodations to manage calves individually for the first 3 to 7 days.
- A well ventilated and drained facility to minimize risks of respiratory disease.
- A feeding plan to provide the sufficient nutrients to enable the calf to double its birth weight in 56 days. This allows for differences in breed, genetics within breed, and changing environmental conditions.
- The correct personnel to manage such a system. These are not "calf feeders" but calf managers capable of implementing the desired feeding program and detecting disease early through subtle differences in feeding and animal behavior. They are more data oriented and capable of managing sophisticated equipment as well as the calves.

Colostrum Management

Given the perceived risks of greater calf-to-calf contact, it is imperative that systems be developed and initiated on the dairy that optimize the likelihood that calves receive adequate colostrum intake. This is achieved by the timely intake of at least 150 g of immunoglobin G (**IgG**) from colostrum with low levels of bacterial contamination (<100,000 cfu/mL) within the first 6 hours of life. This is achieved when facilities are utilized which make it convenient to maintain a clean calving environment where calving can be observed easily, fresh cows are milked into clean receptacles, and colostrum is fed immediately or cooled immediately. Any delays in colostrum harvest or feeding reduces the chances of success. In some cases, the use of colostrum replacers providing 150 g of IgG should be considered. Routine monitoring of colostrum management through the measurement of serum proteins (>5.2 g/100 mL) is highly recommended.

Transition Calf Management

It is highly recommended that facilities exist to house calves individually during the first 3 to 7 days of life. This may be in calf hutches or individual pens located adjacent to group housing facilities. Provisions should be included to sanitize them between calves and to maintain sufficient bedding and supplemental heat in colder climates. The length of time for housing calves individually is dependent upon the dry cow management program and the success of colostrum management. Housing calves individually for longer periods may help with early detection of disease, but it contributes to labor inefficiency and may present challenges in adopting calves to the group housing system.

Ventilation and Drainage

This factor is probably just as important with individually housed calves as group housed calves, but the impact can be far greater since all calves share the same environment. In poorly designed facilities, one will notice that calves will congregate in a small area, thereby enhancing the ability of calf-to-calf transmission of disease. Producers are highly recommended to seek the advice of experts in designing facilities to provide adequate ventilation and drainage. The Dairyland Initiative website (https://thedairylandinitiative.vetmed.wisc.edu/) provides excellent information and offers training sessions each fall on the use of software to aid in developing facilities for young calves and heifers.

Behavior of Group-Housed Calves

Workers in Denmark (Jensen, 2003, 2004, 2005) and Canada (Khan, et al, 2011) have conducted numerous behavioral studies that have enabled the development of recommendations for management of group-housed systems. A common problem observed in calves housed individually is the "post weaning" slump that is apparently related to the adjustment of calves to group housing and the competition for feed. Studies by Chua et al. (2001) found that calves raised in pairs prior to weaning continued to gain weight normally during the week of weaning, while those housed individually experienced the "growth check" commonly observed in traditional calf rearing systems. This suggests that group housing calves prior to weaning promotes development of social skills and reduces fear of interaction with other calves. Another significant concern of group-housed and fed calves is the occurrence of cross sucking. Jensen (2003) found that feeding calves via nipple buckets as opposed to open buckets resulted in a significant reduction of cross sucking. Cross sucking tends not to be a problem in acidified free choice and calf autofeeder systems as compared to mob feeders. Feeding larger amounts of milk or milk replacer (>2 lb of solids or 2 gallons of liquid) reduces cross sucking. Reductions in flow rate of milk to prolong milk feeding also seems to satisfy the calves urge to suck after completing the liquid feeding meal, particularly when lower amounts of milk are fed daily (<1.5 lb of milk solids or 6 quarts).

A variation of individual calf housing has been the adoption of individual housed calves to paired housing at some time after the first week of age. In such systems, dividers between pens are removed or hutch pens are joined permitting calves to interact with each other without reductions in the resting area allocation per calf. Costa et al. (2015) compared dietary intake and performance of calves housed individually or paired with another calf at 6 or 43 days. All calves were fed 8L of milk for 4 weeks, 6L of milk from 4 to 7 weeks, and weaned at 8 weeks. Intake of calf starter and average daily gains were higher for calves paired at 6 days than other treatments. There was no difference in health. In addition, the growth check commonly observed in calves during weaning was less pronounced for pair housed calves, regardless of the age at pairing.

Feeding Plan

There are several ways to deliver the liquid diet to group housed calves.

- Mob feeding,
- Free choice acidified milk or milk replacer, or
- Computer controlled automatic feeders

Mob feeding of calves is a common practice in grazing dairy farms practicing

seasonal calving. However, conventional dairy farms have also used this method. This practice involves placing larger containers with multiple nipples in the calf pen until all the liquid is consumed, which is generally less than 30 minutes. Sufficient liquid is added to provide the average calf with the desired amount of liquid. Although it encourages labor efficiency, there are some challenges with this system. The most common problem is cross sucking that is a greater problem if the feeder is removed from the pen shortly after calves have finished eating or if lower amounts of milk solids are offered as discussed previously.

More elaborate systems using acidified milk or milk replacer to preserve and limit liquid intake are gaining popularity on some dairy farms. These systems provide a very labor efficient way of feeding calves higher levels of milk or milk replacer solids. Typically, calves are placed in groups of similar age within 3 to 5 days of life. Systems developed in Canada utilize formic acid to decrease the pH of the liquid to approximately 4.2. At this level, the growth of harmful bacteria is inhibited. However, the use of formic acid is illegal in the U.S. Commercial milk replacer powders are available which use organic acids and have proven to be highly successful. The advantage of using a commercial milk replacer is that uniformity of nutrient content and acid level is likely to be more consistent. Users should be aware that acidification of waste milk impedes the growth but does not "kill" pathogenic organisms, such as *Mycobacterium avium paratuberculosis*. Producer experience with these systems has shown the calves will consume as much as 3 gallons daily. Weaning is achieved by limiting the time available to the nipples or the number of nipples available within the group pen. The reader is encouraged to read the publication by Anderson (2008) for further information on free access acidified liquid feeding systems.

Computer controlled automatic calf feeding systems are gaining rapidly in popularity as a means of accurately delivering the liquid diet while controlling meal size, daily allotment, and frequency of feeding. More sophisticated systems provide valuable management information to enable the calf manager to monitor diet consumption by individual calves and make timely intervention for calves becoming ill.

Calf autofeeders consist of the basic components (Figure 1; Biotic Industries, Bell Buckle, TN). These systems vary widely in sophistication and price ranging from systems that record minimal data and have simple feeding programs to more involved systems with extensive capabilities to program different feeding plans for individual calves in a group and monitor calf performance. The essential features of autofeeders include a feeding stall and feed box that contain a device enabling electronic identification of calves. Most new systems utilize the radio-frequency identification (**RFID**) ear tags. The nipple is connected via a flexible tube to a mixing bowl where defined amounts of powder and water are mixed as prescribed by the system. Calf meals are limited by meal size, number of meals per day, and time intervals between meals. Additional features of systems will be described later in this manuscript.

The work conducted by Jensen (2004, 2005) and von Keyserlingk et al. (2004) has resulted in the recommendations for stocking rates given by major manufacturers of calf autofeeder systems. General relationships are what would be expected in group housing situations. More calves per feeder results in greater competition for the nipple and an increased rate of intake. A second important factor governing autofeeder management recommendations is the milk allowance per day and per feeding. When calves are limit-fed

milk (less than 1.5 lb of solids per day) calves spent more time in the feeder without being rewarded with additional milk. Similarly, when milk allowances per feeding session are small (one pint or less) calves remain in the stall longer without being rewarded.

General recommendations and features of calf autofeeder systems (Note to reader: Many of the autofeeder systems are manufactured in Europe and use the metric system).

- Age when calves are introduced to the autofeeder system is strongly dependent upon fresh cow and newborn calf management. Aggressive colostrum management programs are essential to successful adaptation to the autofeeder system. Consider routine monitoring of serum proteins during the first week to assess success of the colostrum program. Most farms house calves in individual housing systems for at least the first 5 days to ensure that the calf is eating well. Provide sufficient facilities to house young calves for 5 to 7 days during a heavy calving season.

- Calves are trained to feeders by gently leading them to the nipple when they are moved into the group housing. Eliminating the morning feeding the day that calves are moved into the autofeeder group encourages adaptation to the system. Research by Svennson and Liberg (2006) and Jensen (2008) shows that moving calves onto the feeder at less than 6 days requires more effort to train calves to the feeder. Research by Jensen (2006) has shown that calves introduced to feeders at day 14 required less training time. Calves introduced to the feeder at day 6 spent less time in the feeder after ingesting milk and ingested less milk. They were less successful in competing for milk feeder access, particularly when there is a wider range in age of calves in the pen and with higher stocking rates per feeding station (>25). There also appears to be less risk of respiratory disease when entrance into the feeder is delayed until 10 to 14 days of age. However, experience by most autofeeder system users has shown that moving calves to the autofeeder group is feasible within 7 days of age, particularly when the range of age of calves in the pen is relatively uniform (< 14 days) and there is an effective colostrum management program and excellent newborn calf care.

- Stocking rates of no more than 25 calves per nipple are advised.

- Daily milk allowances range from 1.5 to as much as 2.7 lb (680 to 1225 g) of milk solids per calf per day. On a volume basis, this amounts to 1.4 to 2.6 gallons (5.3 to 10 L) of liquid per day. Higher milk or milk replacer solids levels are recommended.

- Meal sizes vary from 1 pint to 2.6 quarts (0.5 to 3.0 L) each. In many systems, calves must earn enough credits to be able to receive milk or milk replacer from the feeder. As an example, if a calf is allocated 8 liters of "milk" per day, they will earn about 0.33-liter allocation for each hour of the day. They must accrue enough "credits" to achieve their minimum meal size specified by the system that might be 1.5 L. This would mean that there must be a minimum of about 5 hours between feedings. The feeder mixes milk replacer or delivers milk in 0.5 L increments until reaching the maximum meal size. Should the calf wait longer before visiting the feeder, they would be allowed to consume more milk until reaching the maximum meal size limit specified. Typically, maximum meal sizes increase from 2 to as much as 3.5 L as calves age.

- When milk replacer is used, powder is diluted with water to approximately 13 to 15% solids. Caution is advised when specifying dilution as most autofeeding systems express the grams of milk replacer to add to each liter of water. Therefore, 150 g added to a liter of water is not 15% solids but 13% (1,000 ml of water + 150 g of powder = 1150 final weight). Therefore, 150 g of powder/1150 g of total weight = 13% solids).

- Number of meals per day varies by the system. Some basic calf autofeeders have a small mixing bowl and provide meals of 1 pint per visit. In these systems, milk allowances exceeding 1 to 1.5 gallons daily require numerous daily visits to obtain the daily allowance (>12). In other systems, calves are limited to a maximum amount per visit, and the feeder will mix multiple batches of liquid up to the maximum. Typically, calves nursing from systems that are more sophisticated consume ~4 to 5 meals per day.

- Feeding programs vary considerably depending upon the system. The basic systems are frequently programmed to provide all calves with similar meal sizes and daily allowances, regardless of their age. However, the more sophisticated systems enable feeding a defined feeding program in which milk allowance is gradually increased over several days and then decreases to accomplish a "soft" weaning, which reduces the stress of weaning. An example of such a feeding program is shown in Figure 2. (Courtesy: T.J. Earleywine, Land O Lakes Animal Milk, Shoreview, MN). In more sophisticated systems, multiple feeding programs can be in effect within one pen so that smaller calves or those of a different breed are accommodated.

Systems that are more sophisticated also enable use of pasteurized waste milk in addition to milk replacer. A system utilized by one autofeeder manufacturer enables the calf to consume milk or milk replacer ad libitum for a specified period in the group pen (usually 28 days). Then the liquid diet daily allocation is reduced to 8 L/day to stimulate starter grain consumption. Allocation is held constant until gradual weaning over 7 to 10 days at approximately 42 days.

- Systems that are more sophisticated enable dispensing additives in either the liquid or the dry form to calves. This enables the manager to administer additional electrolytes, antibiotics, or other therapies on an individual basis.

- Sanitation of the autofeeder is automatic in some systems and manual in others.

- More advanced computer controlled stations will also deliver calf starter grain through a separate feeding stall. These systems will trigger "soft" weaning from liquids when calf starter grain intake reaches levels indicated by the computer. However, experiences on dairy farms has shown that these systems do not encourage intake and many users provide small open feed bunks with free choice calf starter.

Several field studies have been conducted in herds that utilized automatic calf feeder systems (Machado et al., 2012; Dietrich et al., 2015; Jorgensen et al., 2015; Knauer et al., 2017). As expected, there are a wide variety of installations and management practices. Maintenance of equipment to follow manufacturer's recommendations is necessary to maintain low levels of microbial growth and delivery of liquid diets with desired solids level and temperature. These studies

have shown a higher treatment rate for calves housed in autofeeder systems as compared to individual calf feeding systems. This appears to be related to earlier detection of disease that was predominantly diarrhea and was treated with electrolytes. Mortality was less than 1.5% in these field studies that may be due to more timely treatment.

It appears that drinking speed, which is calculated by some systems, is a useful tool for predicting onset of digestive disease but not respiratory disease. Calves frequently will consume their daily allocation of liquid while they are becoming ill, but at a slower rate. Research is ongoing to develop algorithms that might be used to "flag" calves, which would require further closer evaluation.

Risk Factors for Disease in Autofeeder Systems (Endres and James, 2017)

- Farms with greater numbers of calves per group have poorer health scores. It is suggested that average group size be limited to 15 calves. Herds practicing all-in all-out strategies were more successful with larger group sizes. Larger group sizes can be successful if ventilation, drainage, and maintenance of bedding is optimal.

- Space per calf. The minimum space per calf is 35 sq. ft. Herds with 45 to 50 sq. ft. of bedded resting space have better health scores.

- Time to reach peak milk allowance. Herds that are too slow (>14 days) in increasing the liquid diet to maximum levels have poorer health scores. Calves may have looser manure but higher milk intake earlier promotes better gains and health.

- Herds without positive pressure ventilation systems are associated with much higher incidence in morbidity. The investment in engineering advice and installation of these ventilation systems is essential for success.

- Strict adherence to recommended sanitation of the system is essential. Routinely scheduling automatic cleaning of the internal surfaces 4 X per day is associated with lower microbial growth. Once daily circuit cleaning of all surfaces and the feeding nipple is recommended. Use of recommended sanitizers and detergents which are designed for use at lower temperatures found in autofeeder systems is also critical.

- Milk replacers must be formulated to mix at the lower temperatures utilized in autofeeders (~105°F). Utilization of milk replacers requiring higher mixing temperatures will not work well in autofeeder systems!

- Machines that are more sophisticated handle waste milk in addition to milk replacer. This creates a new set of management challenges as waste milk should be pasteurized, cooled for storage, and then warmed again prior to feeding. Some systems, given the known solids content, will automatically add milk replacer powder and water to achieve the desired final solids level in the diet. Given the variable supply of waste milk and the variable solids content of waste milk, it is challenging to maintain consistency in the feeding program and to successfully sanitize the equipment.

- Dairy producers interested in adopting this technology should have the proper management mindset. These individuals should have the following skills and management behaviors:

  - o They are data oriented and should evaluate the intake and other management information provided each morning and periodically throughout the day.

  - o Calf managers should "walk" the pens periodically to evaluate calf behavior and detect illnesses prior to viewing computer reports of calf feeding behavior.

  - o There is an opportunity for improved labor efficiency with autofeeder systems. However, many producers note that time formerly spent feeding and cleaning buckets or bottles is spent reviewing reports, walking pens, and maintaining the feeder.

- Calf behavior is dramatically different for group-housed calves.When calves are fed twice daily in individual pens, they respond to people entering the barn through increased activity and vocalization. Calves fed via an autofeeder system will not respond to people entering the pen as much. If a calf does so, it usually means that they may not have trained to the feeder or there is an equipment malfunction.

Conclusions

Group housing systems have been successfully adapted on many dairy facilities. The choice of what system will depend upon herd size, financial resources, and management preferences. Use of mob feeders tend to be more successful in smaller herds. Acidified free choice systems have been successful in a variety of herd sizes. Autofeeders are a proven technology that offers some attributes that are very positive for calf nutrition and management but are probably more appealing to herds of at least 200 cows or more when the fixed costs of the system can be spread over more animal units. More frequent feeding is probably less stressful for the calf and appears to promote more efficient feed utilization. It is easier to feed more without added labor or stressing the calf with large meal sizes or higher percentages of milk solids required for intensive feeding systems limited to twice a day feeding in buckets or bottles. The field studies of farms using autofeeders emphasizes the need for well-designed facilities and routine monitoring of temperature, solids delivery calibration, and sanitation. Although they are marketed for their labor saving, field studies have indicated that although routine labor is reduced, increased emphasis is placed on monitoring the equipment, evaluating calf consumption, sanitation, and in monitoring calf health.

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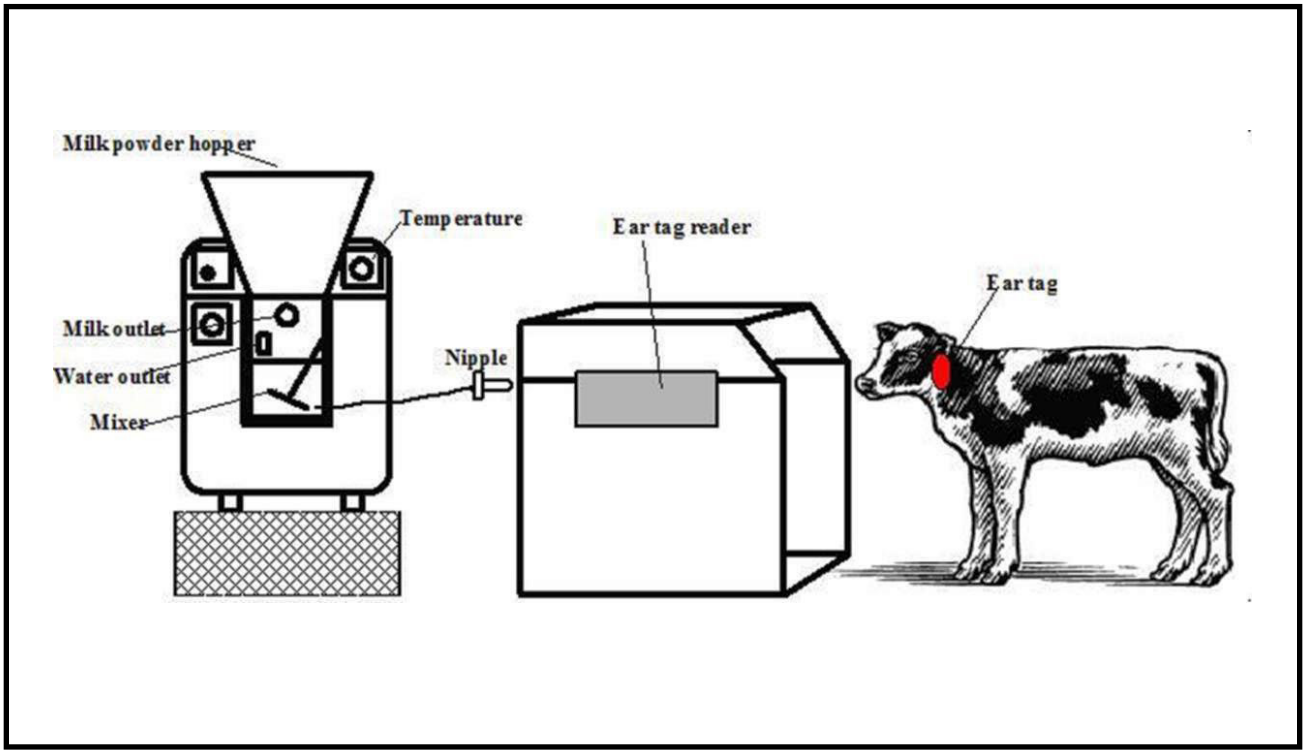

Figure 1. Basic components of a calf autofeeder.

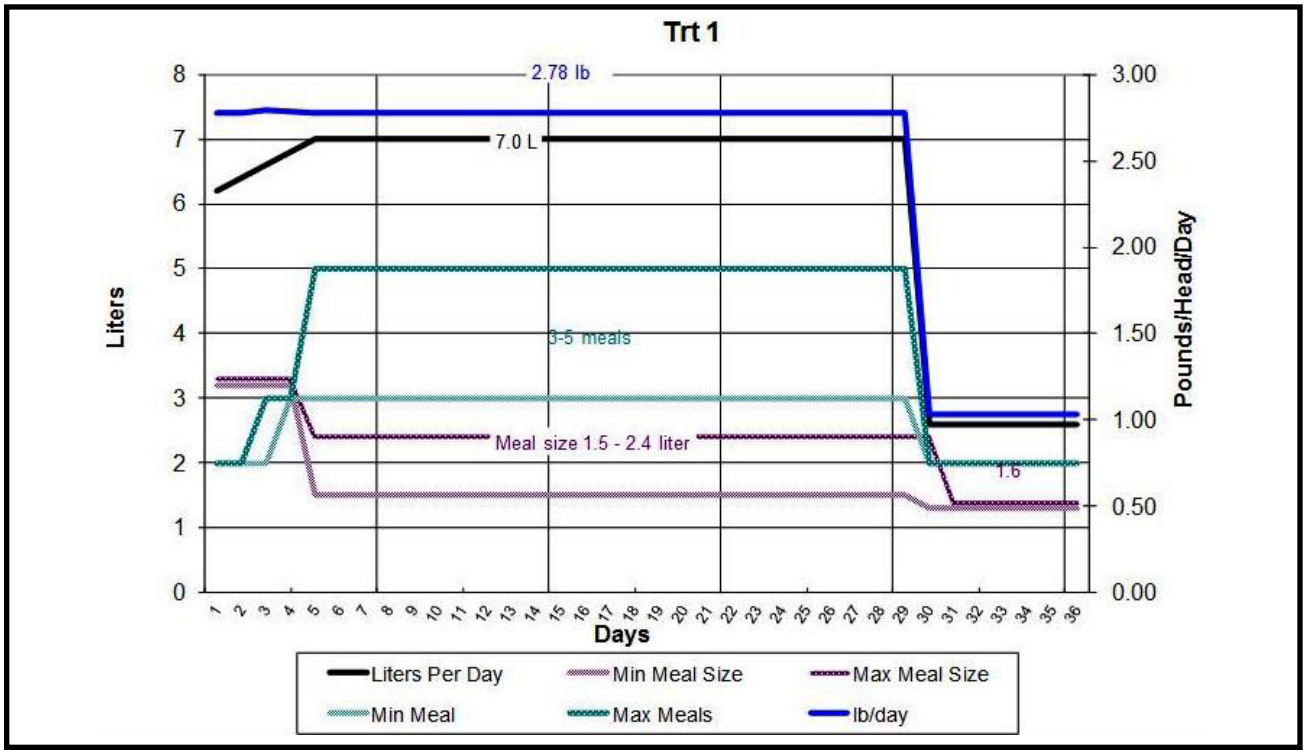

Figure 2. Example of a feeding program with calf auto feeders that permit gradual increases in milk allowance and then decreases milk allowance to prepare for weaning.

Update on Fatty Acid Digestion and Metabolism and Impacts on Milk Production

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Introduction

Recently, the effects of individual fatty acid (**FA**) on digestibility, metabolism, and production responses of dairy cows has received renewed attention. The addition of supplemental FA sources to diets is a common practice in dairy nutrition to increase dietary energy density and to support milk production. The ability to understand and model FA, the effects of individual FA, and different FA supplements on production parameters has direct impact on dairy industry recommendations and the usefulness of FA supplementation strategies. We will briefly review the biological processes and quantitative changes during the metabolism of FA in the rumen and the effect this has on FA availability to the dairy cow, the digestibility of these FA, and their overall impact on performance. Our emphasis in the current paper is on recent research supplementing palmitic (C16:0), stearic (C18:0), and oleic (*cis*-9 C18:1) acids on feed intake, nutrient digestibility, milk production and milk composition, and energy partitioning.

Fatty Acid Metabolism in the Rumen

As well as being derived from specific supplements, FA in the dairy cow's diet are also present in forages and concentrates. Each feed/fat source is composed of a different mix of individual FA. The majority of FA in dairy cow diets contain 16- and 18-carbons. Generally, most cereal grains and seeds contain a high concentration of linoleic acid (C18:2 n-6), whereas linolenic acid (C18:3 n-3) is typically the predominant FA in forage sources. Unsaturated FA are toxic to many rumen bacteria, thus an extensive metabolism of dietary lipids occurs in the rumen, which has a major impact on the profile of FA available for absorption and tissue utilization (Palmquist et al., 2005). The 2 major processes that occur are hydrolysis of ester linkages in lipids found in feedstuffs and the biohydrogenation of unsaturated FA. It appears that the degree of toxicity of different unsaturated FA varies for individual ruminal bacteria species; all the main species that comprise the ruminal cellulolytic bacteria appear vulnerable to inhibition by unsaturated FA (Maia et al., 2007, 2010). Biohydrogenation of unsaturated FA results in the conversion of unsaturated FA to saturated FA, mainly C18:0, through a series of biohydrogenation intermediates (conjugated C18:2 and *trans* C18:1 FA). The major substrates are 18:2 n-6 and 18:3 n-3 and the rate of rumen biohydrogenation is in the range of 70 to 95% and 85 to 100%, respectively (Jenkins et al., 2008); thus, C18:0 is the predominant FA available for absorption by the dairy cow under typical feeding situations (Bauman and Lock, 2006).

FA supplements are often used as a means to increase the energy density of the diet and many of these are referred to as inert.

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In this case, inertness simply means that the FA supplement has minimal affects on rumen fermentation. Although deemed inert at the level used, they can still be hydrolyzed, if a triglyceride, or biohydrogenated, if unsaturated. Often, calcium-salts of palm FA or canola are referred to as 'protected'. However, these are not protected from rumen biohydrogenation but rather are considered to be ruminally inert with regard to their effects on the microbial population (Palmquist, 2006).

Fatty Acid Metabolism in the Intestine

The lipid material that reaches the intestine consists of approximately 80 to 90% free FA attached to feed particles. The remaining lipid components are microbial phospholipids plus small amounts of triglycerides and glycolipids from residual feed material. These esterified FA are hydrolyzed by intestinal and pancreatic lipases (Doreau and Ferlay, 1994). FA absorption occurs predominantly in the jejunum region of the small intestine. Prior to reaching the jejunum, 2 secretions, bile and pancreatic juice, are added to the digesta in the duodenum. Before FA absorption can occur, it is necessary for the lipid material absorbed onto the feed particles to be solubilized into the aqueous environment. Lysolecithin acts as an amphiphile (substance with both water and lipid-loving capacity) and further increases the solubility of saturated FA (Freeman, 1969). Lysolecithin together with bile salts desorb FA from feed particles and bacteria, allowing the formation of the micelles (Lock et al., 2005). In ruminants, micelle formation is the key to this process, and therefore, key to efficient FA absorption (Lock et al., 2005). Once micelles are formed, they facilitate transfer of water-insoluble FA across the unstirred water layer of intestinal epithelial cells, where the FA and lysolecithin are absorbed.

Effects of C16:0, C18:0, and *cis*-9 C18:1 on Fatty Acid Digestibility

Our recent FA digestibility research has utilized and focused on C16:0 and C18:0-enriched supplements. Of particular importance, Boerman et al. (2017) fed increasing levels of a C18:0-enriched supplement (85% C18:0) to dairy cows and observed no positive effect on production responses, which was likely associated with the pronounced decrease in total FA digestibility as FA intake increased (Figure 1A). Similarly, Rico et al. (2017) fed increasing levels of a C16:0-enriched supplement (87% C16:0) to dairy cows, and even though a positive effect was observed on production response up to 1.5% diet DM, a decrease in total FA digestibility as FA intake increased was observed (Figure 1B). However, considering that the range on FA intake was similar across both studies, the decrease in total FA digestibility was more pronounced when there was increased intake/rumen outflow of C18:0 rather than C16:0. This is supported by our meta-analysis, in which a negative relationship between the total flow and digestibility of FA was observed (Figure 2A), with the decrease in total FA digestibility driven by the digestibility of C18:0 (Figure 2B) because of the negative relationship between duodenal flow and digestibility of C18:0 (Boerman et al., 2015). The exact mechanisms for these differences in digestibility are not understood; however, potential causes include the lower solubility of C18:0 compared to C16:0, which would be more dependent of emulsification for absorption (Drackey, 2000). Additionally, results have shown that *cis*-9 C18:1 has greater digestibility than C18:0 and C16:0 (Boerman et al., 2015). Also, Freeman (1969) examined the amphiphilic properties of polar lipid solutes and found that *cis*-9 C18:1 had a positive effect on the micellar solubility of C18:0.

To further understand what factors influence FA digestibility, we recently utilized a random regression model to analyze available individual cow data from 5 studies that fed a C16:0-enriched supplement to dairy cows. We observed that total FA digestibility was negatively impacted by total FA intake but positively influenced by the intake of *cis*-9 C18:1 (unpublished results). This suggests that a combination of 16-carbon and unsaturated 18-carbon FA may improve FA digestibility, but reasons for this needs to be determined. This is supported by our recent results comparing combinations of C16:0, C18:0, and *cis*-9 C18:1 in supplemental fat (de Souza et al., 2016a); we observed that FA digestibility increased when a supplement containing more *cis*-9 C18:1 was fed compared with a control diet (Figure 3). Also, FA digestibility was markedly reduced when a supplement containing more C18:0 was fed compared with the other FA treatments due to decreases in both 16- and 18-carbon FA digestibility (Figure 3).

Effect of Fatty Acids on NDF Digestibility

The amount of FA that are included in the diet is relatively small for lactating dairy cattle, and changes in FA digestibility therefore may have minimal effects on overall DM digestibility and digestible energy intake. Changes in intake and digestibility of other nutrients, such as NDF, due to FA supplementation may affect positively or negatively the digestible energy value of the fat supplement.

Weld and Armentano (2017) performed a meta-analysis to evaluate the effects of fat supplementation on DMI and NDF digestibility of dairy cows. Supplementation of fat supplements high in medium chain FA (12 and 14-carbons) decreased both DMI and NDF digestibility. Addition of vegetable oil decreased NDF digestibility by 2.1 percentage units, but did not affect DMI. Also, feeding saturated prilled fat (combinations of C16:0 and C18:0) did not affect DMI, but increased NDF digestibility by 0.22 percentage units. Overall, the authors concluded that the addition of a fat supplement, in which the FA are 16-carbon or greater in length, has minimal effects on NDF digestibility.

We recently utilized a random regression model to analyze available individual cow data from 6 studies that fed a C16:0-enriched supplement to dairy cows (de Souza et al., 2016b). We observed that NDF digestibility was positively impacted by total C16:0 intake (Figure 4A) and DMI was not affected. This suggests that that the increase in NDF digestibility when C16:0-enriched supplements are fed to dairy cows is not explained through a decrease in DMI. Additionally, when comparing combinations of C16:0, C18:0, and *cis*-9 C18:1 in supplemental fat, we observed that feeding supplements containing C16:0 or C16:0 and *cis*-9 C18:1 increased NDF digestibility compared with a supplement containing C16:0 and C18:0 (de Souza et al., 2016a; Figure 4B).

Overall Impact of Fatty Acid Supplementation on Production Responses

There is a wide range of FA supplements available for lactating dairy cattle. For example, calcium-salts of free FA and prilled saturated free FA are 2 common types of supplements used in the dairy industry and they differ in FA content and profile. Calcium-salt supplements typically contain 80 to 85% FA, and these provide approximately 50% saturated and 50% unsaturated FA. By comparison, prilled saturated free FA contain approximately 99% FA, which are approximately 90% saturated, 10% unsaturated. A summary of the FA profile of some commonly used supplements is provided in Table 1. Although in general FA supplementation has been shown to increase milk yield, milk fat

yield, and the efficiency of milk production, great variation has been reported in production performance for different FA types, and indeed, the same supplement across different diets and studies. This is evident in a meta-analysis examining the effect of FA supplementation to diets of dairy cows (Rabiee et al., 2012). In general, milk production and milk fat content and yield increased, DMI and milk protein concentration decreased, and milk protein yield was not affected by FA supplementation. There was a wide range of responses (~5 standard deviations) for all variables, indicating varied and marked biological effects of the different FA supplements (Rabiee et al., 2012).

Utilizing a larger data set than Rabiee et al. (2012), we recently performed a meta-analysis of production responses to commercially available FA supplements (Boerman and Lock, 2014). Overall, FA supplementation increased yield of milk and milk components and reduced DMI. However, type of supplement influenced response with prilled saturated FA supplements not reducing DMI, tallow having no effect on milk fat yield, and Ca-salts of palm FA having no effect on milk protein yield. It is important to note that most studies simply compared a single commercial FA supplement with a non-FA supplemented control diet. This makes direct comparisons between different FA supplements difficult to interpret, and importantly, to provide accurate answers to commonly asked questions (by farmers and nutritionists) as to which are the best FA supplements to use. There are limited reports in the published literature that have undertaken direct comparisons between different commercially available FA supplements. Results also suggest that responses to FA supplements interact with other dietary components, and this should be examined further.

Effects of C16:0, C18:0, and *cis*-9 C18:1 on Production Responses

We have recently carried out a series of studies examining the effect of individual saturated FA on production and metabolic responses of lactating cows (Lock et al., 2013, Piantoni et al., 2013, Rico et al., 2014, Piantoni et al., 2015). Piantoni et al. (2015) reported that C18:0 increased DMI and yields of milk and milk components, with increases more evident in cows with higher milk yields, but the response occurred only in 1 of the 2 periods of the crossover design. Reasons why only higher yielding cows responded more positively to C18:0 supplementation and only in one period remains to be determined. Also, our results indicate that C16:0 supplementation has the potential to increase yields of 3.5% FCM and milk fat, as well as the conversion of feed to milk, independent of production level when it was included in the diet for soyhulls or C18:0 (Table 2). Additionally, in a recent dose response study with mid lactation cows, feeding a C18:0-enriched supplement (85% C18:0) increased DMI but had no effect on the yields of milk or milk components when compared to a non-FA supplemented control diet, which was probably associated with the decrease in FA digestibility (Figure 1, Boerman et al., 2017).

Furthermore, we recently utilized a random regression model to analyze available individual cow data from 10 studies that fed a C16:0-enriched supplement to dairy cows (de Souza et al., 2016b). We observed that energy partitioning toward milk was increased linearly with C16:0 intake, as a result of a linear increase in milk fat yield and energy corrected milk (**ECM**) with increasing intake of C16:0. In a recent study (unpublished results), we evaluated the long-term effects of C16:0 supplementation and observed that C16:0 consistently increased DMI, milk yield, and ECM compared with a

non-fat control diet over the 10-wk period of supplementation (Figure 5). Also, in a study with fresh cows (1 to 70 DIM; unpublished data), we evaluated the effects of C16:0 supplementation on performance and observed that C16:0 consistently increased milk fat yield and ECM compared with a non-fat control diet throughout the feeding period (Figure 6).

When we compared combinations of C16:0, C18:0, and *cis*-9 C18:1 in a FA supplement, a supplement containing more C16:0 increased energy partitioning toward milk due to the greater milk fat yield response compared with the other treatments (de Souza et al., 2016a). In contrast, a FA supplement containing C16:0 and *cis*-9 C18:1 increased energy allocated to body reserves compared with other treatments. The FA supplement containing a combination of C16:0 and C18:0 reduced nutrient digestibility, which most likely explains the lower production responses observed compared with the other treatments. This may suggest that C16:0 and *cis*-9 C18:1 are able to alter energy partitioning between the mammary gland and adipose tissue, which may allow for different FA supplements to be fed in specific situations according to the metabolic priority and needs of dairy cows. Further research is needed to confirm these results in cows at different stages of lactation or other physiological conditions.

Conclusions

The addition of supplemental FA to diets is a common practice in dairy nutrition to increase dietary energy density and to support milk production. Although in general FA supplementation has been shown to increase milk yield, milk fat yield, and the efficiency of milk production, great variation has been reported in production performance for different FA supplements, and indeed, the same supplement across different diets and studies. Just as we recognize that not all protein sources are the same it is important to remember that not all FA supplements are the same. The key is to know what FA are present in the supplement, particularly FA chain length and their degree of unsaturation. The digestibility of the FA supplement, as well as potential interactions with other dietary factors, is important for determining the energetic value of a supplement. Once this information is known, it is important to consider the possible effects of these FA on DMI, rumen metabolism, small intestine digestibility, milk component synthesis in the mammary gland, energy partitioning between the mammary gland and other tissues, and body condition. The extent of these simultaneous changes, along with the goal of the nutritional strategy employed, will ultimately determine the overall effect of the supplemental FA and the associated decision regarding their inclusion in diets for lactating dairy cows.

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Table 1. Fatty acid (**FA**) composition of common fat supplements (data from our laboratory).

FA, g/100 g	Tallow	Ca-salt palm FA	Saturated free FA	C16:0-enriched
C14:0	3.0	2.0	2.7	1.6
C16:0	24.4	51.0	36.9	89.7
C18:0	17.9	4.0	45.8	1.0
C18:1	41.6	36.0	4.2	5.9
C18:2	1.1	7.0	0.4	1.3

Table 2. Summary of DMI, milk production and composition, body weight, and body condition score (**BCS**) for cows supplemented with C16:0 and C18:0 supplements. The C16:0 supplement contained ~ 99% C16:0 and the C18:0 supplement contained ~ 98% C18:0.

	Piantoni et al. (2013)[1]			Piantoni et al. (2015)[2]			Rico et al. (2014)[3]		
Variable	Control	C16:0	SEM	Control	C18:0	SEM	C16:0	C18:0	SEM
DMI, kg/day	27.8	27.8	0.54	25.2^{n}	26.1^{m}	0.42	32.1	32.3	0.44
Milk yield, kg/day	44.9^{b}	46.0^{a}	1.7	38.5^{n}	40.2^{m}	0.71	46.6	45.8	2.02
Fat yield, kg/day	1.45^{b}	1.53^{a}	0.05	1.35^{n}	1.42^{m}	0.03	1.68^{y}	1.59^{z}	0.05
Milk fat, %	3.29^{b}	3.40^{a}	0.11	3.60	3.59	0.12	3.66^{y}	3.55^{z}	0.09
Protein yield, kg/day	1.38	1.41	0.04	1.14^{n}	1.19^{m}	0.02	1.50	1.49	0.05
Milk protein %	3.11	3.09	0.05	3.00	2.99	0.05	3.24	3.29	0.05
3.5% FCM, kg/day	42.9^{b}	44.6^{a}	1.35	38.6^{n}	40.5^{m}	0.76	47.5^{y}	45.6^{z}	1.64
3.5% FCM/DMI	1.54^{b}	1.60^{a}	0.03	1.53	1.55	0.04	1.48^{y}	1.40^{z}	0.05
Body weight, kg	722	723	14.7	727	730	12.8	720	723	13.6
BCS	2.99	2.93	0.15	2.67	2.67	0.11	2.93^{z}	2.99^{y}	0.11

[1]Treatments were either a control diet (with 2% of diet DM as added soyhulls) or a C16:0-supplemented diet (with 2% of diet DM as C16:0). Means within a row with different superscripts (a, b) differ ($P < 0.05$).

[2]Treatments were either a control diet (with 2% of diet DM as added soyhulls) or a C18:0-supplemented diet (with 2% of diet DM as C18:0). Means within a row with different superscripts (m, n) differ ($P < 0.05$).

[3]Treatments were either a C16:0-supplemented diet (with 2% of diet DM as C16:0) or a C18:0-supplemented diet (with 2% of diet DM as C18:0). Means within a row with different superscripts (y, z) differ ($P < 0.05$).

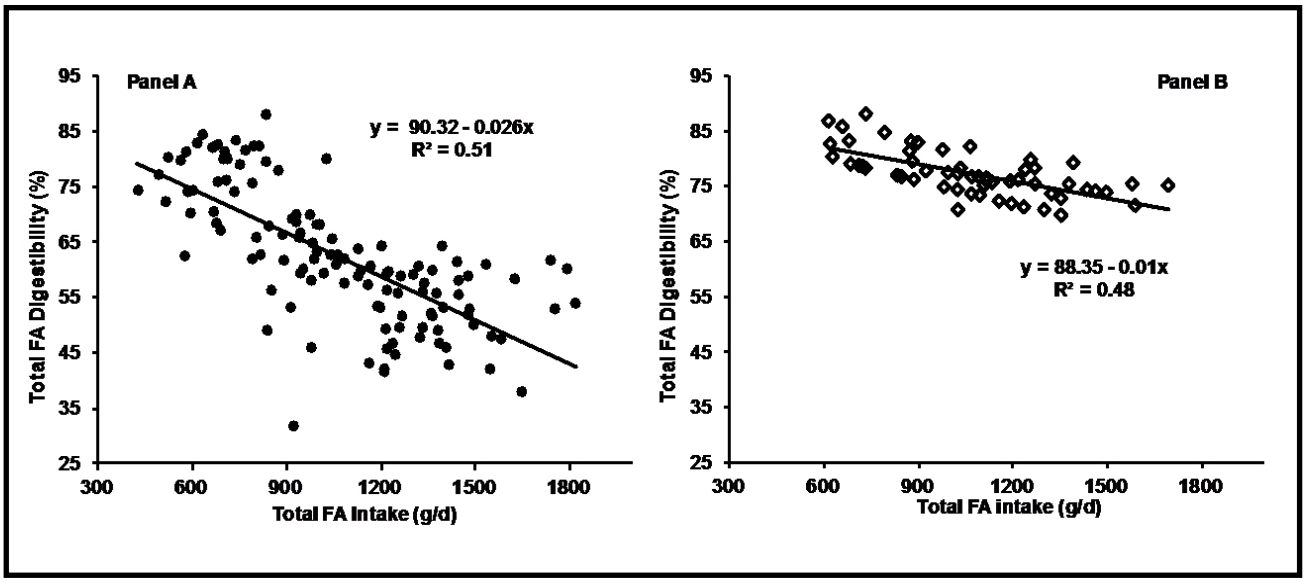

Figure 1. Relationship between total fatty (**FA**) intake and apparent total-tract FA digestibility of dairy cows supplemented with either a C18:0-enriched supplement (Panel A) or a C16:0-enriched supplement (Panel B). Results in Panel A utilized 32 mid-lactation cows receiving diets with increasing levels (0 to 2.3% of dry matter) of a C18:0-enriched supplement (85% C18:0) in a 4 X 4 Latin square design with 21-day periods (Boerman et al., 2017). Results in Panel B utilized 16 mid-lactation cows receiving diets with increasing levels (0 to 2.25% of dry matter) of a C16:0-enriched supplement (87% C16:0) in a 4 X 4 Latin square design with 14-day periods (Rico et al., 2017).

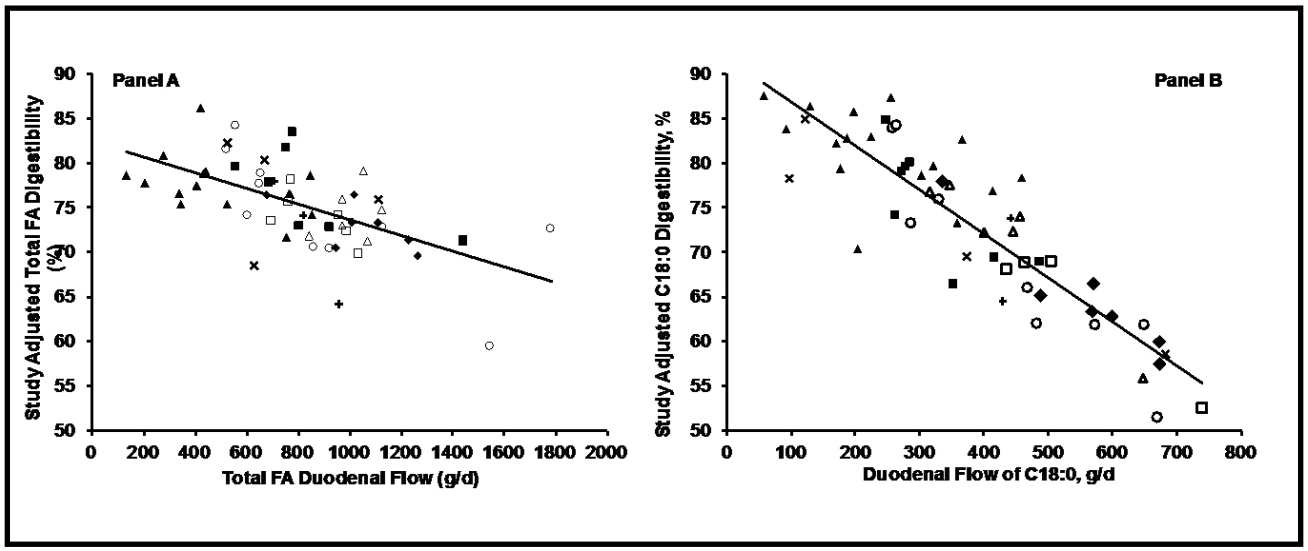

Figure 2. Relationship between study adjusted apparent total fatty acid (**FA**) intestinal digestibility and total FA duodenal flow (Panel A) and study adjusted C18:0 apparent intestinal digestibility and duodenal flow of C18:0 (Panel B). Results from a meta-analysis using 15 published studies that measured duodenal flow and intestinal digestibility of FA in dairy cows (Boerman et al., 2015). Control treatments represented by black triangles; animal-vegetable fat treatments represented by black diamonds; calcium salt treatments represented by black squares; tallow treatments represented by open circles; vegetable oil treatments represented by open triangles; seed meal treatments represented by open squares; whole seed treatments represented by black addition sign; and other treatments represented by black multiplication sign.

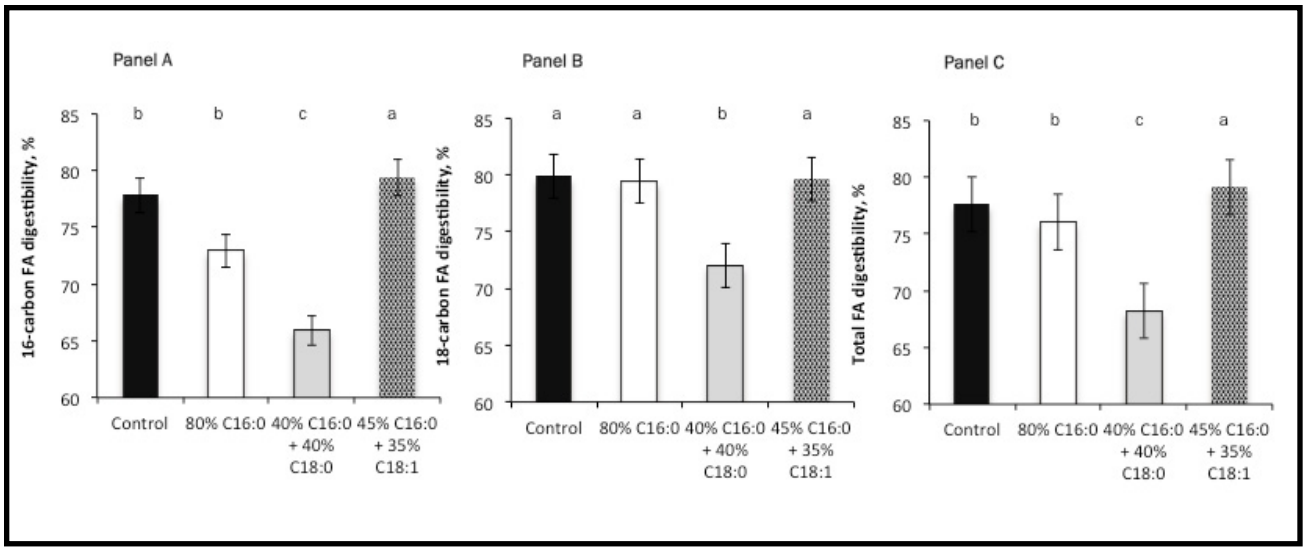

Figure 3. The effects of different dietary ratios of fatty acid (**FA**) on digestibility of 16-carbon (Panel A), 18-carbon (Panel B), and total FA (Panel C). Results utilized 24 mid-lactation cows receiving the following diets: CON (Control diet); PA (1.5% of FA supplement blend to provide ~ 80% of C16:0); PA+SA (1.5% of FA supplement blend to provide ~ 40% of C16:0 + 40% of C18:0); and PA+OA (1.5% of FA supplement blend to provide ~ 45% of C16:0 + 35% of C18:1 cis-9). in a 4 X 4 Latin square design with 21-day periods (de Souza et al., 2016a).

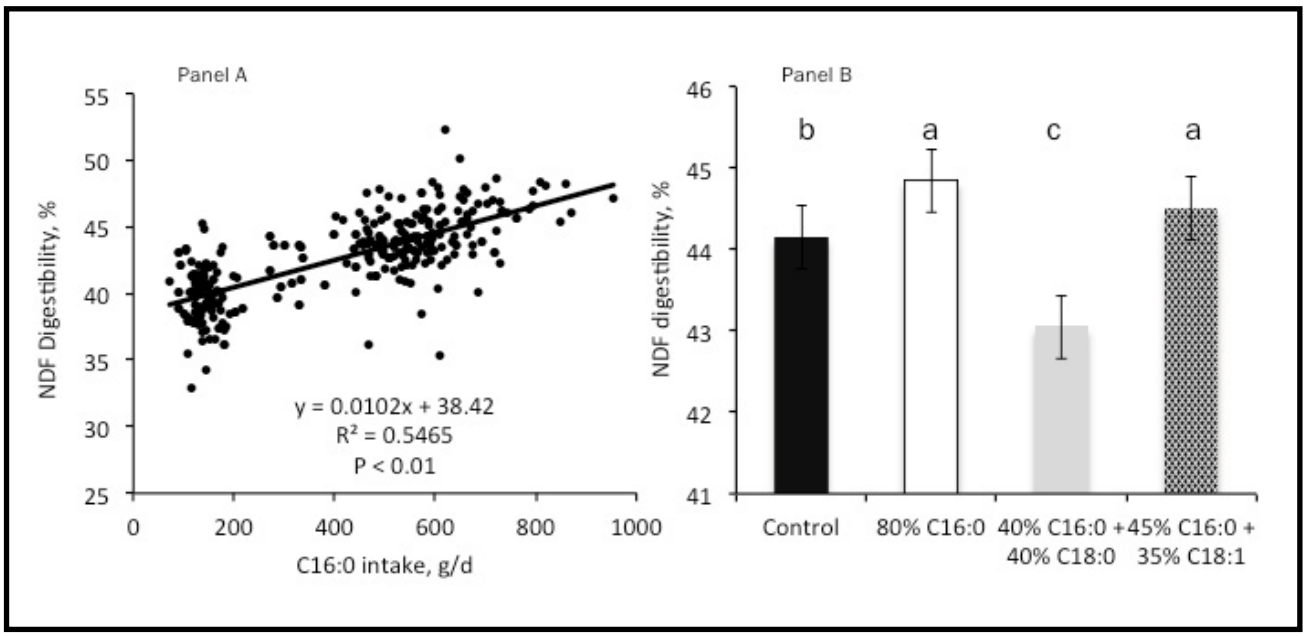

Figure 4. Panel A: Relationship between C16:0 intake and NDF digestibility of dairy cows fed C16:0-enriched fatty acid (**FA**) supplements. Panel B: The effects of different dietary ratios of FA on NDF digestibility. Results in Panel A represent a combined data set evaluated using a random regression model from 6 studies feeding C16:0-enriched supplements on NDF digestibility of dairy cows (de Souza et al., 2016b). Results in Panel B utilized 24 mid-lactation cows receiving the following diets: CON (Control diet); PA (1.5% of FA supplement blend to provide ~ 80% of C16:0); PA+SA (1.5% of FA supplement blend to provide ~ 40% of C16:0 + 40% of C18:0); and PA+OA (1.5% of FA supplement blend to provide ~ 45% of C16:0 + 35% of C18:1 cis-9). in a 4 X 4 Latin square design with 21-day periods (de Souza et al., 2016a).

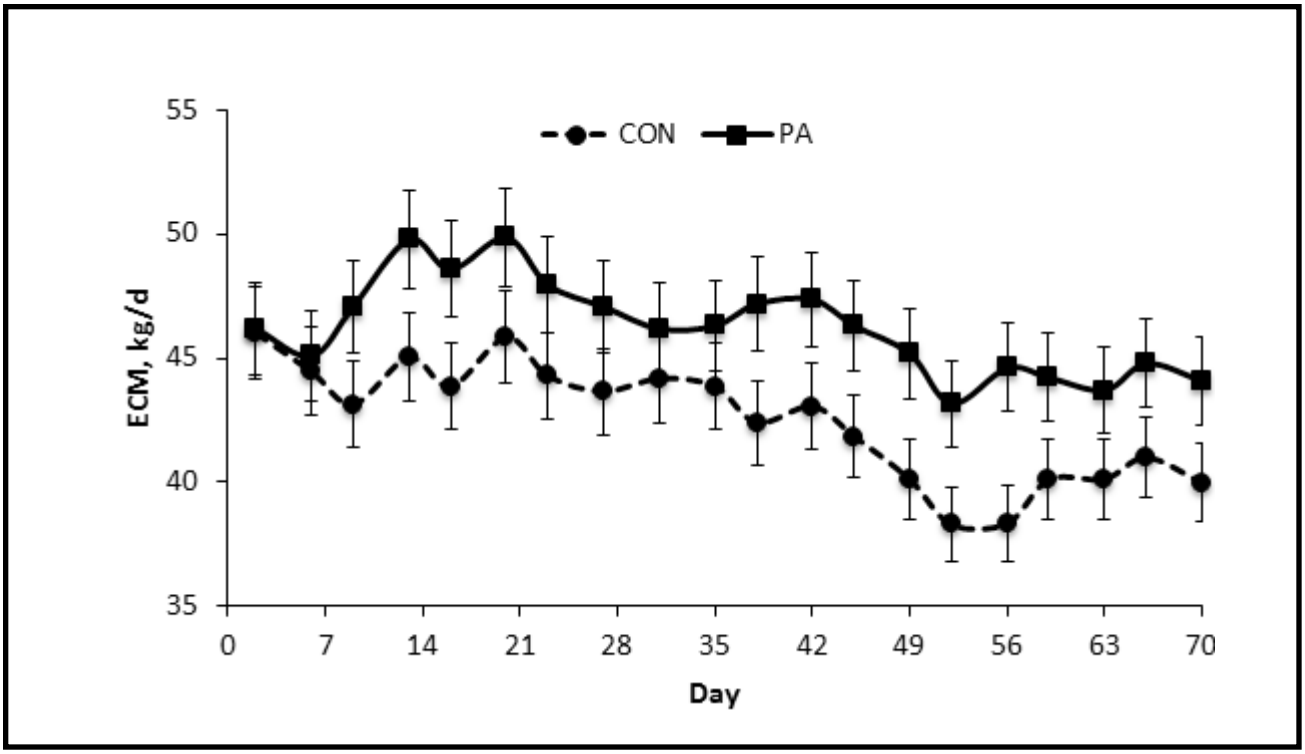

Figure 5. Effects of C16:0 supplementation on the yield of energy corrected milk in mid-lactation cows. The study utilized 40 mid-lactation cows in a block design receiving either a control diet containing no supplemental fat (**CON**) or a C16:0-enriched supplemented diet (**PA**; 1.5% diet DM) fed for 10 wks (unpublished results).

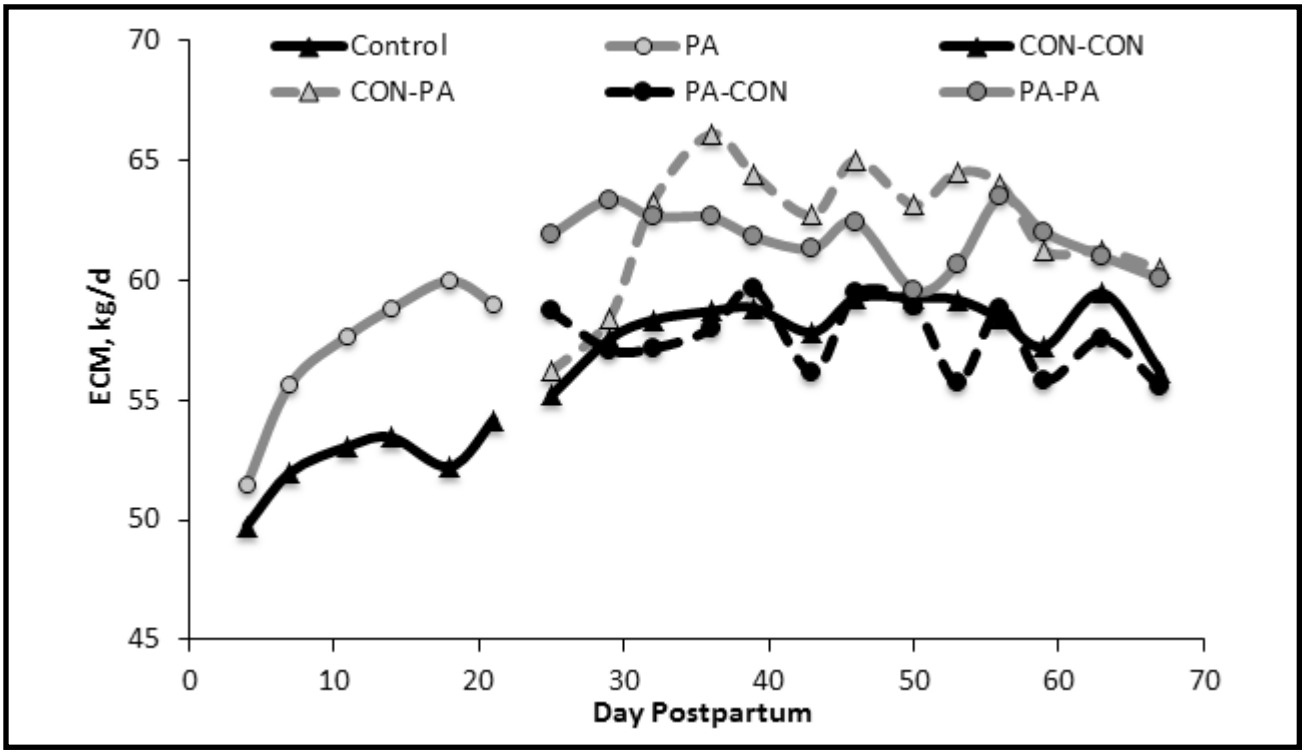

Figure 6. Effects of C16:0 supplementation on the yield of energy corrected milk in early lactation cows. The study utilized 52 early-lactation cows in a block design receiving either a control diet containing no supplemental fat (**CON**) or a C16:0-enriched supplemented diet (**PA**; 1.5% diet DM) that was fed either from calving (1 to 24 days; Fresh period) or after 3 weeks from calving (25 to 67 days; Lactation period). (Unpublished results).

A New Approach for Calculating Metabolizable Protein Requirements by Lactating Dairy Cows

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Abstract

This article describes a new system for calculating metabolizable protein (**MP**) requirements by lactating dairy cows. The system was developed with 133 treatment means from 36 scientific publications. The nonlinear relationship between total protein output (scurf + endogenous urinary + metabolic fecal + milk) and MP supply was used to construct a response model determining changes in protein output with varying supplies. The efficiency of MP utilization predicted by the model decreased nonlinearly with supply, ranging from 0.85 to 0.43 as protein supply increased from 0.78 to 3.28 kg/day (1.72 to 7.22 lb/day). The combined MP requirement (i.e., lactation plus maintenance) was defined as the MP supply needed to predict a given total protein output in the estimated response curve. A requirement function was constructed by solving the estimated nonlinear response curve in terms of the MP supply. This function directly computes the supply needed for a given total protein output while accounting for a variable efficiency at different protein supply levels. For protein outputs below 1.1 kg/day (2.42 lb/day), the calculated requirements were lower than the ones from the current Northern American feeding system for dairy cows. Conversely, for total protein outputs beyond 1.1 kg/day (2.42 lb/day), the calculated requirements were higher than predicted by current feeding systems. Finally, one example is presented with the detailed use of the new system for calculating the combined MP requirements.

Introduction

The current Northern American feeding system for dairy cows (NRC, 2001) assumes a constant efficiency of MP use for lactation and for most of maintenance components. The direct implication of a constant efficiency is that the supplied MP is utilized with the same efficiency, regardless of the feeding level. In the same system, the requirement of MP for lactation is determined by dividing the protein yield in milk by the constant 0.67 efficiency. As a consequence, approximately 1.5 kg of MP is required for each kg of protein outputted in milk, regardless of the level of milk production or the MP supply. Biological principles imply that cows have a genetic potential for milk production and an asymptotic potential milk production must limit protein yield when MP supply grows infinitely large. Furthermore, it is well established that the efficiency of nutrient utilization for production functions may be relatively lower at higher nutrient supplies. For instance, recent studies have shown that at higher feeding levels, MP is utilized with a relatively lower efficiency (Hanigan et al., 1998). Likewise, Metcalf et al. (2008) reported efficiencies of MP utilization decreasing from 0.77 to 0.50 with MP supplies varying from 25% below to 25% above requirement. Both Metcalf

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et al. (2008) and Arriola Apelo et al. (2014) suggested that the efficiency of MP utilization is not constant and decreases nonlinearly with MP supply. The use of a constant efficiency of MP utilization may be one of the underlying reasons the NRC (2001) system underestimates MP allowable milk at lower MP supplies and overestimates at relatively higher supplies (Lapierre et al., 2007).

In this context, the objective of this article is to describe a new system to calculate MP requirements by lactating dairy cows. The system is built on the principle of variable efficiency of MP utilization. Further, it relies on a nonlinear response curve to derive a requirement function determining the requirement of MP for a given level of total protein output. In the next sections, we describe the data used for the system development, the system properties, and how to use the system in practice.

Total Protein Output and MP Supply

The first step in the development of the system was to define the lactating cow's protein output and MP supply. The total protein output was defined as the protein output in milk and in maintenance components. The reason for using a total protein output was to estimate a combined efficiency and a combined MP requirement rather than separate factorial requirements for maintenance and lactation. The use of combined efficiency and requirement was suggested by Lapierre et al. (2014) with the reasoning that the removal of surplus amino acids is associated with tissues having the catabolic enzymes rather than with tissues involved in protein synthesis and exportation (Lapierre et al., 2014). Maintenance protein output was composed of scurf, endogenous urinary, and metabolic fecal protein outputs.The scurf protein output was set at 0.2 g CP/kg $BW^{0.6}$ (Swanson, 1977), the urinary endogenous protein output set at 2.75 g CP/kg $BW^{0.5}$ (Swanson, 1977) and metabolic fecal protein set at 15.8 g CP/kg DMI with an average proportion of true protein/CP of 0.80 (Lapierre et al., 2014). The MP supply was defined as the calculated MP supply (NRC, 2001) minus the MP supply from endogenous sources entering the duodenum (also calculated with NRC, 2001) as described in Lapierre et al. (2014).

The data used for system development was a subset of the data from Martineau et al. (2016). The subset is composed of 133 treatment means from 36 scientific publications. In short, milk true protein yield was used as milk protein output, and when not reported, it was assumed to be 0.955 times milk CP yield. Body weight means, when not available, was assumed to be, respectively, 602 and 564 kg for North American cows and cows from Europe and other countries (Martineau et al., 2016). The relationship between total protein output and MP supply is presented in Figure 1. Treatment means are represented by solid circles and connected by a dashed line if originated from the same publication.

Calculation of MP Requirements

The general strategy for determining the combined MP requirement (i.e., the MP required for maintenance plus milk production) was to construct a requirement function that calculates the MP supply required for a given level of total protein output.

The relationship between protein output and MP supply

The first step in the construction of a requirement function was to develop a model that describes the total protein output response to the MP supply. The model relies on a response curve f that represents the mean trajectory:

$$PO = f\left(MP\right) + Error$$

where *PO* is the total protein output (kg/day) and *MP* is the MP supply (kg/day). A nonlinear asymptotic curve was chosen to describe changes in total protein output as a function of MP supply. A sigmoidal curve was selected to represent *f* as suggested by Figure 1 and by recent studies in the literature (Doepel et al., 2004; St-Pierre and Weiss, 2012). The curve is described as follows:

$$f\left(MP\right) = PO_0 \exp\left[\frac{MP}{MP + MP_0}\log\left(\frac{PO_{asym}}{PO_0}\right)\right]$$

where PO_0, MP_0 and PO_{asym} are the parameters in *f* to be estimated. The PO_0 represents the estimated total protein output at zero MP supply. MP_0 is a positive parameter (in MP units) associated with the specific rate of change of the curve and PO_{asym} is the asymptote, that is, the value the curve converges to as MP supply gets infinitely large. This curve is known as the Schumacher growth model [see Thornley and France (2005) for a detailed mathematical derivation].

The estimation of parameters in *f* with the 133 treatment means presented a few challenges. Firstly, the data comprises treatment means rather than individual level observations. Treatment means from different studies have different standard errors, consequently the traditional assumption of errors' variance homogeneity may not be valid. Secondly, because there may be intrinsic differences within studies that may not be accounted by the model structure, a meta-analysis approach should be used (St-Pierre, 2001). Further, the relationship between protein output and MP supply follows a nonlinear functional form (Figure 1), suggesting the need for a nonlinear mixed model. In this context, a Bayesian hierarchical modeling approach (Gelman et al., 2004) was used to fit the nonlinear response curve to data using the rstan R package (Stan Development Team, 2016). This approach allows each study to have a random deviation on all parameters of the nonlinear model and accounts for possible heterogeneous errors' variances across studies. The fitted curve is presented in Figure 2 and the estimated parameters are in Table 1.

The estimated PO_0 was 0.264 (SE = 0.092), suggesting that approximately 0.264 kg/day (0.58/lb/day) of protein is outputted daily when the MP supply is zero. The estimated PO_{asym} was 2.665 (SE = 0.376), suggesting that the asymptotic total protein output (i.e., limiting protein output when MP supply gets infinitely large) is 2.665 kg/day (5.86 lb/day). The model fit in Figure 2 suggests a good agreement between the treatment means and the fitted curve. However, if the model is going to be used for determining MP requirements, a formal evaluation of its ability in predicting total protein outputs is required. Therefore, we conducted a model evaluation through a cross-validation. In short, we iteratively left treatment means out of the data used for model fitting and evaluated the model predictive ability with means that were not used for model fitting. As a measure of model predictive ability, we calculated the root mean square prediction error. The estimated error (expressed as a percentage of the mean total protein output) was 14%, suggesting very good ability of the model in predicting total protein outputs with varying MP supplies.

The predicted efficiencies

Once a model that precisely describes the relationship between protein output and MP supply is identified, the next step is to develop a strategy for its use in the calculation of efficiencies and requirement. One important characteristic of the selected model is that it has a variable efficiency of MP utilization for protein secretion. Understanding the changes

in efficiency determined by a model is key to a better understand of its mathematical properties and how these relate to modeling protein output responses. For instance, if the first derivative of the curve is a representation of a marginal efficiency, it changes nonlinearly at each level of MP supply. Further, if the cumulative efficiency of MP utilization is defined as the ratio of the total protein output and the MP supply, it can be predicted as the model predicted total protein output divided by the corresponding MP supply. The observed cumulative efficiencies, as well as the ones predicted by the nonlinear model, are presented in Figure 3. The predicted efficiencies decreased, as expected, nonlinearly with MP supply and ranged from 0.85 to 0.43. It is important to note that the predicted efficiencies are in good agreement with both Metcalf et al. (2008) and Arriola Apelo et al. (2014) who suggested a nonlinear decrease of the efficiency with increasing MP supplies.

Determining MP requirements

Up to this point, we have a model that properly predicts the protein output response to MP supply and is built on the principle of a variable efficiency of MP utilization. The final step in the development of the system was to develop a strategy for using this model to calculate the MP supply required for a given level of total protein output. The strategy was to construct a requirement function by inverting the response curve *f*. The MP requirement is therefore defined as the MP supply needed to predict a given total protein output in the response curve. The operation of inverting the curve can be seen, in this context, as solving an equation in "terms of *x*". This operation is, in fact, simple and relies on techniques that most of us learned during algebra classes in high school. For example, if we have a linear function: $y = a + bx$ and want to "solve it for *x*", we use the following sequential steps: i) subtract *a* from both sides of the equation: $y - a = bx$ and ii) divide both sides by *b*, yielding: $(y - a) / b = x$. The result is a function that is the inverse of the original linear equation and is a function of *y* instead of *x*.

The strategy to develop the MP requirement function follows exactly the same logic: we invert the nonlinear response curve *f* to derive an equation that is a function of the total protein output. Inverting the nonlinear response curve is a little harder that inverting a linear equation, but the principle is exactly the same: we invert *f* by "solving for" the MP supply. This inverted function computes the MP supply needed to predict a given total protein output in the fitted curve. Therefore, the calculation of the MP requirement follows the principle of a variable efficiency through the requirement function, defined as *R*:

$$R(PO) = MP_0\left[\log\left(\frac{PO / PO_0}{PO_{asym} / PO}\right)\right]$$

where $R(\bullet)$ is the requirement functions determining the MP supply required for a given level of total protein output (***PO***). The requirements computed with *R* are presented in Figure 4. For comparison purposes, the MP requirements calculated using the NRC (2001) system are also presented in Figure 4. It is easy to see that the developed system determines MP requirements lower than the NRC (2001) system at lower protein outputs (Figure 4). Conversely, the new system determines MP requirements higher than the NRC (2001) system at relatively higher protein outputs. A protein output of approximately 1.1 kg/day (2.42 lb/day) seems to be the point at which our system coincides with the NRC (2001) and separates MP requirements that are relatively lower or relatively higher than the current feeding system. These results are in alignment with Lapierre et al. (2007) who suggested the NRC (2001) system underestimates MP allowable

milk at lower MP supplies and overestimates at relatively higher supplies.

Using the system in practice

In order to demonstrate the use of the system in practice, we calculated the MP requirement for one cow in our data set using the estimated requirement function. The cow outputs 963 g/day of protein in milk, with a 602 kg (1324 lb) BW and a DMI of 18.5 kg/day (40.7 lb/day). Using Lapierre et al. (2014), the scurf protein output is 9.3 g (0.2 g CP/kg $BW^{0.6}$), the urinary endogenous protein output is 67.5 g (2.75 g CP/kg $BW^{0.5}$), and the metabolic fecal protein is 292 g (15.8 g CP/kg DMI). Assuming that the conversion factor of CP to true protein for milk, scurf, endogenous urinary and metabolic fecal and milk protein are 0.955, 1, 1 and 0.8 (Lapierre et al., 2014), the total true protein output (scurf + endogenous urinary + metabolic fecal + milk) of this cow is 1.23 kg/day (2.71 lb/day). Using the parameter estimates from Table 1, the estimated response curve describing the total protein output response to MP supply is:

$$f\left(MP\right) = 0.264 \exp\left[\frac{MP}{MP + 1.177} \log\left(\frac{2.665}{0.264}\right)\right]$$

Inverting this curve, i.e., solving it in terms of the MP supply yields the estimated requirement function:

$$R\left(PO\right) = 1.177\left[\log\left(\frac{PO / 0.264}{2.665 / PO}\right)\right]$$

The calculated MP requirement is obtained by plugging in the *PO* in *R*(*PO*) above. In this example, *PO* is 1.23 kg/day (2.71 lb/day) and the calculated MP requirement is therefore 2.34 kg/day (5.15 lb/day). It is important to note that using the NRC (2001) system, the MP requirement for this cow is 2.05 kg/day (4.51 lb/day), reinforcing that requirements determined with our model are higher than the ones calculated with a fixed 0.67 efficiency at high MP supplies.

Conclusions

A new system is proposed for the calculation of MP requirements by lactating dairy cows. The system is built on the principle of variable efficiency of MP utilization and determines MP requirements for total protein output with a requirement function. The efficiencies predicted by the system decreased nonlinearly with MP supply and range from 0.85 to 0.43. At approximately 1.1 kg/day (2.42 lb/day) of total protein output, the system determines MP requirements that are similar to the ones calculated with the NRC (2001) system. MP requirements below this output level are predicted by the system as consistently smaller than requirements calculated by the current feeding system. Above 1.1 kg/day (2.42 lb/day) of total protein output, the system calculates MP requirements that are higher than the NRC (2001).

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Table 1. Parameter estimates (Bayesian posterior means), standard errors [Bayesian posterior standard deviation (**SD**)] and 95% Intervals (Bayesian Credible Intervals) for the nonlinear response curve describing the relationship between total protein output (kg/day) and MP supply (kg/day).

Parameter[1]	Posterior Mean	Posterior SD	95% CrI
PO_{asym}	2.665	0.376	(1.754, 3.237)
PO_0	0.264	0.092	(0.040, 0.391)
MP_0	1.177	0.369	(0.278, 1.669)

[1]PO_0 represents the estimated total protein output at zero MP supply, MP_0 is a positive parameter associated with the specific rate of change of the curve, and PO_{asym} is the asymptote total protein output which the function converges to as MP goes to infinity.

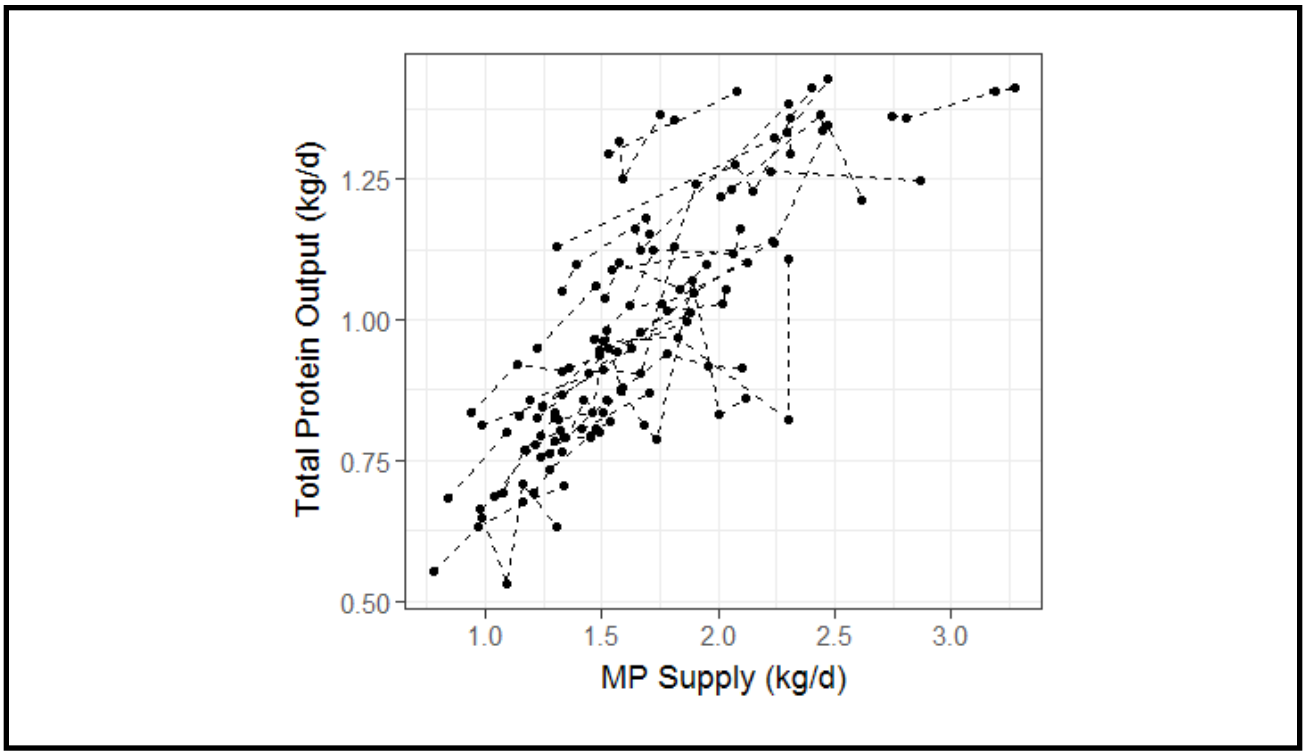

Figure 1. Total protein output (scurf + endogenous urinary + metabolic fecal + milk) versus metabolizable protein (**MP**) supply. The solid circles represent 133 treatment means from 36 publications. The dashed lines connect means from the same publication.

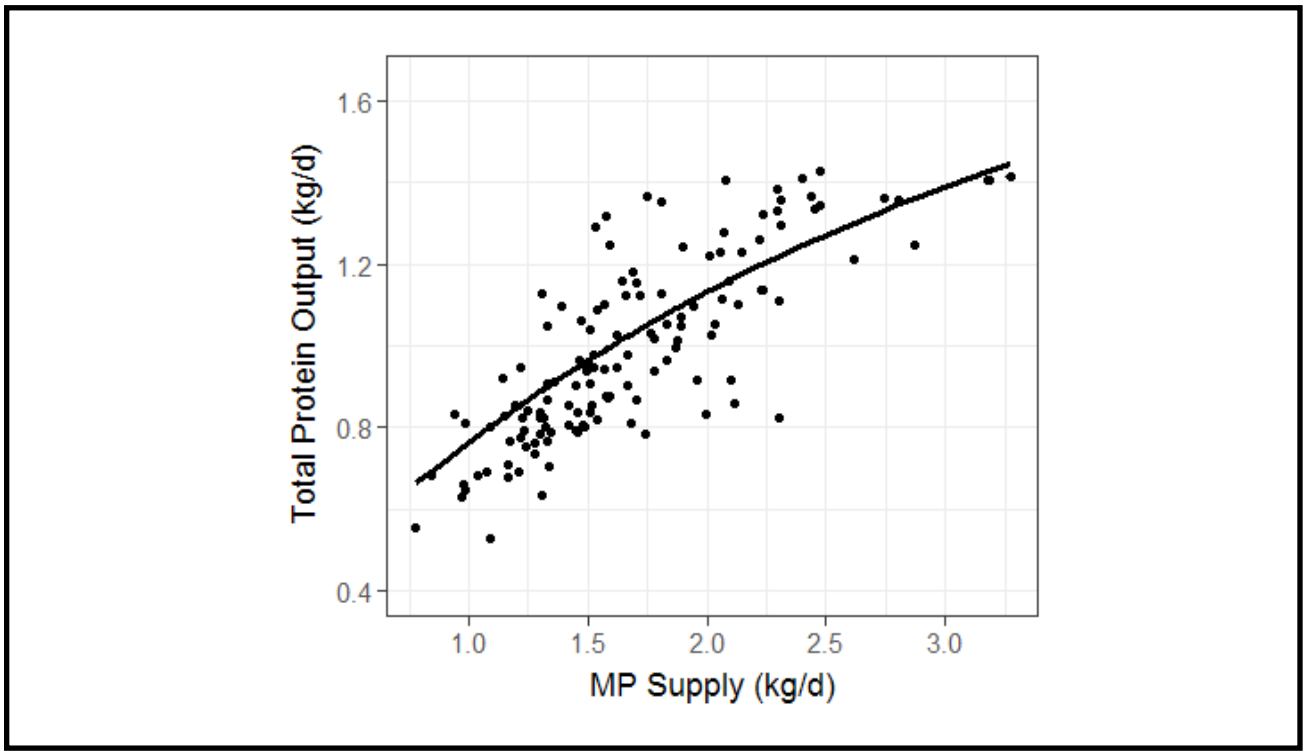

Figure 2. Total protein output (scurf + endogenous urinary + metabolic fecal + milk) versus metabolizable protein (**MP**) supply. The solid circles represent 133 treatment means from 36 publications. The curve is the fitted nonlinear Schumacher function using a Bayesian hierarchical modeling approach.

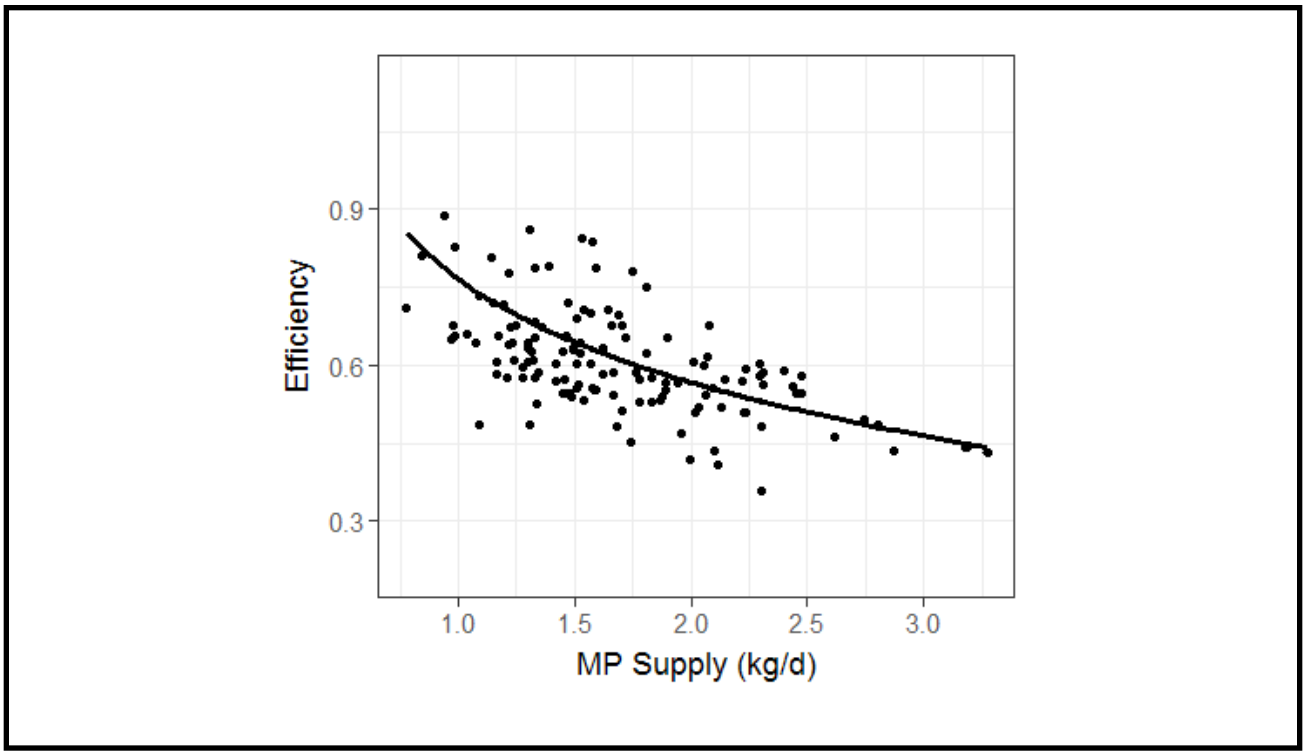

Figure 3. Combined cumulative efficiencies (total protein output divided by the metabolizable protein supply) versus metabolizable protein (**MP**) supply. Points are the records (Total Protein Output / MP Supply) and the curve collects the predicted efficiencies using the nonlinear Schumacher function (i.e., Predicted Total Protein Output / MP Supply).

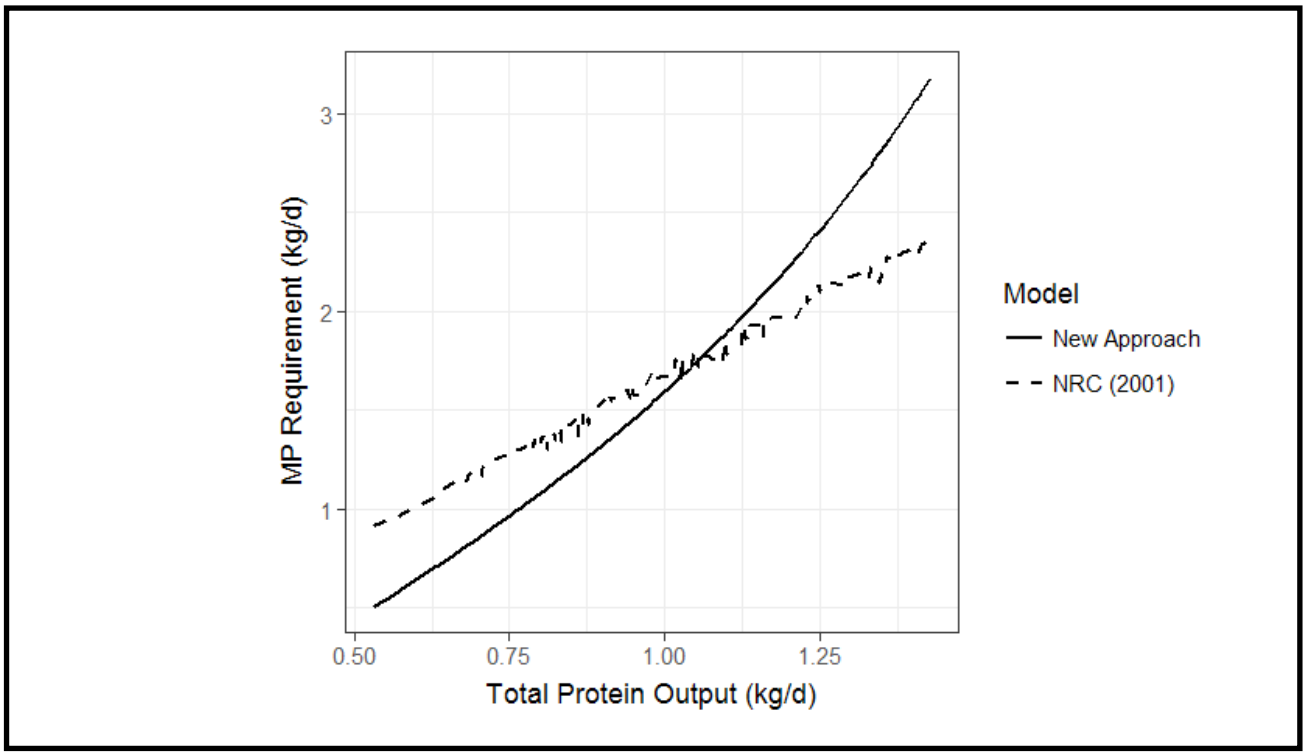

Figure 4. Calculated metabolizable protein (**MP**) requirement (requirement for scurf + endogenous urinary + metabolic fecal + milk) for a given level of total protein output using the estimated requirement function. The dashed curve is the MP requirement calculated using the NRC (2001) system.

Modeling the Effects of Liquid Intake and Weaning on Digestibility of Nutrients in Pre- and Post-Weaned Dairy Calves

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Introduction

Accurate predictions of nutrient supply and nutrient requirements are essential to modern ration formulations and animal production. Accurate and precise models allow provision of nutrients to meet requirements for maintenance and optimal production without supplying excess nutrients that contribute to inefficiency or environmental damage.

Most nutrient models predict supply of metabolizable energy (**ME**) and metabolizable protein (**MP**); in lactation models, flow of nutrients are predicted from endogenous, microbial, and undegraded dietary sources. Nutrient requirements are usually predicted using factorial calculation of requirements for maintenance (adjusted for environmental and management considerations), growth, pregnancy, and lactation. Only maintenance and growth predictions are used to predict nutrient requirements for calves, with requirements for pregnancy included for primiparous heifers.

For young calves and heifers, prediction of nutrient supply by the 2001 Nutrient Requirements of Dairy Cattle (NRC, 2001) assumes fixed digestibility and metabolizability of energy and protein. For example, calculation of ME from milk replacer is assumed to be the caloric content of protein, fat, and lactose adjusted for digestibility and metabolizability:

ME (Mcal/kg) = [(0.057 x CP) + (0.092 x EE) + (0.0395 x CHO)] x 97% x 96%, where:

CP = crude protein %, EE = ether extract %, CHO = carbohydrate %, 97% = digestibility of nutrients, and 96% = metabolizability of digested nutrients.

Metabolizable energy content of calf starters is calculated as the sum of the digestible fractions of protein, non-fiber carbohydrates, neutral detergent fiber (**NDF**), crude protein (**CP**), and fat as described in the 2001 Dairy NRC (NRC, 2001) for adult cattle. Neither liquid nor starter feeds are corrected for differences in digestibility caused by age or development of the gastrointestinal tract in these models.

In young calves, digestibility of dry feeds (concentrates and forages) depends on development of ruminal fermentation and intestinal digestion. This is particularly true for NDF (primarily fermented in the rumen) and starch (dependent on ruminal fermentation and small intestinal digestion). Studies have shown that fiber fermentation is limited in neonatal calves (Chapman et al., 2016; Hill et al., 2016a, b). Further, pancreatic α-amylase production is low at birth (Siddons, 1968) but increases with age (Huber et al., 1961; Morrill et al., 1970) along with total pancreatic secretion (McCormick and Stewart, 1966), thereby affecting small intestinal digestion of starch (Morrill et al., 1970).

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Development of microbial fermentation changes flow of nutrients from the stomach. Prior to weaning, nutrients are derived primarily from milk protein, fat, and lactose; after weaning, nutrients are provided by volatile fatty acids absorbed from the rumen and microbial protein that increases in flow with increasing dry feed intake (Leibholz, 1975; Quigley et al., 1985).

Changing amounts and types of liquid fed to calves may alter age at which dry feed intake begins (Strzetelski et al., 2001; Hill et al., 2006a,b) thereby altering rumen development. This is particularly true when large amounts of liquid are fed (i.e., greater than about 700 g/day of solids from liquid for Holstein calves), since large amounts of liquid consumed will delay rumen development (Terré, et al., 2007). Several studies have reported increased BW at weaning for calves fed large amounts of liquid pre-weaning; however, the advantage in growth compared to conventional feeding methods (500 to 700 g/day of solids) may be lost as BW gain slows dramatically in the period immediately post-weaning. We have attempted to quantify the effects of increased milk replacer allowance on digestibility of starter and its effects on growth and efficiency of young calves to determine if differences in digestion of nutrients, but particularly of carbohydrates, which may be at least partially responsible for differences in growth.

Digestion of Solid Feed

Calves are commonly weaned between 1 and 3 months of age in most dairy systems, with the most common age being approximately 9 weeks of age in the U.S. (USDA, 2016). Weaning to dry feed requires that the calf has sufficient digestive and fermentative capability to provide nutrients to support maintenance and growth. Further, the source of nutrients changes from milk digested primarily in the small intestine to grain-based ingredients fermented in the rumen and (or) digested in the small intestine. Therefore, gastrointestinal, hepatic, and systemic enzyme systems must be sufficiently adapted to changing sources of nutrients. If a calf is inadequately prepared for weaning, performance may suffer and predispose calves to reduced growth, poor efficiency, and even increased susceptibility to disease (Roth et al., 2008, 2009).

The most important factor in promoting rumen development and adaptation in preparation for weaning is consumption of dry feed containing fermentable carbohydrates – particularly sugars and starch – that are fermented to propionate and butyrate in the rumen by resident rumen bacteria. Production of volatile fatty acids and microbial protein stimulate a series of adaptations in the rumen, gastrointestinal tract, hepatic tissues, and systemically that promote gluconeogenesis, production, and release of β-hydroxybutyrate by rumen epithelium and utilization of acetate by peripheral tissues (Howarth et al., 1968; Huber, 1969; Baldwin et al., 2004).

In the past 15 years, some dairy experts have recommended feeding milk or milk replacer in excess of the traditional recommendations (approximately 10% of body weight as milk or reconstituted milk replacer) to increase rate of gain and take advantage of improved calf efficiency (Diaz et al., 2001; Moallem et al., 2010; Davis-Rincker et al., 2011). High digestibility and metabolizability of liquid feeds compared to higher fiber ingredients in calf starters naturally contributes to greater efficiency of BW gain.

Calves fed whole milk for *ad libitum* consumption or milk replacer to amounts >1 kg/day of powder gain impressive amounts of BW. For example, Jasper and Weary (2002)

reported that calves fed milk for *ad libitum* consumption were 8 kg heavier at the end of a 63-day feeding period compared to calves fed milk at 10% of BW. All calves were weaned at 42 days. However, daily BW gains in calves fed for *ad libitum* consumption were markedly lower during the week of weaning (0.36 vs. 0.53 kg) and after weaning (0.68 vs. 0.85 kg), so that BW differences at 63 days were not as great as the difference prior to weaning.

Differences in growth rate post-weaning in calves fed differently pre-weaning may be due to differences in gastrointestinal development and digestion. Several recent studies indicate that digestion of nutrients from dry feeds varies when calves are fed varying amounts of liquid pre-weaning.

Terré et al. (2007) fed Holstein bull calves (19 days of age at start of the trial) milk replacer (**MR**) at levels typical of conventional feeding (CF; 4 L/day with weaning at 35 days of the study) or an enhanced feeding (**EF**) program wherein amount of MR was increased to 7 L/day and then reduced to weaning.

Total starter intake on the CF and EF programs prior to weaning were 23.8 and 12.6 kg, respectively. Results of a digestion trial conducted during days 38 to 42 of the study are in Table 1. These data indicate clearly that digestion of dry feed was impaired in calves fed EF, likely due to inadequate rumen development as a result of lower starter intake.

Digestion of NDF (derived primarily from wheat middlings, soybean hulls, and wheat distiller's grains) in the study by Terré et al. (2007) was lower in EF calves compared to CF calves (20.3 vs. 34.7%; Table 1). Since disappearance of NDF is due primarily to ruminal fermentation, it is likely that reduced NDF digestion was due to inadequate or incomplete rumen fermentation in EF calves. Reduced NDF digestibility occurred in EF calves in spite of a higher rumen pH (5.73 vs. 5.99). Ruminal pH less than approximately 6.0 is associated with impaired ruminal fiber fermentation (Shriver et al., 1986; Allen, 1997) due to pH sensitivity of cellulolytic bacteria in the rumen (Hoover, 1986; Russell and Wilson, 1996). In the study by Terré et al. (2007), the authors attributed higher ruminal pH to lower ruminal activity due to lower starter intake and a lack of substrate available for fermentation.

Leibholz (1975) monitored digestion of nutrients in calves fed whole milk or MR to weaning at 35 days of age. After weaning, calves were offered a pelleted feed consisting of 58% barley, 20% soybean meal, 15% wheat straw, and 3% molasses plus vitamins and minerals. The diet contained 15% protein and 13% ADF; we estimated the diet contained 2.7 Mcal of ME/kg and 50% non-fiber carbohydrate.

By 6 weeks of age (1 week post-weaning), digestibility of ADF reached 57% and did not change markedly thereafter. However, the site of ADF digestion changed dramatically with time after weaning as most ADF was digested in the hindgut during the first 4 wk of the trial (Figure 1).

Weekly DMI for each week of the 8 week study were 0.6, 1.1, 1.5, 2.1, 2.2, 2.4, 2.5 and 2.5 kg/day. Intake of ADF ranged from 77 g/day in the 1st week post-weaning to 325 g/day at week 8. Therefore, it is possible that higher digestion of ADF in the hindgut during the first few weeks after weaning was due to small amounts of ADF consumed.

Hill et al. (2010) fed calves (2 to 3 days of age at start of study) 1 of 4 MR programs: 0.44 kg/day of DM of a 21% CP, 21% fat MR powder for 42 days (A); 0.66 kg/day of DM of

a 27% CP, 17% fat MR powder for 42 days (B); 0.66 kg/day of DM of a 27% CP, 17% fat MR powder for 28 days (C); or up to 1.09 kg/day of DM of a 29% CP, 21% fat MR for 49 days (D). Digestibility estimates were made on days 53 to 56. Table 2 shows clearly that digestion of dry matter (**DM**) and organic matter (**OM**) were lower when calves were fed large amounts of MR prior to weaning (treatment D). During the digestibility period (days 53 to 56), intake of starter DM was 2.2, 2.3, 2.5 and 1.9 kg/day for treatments A, B, C, and D, respectively. The trend ($P < 0.08$) for low starter DM intake, coupled with significantly lower digestion of DM, resulted in calves on treatment D only consuming about 71% of the digestible DM of calves on the other treatments.

More recently, Chapman et al. (2016) reported that digestion of nutrients, but particularly of NDF and ADF, were reduced during the digestion period of days 52 to 58 of age when calves were fed MR up to 0.87 kg/day (Table 3). Although digestion of all nutrients (except starch) were reduced significantly, digestion of NDF and ADF were reduced nearly 50% in calves fed large amounts of milk pre-weaning.

Conversely, Chapman et al. (2017) reported no difference in NDF digestion when calves were fed MR at 446, 669, or 892 g/day of MR during the digestibility measurement period. Further, NDF digestion was 58, 69, and 69%, respectively, suggesting extensive digestion of fiber by the calves. However, the starter used in the study contained only 16% NDF and starter intake during the trial was 1.1, 0.7 and 0.4 kg/day, respectively. Measurements were taken prior to weaning, which may have increased the error associated with measurement.

A majority of these data suggest that calves fed large amounts of milk pre-weaning may have difficulty digesting nutrients from dry feed during the immediate post-weaning period. There are numerous implications to these findings. For example, digestion of starters containing greater amounts of fibrous by-products may be difficult if calves are fed large amounts of liquid pre-weaning. Also, it may be necessary to use increasingly complex liquid reduction strategies to ensure that starter intake (and digestibility) is adequate prior to weaning.

Because fiber digestion is primarily influenced by cellulolytic fermentation in the rumen, the low digestibilities of ADF and NDF (Table 3) indicate that the rumen is less well developed in calves fed greater amounts of MR (Chapman et al., 2016). Also, fiber digesting microorganisms are established in the rumen more slowly than starch and sugar digesting microorganisms (Anderson et al., 1987). Finally, selection of ingredients that may negatively affect rumen fermentation (e.g., inclusion of oil-containing ingredients) may also reduce total DM digestion (Hill et al., 2015).

To better understand the changes in NDF digestion with age and diet, Hill et al. (2016b) fed calves a moderate or aggressive MR feeding program and monitored changes in nutrient digestion with advancing age. Figure 2 shows changes in NDF digestion with advancing age. The effect of diet is clearly shown, as calves fed more milk (AGG in Figure 2) maintained lower NDF digestion throughout the 3 digestibility periods. Also, calves fed functional fatty acids and nutrients (NeoTec5g®, Provimi North America, Brookville, OH, USA) feed additive (MOD+ and AGG+ in Figure 2) had higher NDF digestion in periods 2 (42 to 46 days of age) and 3 (54 to 58 days of age). Previous studies (Guilloteau et al., 2009, 2010; Hill et al. 2007) have shown that feeding sodium butyrate (a component of NeoTec5g) improved fiber digestion in young calves.

Calves fed the moderate MR program (MOD in Figure 2) consumed more starter throughout the trial, which likely hastened rumen development and the ability of calves to digest NDF. In calves fed MOD, NDF digestion increased from approximately 15% at 19 to 23 days of age to approximately 35% by 51 to 56 days of age. Digestion of NDF in calves fed the higher level of MR (**AGG**) did not change markedly through the 56-day study, and there were few differences with advancing age.

In addition to age of calf, digestion of nutrients post-weaning is affected by ingredient source and form of calf starter. Digestion of DM, OM, and CP were higher in starters containing ground corn, whereas ADF and NDF digestion were greatest in starters containing soybean hulls (Table 4). Hill et al. (2016a) also reported that texturized calf starters containing whole corn and whole oats (51 to 54% starch and 13% NDF) had higher DM, OM, and CP digestibilities than pelleted starters containing wheat middlings, soybean hulls, and dried distiller's grains (20% starch and 36% NDF; Table 5). On the other hand, pelleted, high-fiber starters had higher ADF, NDF, starch, and fat digestion. Gain of BW and hip width increased as OM digestibility increased in these trials.

Collectively, these data suggest that the availability of energy from starters is dependent on type of carbohydrate, form of the starter (texturized vs. pelleted) and carbohydrate, age of the calf, and intake of liquid pre-weaning.

Current nutrient models for calves and heifers (e.g., 2001 Dairy NRC) ignore the effects of previous nutrition and extent of rumen development. The ME content of starters is a static calculation based on expected digestibility of nutrient fractions (NDF, non-fiber carbohydrate, protein, and fat). No provision is made for differing nutrient digestibilities with advancing age or intake. Conversely, other models for lactating cows utilize dynamic calculations of energy based on rates of ruminal digestion of each fraction (NFC, NDF, protein, and fat) and rate of passage (Higgs et al., 2015). Intestinal digestibility coefficients are then applied to the ruminally undegraded fraction to estimate total nutrient supply.

Using data from Chapman et al. (2016) and Hill et al. (2016b), we estimated ME concentrate of calf starter using the method outlined in the 2001 NRC Nutrient Requirements of Dairy Cattle (NRC, 2001), as well as calculated ME based on analyzed values using digestibility data from Table 3 and Figure 2. Results are in Table 6. The column labeled "NRC" contains calculated ME concentration in starter based on the 2001 NRC method, assuming digestibility values typical for adult ruminants. The column "Calculated" contains data using total tract digestibility measured in the studies by Chapman et al. (2016) and Hill et al. (2016b). We also used the 2001 Dairy NRC model to predict ME-allowable BW gain using the ME values calculated for calf starter using the NRC or calculated values in Table 6.

Differences were significant for all measurements, but ME was markedly overestimated in calves fed higher levels of milk in both studies. Consequently, predicted ME-allowable gains using the calculated ME value for calf starter were lower compared to predicted gains using the ME values calculated with the NRC calculations.

The implications of errors in calculation of ME content are clear, as calves fed high levels of milk pre-weaning will be ill prepared for weaning and will be unable to extract nutrients from calf starters efficiently. Consequently, growth of calves will be compromised until sufficient maturation of the digestive tract and

associated tissues allows the calf to fully utilize nutrients in the calf starter. The existing NRC model over-predicts ME supply from starters by 12 to 26% (Table 6).

These data also suggest that additional time may be needed for a weaning transition to ensure that calves fed high levels of milk will consume sufficient starter prior to weaning. In most of the studies cited in this review, liquid intake was reduced for 7 to 10 days prior to weaning. For calves fed 1 kg/day of powder or greater, this is probably insufficient time for adaptation.

Summary

The 2001 Dairy NRC represented an important improvement in our understanding of nutrient requirements for young calves and heifers. Further refinement of methods to estimate nutrient supply of young calves will improve our ability to calculate growth under a wide range of feeding and management conditions.

Feeding varying amounts of liquid from milk or MR has important implications to growth post-weaning. Increasing liquid consumption above approximately 650 to 700 g/day of solids will delay initiation of calf starter intake and will delay onset of rumen development. Digestion of all nutrients, but particularly NDF, is essential to ensure that rumen development is adequate prior to weaning.

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Table 1. Apparent total tract digestibility of dry feed in calves fed 4 L/day of milk replacer (**MR**) at 12.5% DM dilution rate from day 1 to 28, and 2 L/day from day 29 to day 35 (**CF**) or MR at 18% DM dilution rate: 4 L/day from days 1 to 6, 6 L/day from days 7 to 13, 7 L/day from days 14 to 20, 6 L/day from days 21 to 28, and 3 L/day from days 29 to 35 (**EF**). Digestibility was measured the week after weaning. Adapted from Terré et al. (2007).

Digestibility, %	CF	EF	SE	P
Dry matter	77.4	71.8	1.23	0.01
Organic matter	78.7	73.2	1.18	0.01
Crude protein	77.1	71.6	1.29	0.01
Neutral detergent fiber	34.7	20.3	3.79	0.02
Gross energy	75.6	69.8	1.25	0.01

Table 2. Total tract apparent digestion of dry matter (**DM**), organic matter (**OM**), crude protein (**CP**), and fat in calves fed 1 of 4 MR programs: 0.44 kg/day of DM of a 21% CP, 21% fat MR powder fed for 42 days (A); 0.66 kg/day of DM of a 27% CP, 17% fat MR powder fed for 42 days (B); 0.66 kg/day of DM of a 27% CP, 17% fat MR powder fed for 28 days (C); or up to 1.09 kg/day of DM of a 29% CP, 21% fat MR fed for 49 days (D). Adapted from Hill et al., 2010.

Digestion, %	A	B	C	D	SE	P
DM	75.6[a]	78.3[a]	78.7[a]	67.3[b]	2.19	0.01
OM	77.4[a]	78.3[a]	78.7[a]	68.0[b]	2.20	0.01
CP	72.4	72.3	74.1	71.8	2.58	0.83
Fat	70.3	75.4	76.3	75.4	3.37	0.33

[a,b]Means in the same row with different superscripts differ, $P < 0.05$.

Table 3. Body weight (**BW**), DM intake (**DMI**), and total tract digestibility of nutrients in calves fed conventional [CON; 0.44 kg of dry matter (**DM**), 21% crude protein (**CP**), 21% fat powder fed for 42 days], moderate (MOD; 0.66 kg of DM, 27% CP, 17% fat powder fed for 42 days), and aggressive program (AGG; up to 0.87 kg of DM, 27% CP, 17% fat powder fed for 49 days). Digestibility was measured from days 51 to 56. From Chapman et al., 2016.

Item	CON	MOD	AGG	SE	P
BW, kg	62.7[a]	72.3[b]	82.8[c]	4.05	0.01
DMI, kg/day	2.04	2.30	2.28	0.258	0.08
Digestibility, %					
DM	77.6[a]	76.9[a]	66.0[b]	1.67	0.01
OM	79.2[a]	78.2[a]	67.9[b]	1.65	0.01
ADF	56.3[a]	53.2[a]	26.7[b]	3.89	0.01
NDF	54.1[a]	50.7[a]	26.2[b]	2.86	0.01
Starch	96.7	94.5	94.0	1.33	0.36
CP	71.9[a]	74.1[a]	56.3[b]	2.72	0.02
Sugar	93.1[a]	91.5[a]	86.2[b]	1.68	0.02
Fat	81.4[a]	83.2[a]	74.1[b]	1.84	0.01

[a,b,c]Means in the same row with different superscripts differ, $P < 0.05$.

Table 4. Nutrient digestibility in calves 15 to 16 weeks of age fed starters containing soybean hulls (**S**), wheat middlings (**M**), or corn (**C**). Contrast 1 = (S+M) vs. C; and contrast 2 = S vs. M. Adapted from Hill et al., 2016a.

Digestibility, %	S	M	C	SE	Contrast 1	Contrast 2
DM	76.9	78.9	85.2	1.58	0.01	0.23
OM	77.5	79.6	85.8	1.56	0.01	0.21
ADF	65.5	53.5	55.4	3.48	0.20	0.01
NDF	70.7	56.1	66.2	3.13	0.34	0.01
Starch	97.6	98.9	97.0	0.57	0.13	0.15
CP	78.1	80.7	84.4	1.75	0.01	0.16
Sugar	94.2	95.6	94.2	1.79	0.63	0.47
Fat	84.1	86.3	89.6	2.61	0.08	0.42

Table 5. Nutrient digestibility in calves 15 to 16 weeks of age fed high starch texturized (**TX**) or low starch pelleted (**PL**) starters containing low (**MPL**) or high MPH) amounts of metabolizable protein. No main effect of metabolizable protein was reported. P = probability of a main effect of starch level and NS = not significant. Adapted from Hill et al., 2016a.

Digestibility, %	TX-MPL	TX-MPH	PL-MPL	PL-MPH	SEM	P
DM	84.3	84.7	79.7	78.8	0.51	0.001
OM	84.9	85.0	80.2	78.9	0.57	0.001
ADF	41.5	54.0	65.2	66.1	1.86	0.001
NDF	56.8	62.8	69.4	66.1	1.64	0.005
Starch	95.1	95.7	99.0	98.7	0.29	0.001
CP	84.9	84.6	79.5	78.6	0.54	0.001
Sugar	95.3	95.6	95.7	92.4	0.68	NS
Fat	86.3	82.7	88.3	87.8	0.78	0.08

Table 6. Estimated ME concentration (Mcal/kg of DM) in calf starters used by Chapman et al. (2016) and Hill et al. (2016b) using methods of 2001 Dairy NRC (**NRC**) or calculated using total tract digestibilities reported in each experiment. ME-allowable BW gains were calculated using equations [2-4 a-e and 2-5 to 2-10] in 2001 Dairy NRC Requirements for Dairy Cattle (NRC, 2001) or using digestibility estimates from Table 3 and Figure 2, respectively. Digestibility estimates were made at 52 to 56 days.

	Starter ME, Mcal/kg			Predicted ME, kg/day		
Item	NRC	Calculated	%	NRC	Calculated	%
Chapman et al., 2016						
CON	2.81	2.59	92	0.77	0.67	87
MOD	2.81	2.56	91	0.93	0.82	88
AGG	2.84	2.30	81	0.94	0.70	74
Hill et al., 2016b						
MOD-	2.81	2.52	90	0.83	0.71	86
AGG-	2.89	2.45	85	0.61	0.45	74
MOD+	2.83	2.60	92	0.77	0.68	88
AGG+	2.87	2.50	87	0.70	0.55	79

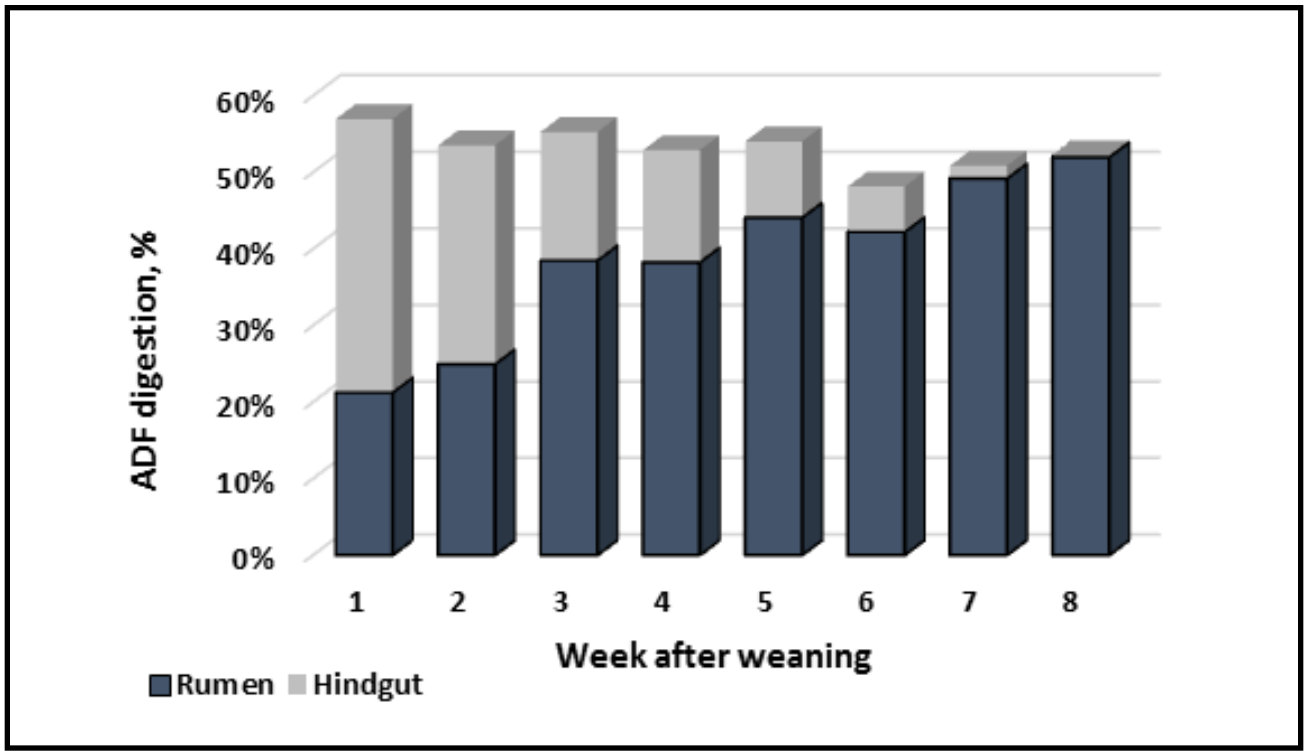

Figure 1. Digestion of acid detergent fiber (**ADF**) in calves fed milk or milk replacer to weaning at 5 weeks of age. Digestion was measured in the stomach and intestines using duodenally cannulated calves. Adapted from Leibholz, 1975.

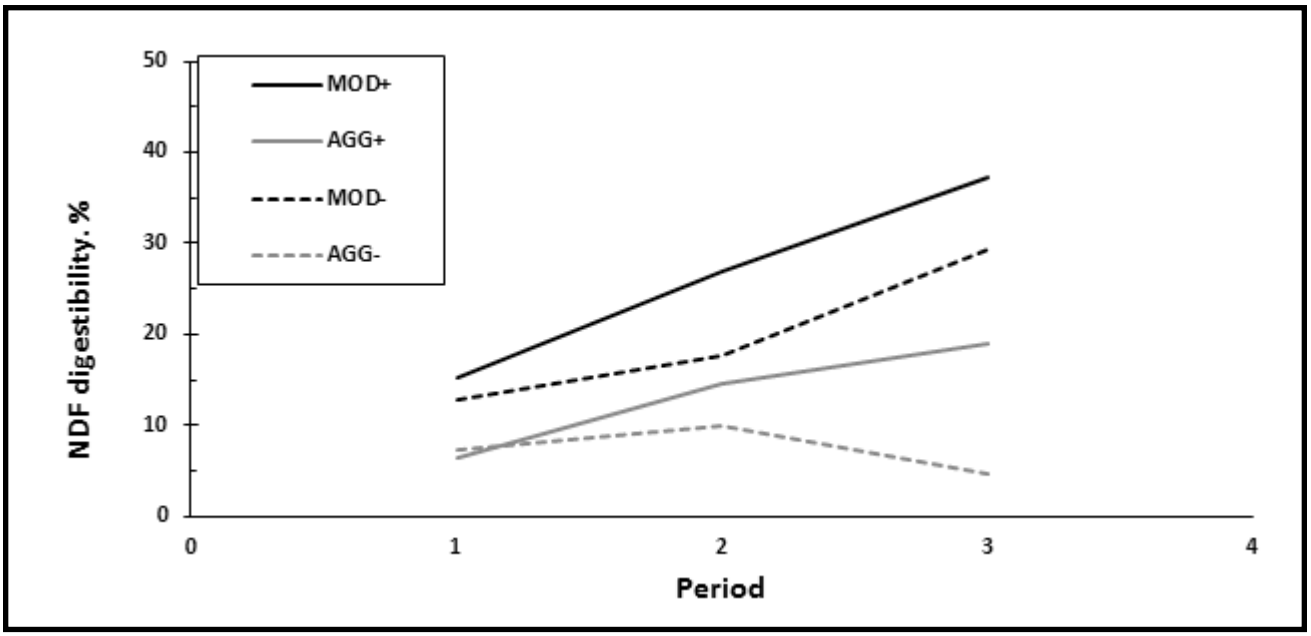

Figure 2. Change in total tract NDF digestibility in calves fed 0.66 kg of DM of a 27% CP, 17% fat MR powder daily fed for 49 days (MOD) without (-) or with (+) added NeoTec4 feed additive; or 0.66 kg of DM of a 27% CP, 17% fat MR powder fed for 4 days, then 0.96 kg of DM for 4 days, then 1.31 kg of DM fed for 34 days, then 0.66 kg of DM for 7 days (AGG). Effect of feeding level, NeoTec4 inclusion, and age were significant ($P < 0.05$). Digestibility periods were 1 = 19 to 23 days; 2 = 40 to 44 days; and 3 = 52 to 56 days of the study. Calves were 2 to 3 days of age at initiation of the study. Adapted from Hill et al. (2016b).

Feeding and Management of Dairy Steers

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Abstract

Finished dairy steers and a few heifers are 16.2% of U.S. fed steer and heifer beef production. Holstein steers and a few heifers are 13.9% of the fed steer and heifer supply. These Holstein cattle have the propensity to yield high quality beef and are estimated to account for 33% of USDA Prime beef production in 2015. Sexed semen use is reportedly having greatest impact in matings involving the less desirable fraction of Jersey cows. Emphasis is placed on provision of 150 to 200 g colostral immunoglobulins to male dairy calves within the first few hours after birth. Complete castration of these bull calves in their first month of age is equally important to avoid the expense associated with stags. The goal for Holstein steer production is to have them achieve 28% body fat by 1400 to 1550 lb, thus yielding USDA Choice or Prime carcasses weighing 850 to 950 lb. This requires a finishing diet with an energy density of at least 0.62 Mcal NEg/lb DM. Effective feedbunk management is critical to sustaining steer performance. Holstein steers are more susceptible to liver abscesses than are native steers and heifers.

Introduction

Dairy steers are an important source of beef production in the U.S. The breed composition of the dairy steer population reflects the breed composition of the dairy herd from which they are produced. Since Holstein is the dominant dairy breed, Holstein steers are the principal breed of dairy steer, though Jersey and Brown Swiss breeds are also represented. "Dairy beef" refers to any dairy herd progeny that are developed to be ruminating cattle (therefore excluding bob and special-fed veal) and harvested at an age that qualifies them for the USDA Prime, Choice, or Select quality grades. The term is not intended to include beef from culled dairy cows or mature dairy bulls. Beef cattle breeds will be termed "native" breeds. This term is based on 3 motivations. First, muscle food derived from dairy breeds, native breeds, and their crossbreds is always referred to as beef. Use of the term "native" allows for distinguishable reference to "native beef" and "dairy beef", rather than use of the redundant term "beef beef" from beef breeds. Secondly, cattle belonging to beef breeds are often referred to as "colored" cattle, but that term should be discomforting to an industry that welcomes racial diversity. Thirdly, "native" is a categorical trade term of the leather industry which uses the terms "native steers", "native dairy steers", "native cows" and "native dairy cows" to report hide market prices (Jacobsen, 2017).

The large-frame dairy breed cows produce steer progeny that also have large frame scores. Consequently, these large frame dairy steers are prone to achieve USDA Choice carcass composition at 1400 to 1700 lbs. Steers with

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body weight (**BW**) of 1640 lb and a dressing percentage of 61% would yield a carcass of 1000 lb. Carcass weights in excess of 1000 lb can incur carcass price discounts (Schaefer and Schaefer, 2016). The ideal live weight at which finished Holstein steers should achieve 28% body fat and be marketed for slaughter is 1400 to 1550 lb. This endpoint is achieved only when forethought is given to initiation of the finishing phase diet and when the finishing phase diet has a sufficient energy density, which is at least 0.62 Mcal Net Energy for gain (**NEg**) per pound DM. Emphasis in this paper will be placed on finishing Holstein steers, since they are the major contributor to dairy beef production and most knowledge of dairy steer production is based on the Holstein breed.

Significance of Dairy Beef Production

USDA Agricultural Marketing Service annual reports and the scientific literature were used to quantify the contribution of dairy steers to U.S. commercial beef production and fed steer and heifer beef production (Boetel, 2016). The assemblage of assumptions, statistical data, and calculations is shown in Table 1. Finished dairy steers and heifers account for 16.2% of federally inspected steer and heifer beef production. Since Holstein cattle constitute 86% of the dairy cow population (NAHMS, 2016), Holstein steers and the few finished Holstein heifers are 13.9% of the fed steer and heifer supply. As Dykstra (2016) discussed, the recent cyclical decline in U.S. beef cow population and stability of the U.S. dairy cow population have the consequence that the proportional contribution of dairy steers to U.S. fed cattle supply has increased in recent years. It is reasonable to surmise that the Holstein contribution makes this population the largest purebred contribution to U.S. beef production. This view is based on the presumption that most native cattle in the fed steer and heifer supply are crossbred cattle. Dykstra (2016) summarized the results of 4 National Cattlemen's Beef Association Beef Quality Audits and reported that Holstein carcasses achieved average and high Choice quality grades at the rate of 25% compared to 18.9% for native cattle. Furthermore, the audit results indicated that 12.9% of Holstein carcasses were graded Prime, while 2.1% of native carcasses were Prime. Using this percentage for Prime and the Boetel (2016) tabulation of Holstein beef production, Holstein beef accounted for 33% of Prime beef in 2015. Since the correlation between estimated breeding value for milk production and marbling score is small and positive (0.21; Tyler, 1970) ,there is reason to believe that continued selection for milk production in the Holstein breed will not compromise the ability of finished Holstein progeny to produce beef carcasses of high quality. Likewise, it is noteworthy that dairy cows contribute 1.9 billion pounds of beef annually, which was 8% of U.S. commercial beef production in 2015 (Table 1). The tenderloins and rounds of these cows are separated and merchandised as whole muscle cuts. Clearly, the dairy herd is an important component of the U.S. beef industry, and this utilization returns a financial benefit to dairy enterprises.

Sexed Semen and Crossbred Dairy Beef

The commercial availability of sexed semen has enabled dairy enterprises with sufficient replacement females to choose alternative sire breeds for mating with less desirable dairy cows. The most common native breeds chosen for dairy female insemination are Angus, Simmental, Limousin, Simmental-Angus, and Limousin-Angus (M. Faust, Senior Research Director, ABS, personal communication). Approximately 4.5% of semen units going into dairy females are from native breed bulls (M. Faust, ABS, personal communication). This practice is especially prevalent in Jersey herds as a method for adding

value to male progeny in preference to producing relatively low value (Mueller et al., 2010) Jersey bull calves. Jersey females account for up to 30% of the native semen units used in dairy females (M. Faust, personal communication). Jersey steers have much slower growth rates than Holstein steers (Lehmkuhler and Ramos, 2008); yet, the Jersey breed has long been recognized as having beef tenderness that excels relative to native cattle breeds (Ramsey et al., 1963), and a propensity to deposit marbling so that these carcasses qualify for USDA Choice quality grade (Koch et al., 1976; Jiang et al., 2013). Given this combination of characteristics, a variety of native breeds could be considered for production of half-blood Jersey steers and heifers that would have enhanced growth and carcass yield characteristics.

Desirable Finished Dairy Beef Cattle

A reasonable thumb rule is to expect steer progeny to finish at a weight which is similar to the weight of mature cows in the herd. A finished steer is defined as an animal that has 28% body fat, which coincides with the small degree of marbling, the threshold for the USDA Choice quality grade (Guiroy et al., 2001). Heifers will achieve this carcass compositional endpoint at a lighter body weight than their steer mates. There seems to be no literature data available from which to estimate mature BW of Holstein cows. Therefore, personal communication with auction market managers has led to the supposition that such weights are 1400 to 1700 lb.

When anabolic implants are inserted into Holstein steers, their effect is to increase the shrunk BW at which the 28% empty body fat endpoint is attained. Perry et al. (1991) implanted 570 lb Holstein steers with an implant containing 140 mg of trenbolone acetate and 28 mg estradiol and harvested these steers at an ultrasound-determined marbling score that coincided with USDA low Choice. The implanted steers had 46 lb more BW, 31 lb more hot carcass weight, and 15 lb more empty body protein. The implanted steers also achieved the carcass compositional endpoint in 16 fewer days. Use of anabolic implants in Holstein steers yields a high return on investment; however, the starting weight, feeding program, and implant program must receive forethought to avoid overweight and/or under-finished steers. The Holstein breed is already late-maturing and has a large frame. The use of implant technology in Holstein steers further emphasizes that these cattle receive a high energy finishing diet ($\geq$ 0.62 Mcal NEg/lb DM) from 770 lb BW or lighter so that they achieve the Choice quality grade, before their carcass weight incurs discounts at greater than 1000 lb.

An appropriately finished Holstein steer is shown in Figure 1. This is an animal that has a body condition score of 7 at a desirable BW with a carcass weight assumed to be 870 lb. This should be the target in beef production from Holstein steers. Since the actual carcass measurements were not available from the steer pictured in Figure 1, appropriately finished Holstein, Jersey and Brown Swiss steers are shown in Figure 2. These steers have fat coverage over their ribs, hooks which are not prominent, some fullness in their briskets due to fat deposition, and evidence of fat pones on both sides of the tailhead. They are relatively young cattle since their muzzles are not elongated, which occurs in older steers.

Jersey steers are likely to incur carcass weight discounts because of light carcass weights (Lehmkuhler and Ramos, 2008). Lehmkuhler and Ramos (2008) found that diets containing 30% and 20% roughage prior to a 10% roughage finishing diet did not change overall gain efficiency, and average daily gain (**ADG**) was diminished by only 3%. Phase feeding could be

used to avoid underweight carcass discounts on Jersey steers, but the duration of overall animal ownership and carcass weight produced will be much less desirable relative to Holstein steer production. Growth rate of the Jersey steers was 70% of Holstein steer growth rate. On the other hand, Holstein steers have greater risk for overweight carcass discounts so they should be started on a high-energy finishing diet by 770 lb.

Pre-Weaning Male Calf Management

The focus of this paper will be on post-weaning nutrition and management of dairy steers. Other papers in this proceedings will address pre-weaning management of dairy heifers and pre-weaned dairy bull calf management was previously reviewed by Chester-Jones et al. (1998). Nutritional and health management of dairy heifers and dairy bull calves is nearly identical. Three topics deserve special mention for dairy male calf rearing methods. The first is colostrum feeding. Since dairy heifers are the future of the dairy herd, it is reasonable to expect that dairy herd managers give preferential treatment to heifer calves in terms of colostrum feeding. Unfortunately, too often dairy bull calves receive no or insufficient quantities of colostrum (Peters, 2014). This results in immunologically deficient steers that consequently have additional challenges to their health and growth.

Many producers now measure the immunoglobulin status of their calves by evaluating serum concentrations of immunoglobulin G (**IgG**) or total serum proteins within 24 to 48 hr after birth (Schaefer et al., 2017). Failure of passive immunity transfer (**FPT**) is declared for < 10 g IgG/L or serum total proteins of < 5.0 to 5.2 g/dL. Adequate quality and quantity of colostrum is a basic need for calves within 8 hr after birth. Challenges include variation in colostral antibody concentrations, inability to measure IgG concentration at the farm level, disease vector contamination of colostrum (e.g., transmission of the causative organism for Johne's disease), and insufficient IgG to prevent FPT. Colostrum supplements (< 100 g IgG/dose) or colostrum replacers (> 100 g IgG/dose) are readily available exogenous sources if maternal colostrum is deficient or unsafe. Freezing colostrum to create colostrum banks is another option. Pasteurization of colostrum is now commonly used to prevent pathogen contamination on many farms. Feeding 4 L of colostrum at the first feeding after birth is an ideal quantity. Absorption of 150 to 200 g Ig within the first few hours after birth is the goal.

The second topic is castration, which should not occur until both testicles can be palpated in the scrotum. When descension of both testicles has not occurred and castration is done, one testicle remains in the body cavity and eventually produces testosterone. Such an animal is termed a stag. It develops secondary sex characteristics resembling those of a bull. The additional masculinity of the stag is evident in quality of its beef, causing packing plants to discount them to a value resembling that of cow carcasses. It is an expensive mistake if a cattle feeder sells a stag and only marginally less expensive for the cattle feeder to surgically remove a testicle remaining from the erroneous first castration.

Castration should be done either pre- or post-weaning but at a time when the procedure will not add to the stress of weaning. Castration done sooner rather than later in the life of the bull calf minimizes stress and growth retardation while healing occurs. Knife castration followed by administration of a disinfectant is the preferred method of castration for bull calves because it "only involves counting to two" to be certain of complete castration. Elastrator bands are the other commonly applied castration

method. Again, it is imperative with this method that both testicles be located in the scrotum before the elastrator band is released to strangle the contents of the scrotum. Since this method can result in tetanus as a secondary consequence, it is necessary that administration of a tetanus toxoid occur. Immunization prior to castration is preferred so that the calf has a pre-established immunity by the time the Clostridium tetani bacteria, which might be present, produce their toxin at the site of the elastrator band infection. Since circulating colostral antibodies could reduce the antigenicity of the immunization, knife castration seems more straightforward and certain. Advice of a veterinarian should be sought if elastration will be the method of castration.

The third topic is age at weaning (Schaefer et al., 2017). The current nutritional paradigm for dairy heifer calves is to feed large amounts of milk (milk replacer or whole milk) and wean later (e.g., >7 wk) when calf starter intake is adequate (minimum of 1.5 lb/day, for 3 days). The goal for dairy steer calves is to wean early (28 to 42 days) and promote feed DM intake so producers can take advantage of the efficient growth up to 400 lb BW. Adjustments should be made for both cold and heat stress conditions. The choice of texturized or pelleted calf starter should be based on both economics and the ability to provide a high energy diet (0.58 to 0.60 Mcal NEg/lb) with 18% crude protein. Use of digestible fiber sources in calf starter formulations has been very beneficial. Protein sources often constitute the most expensive part of starter diet formulations. Any diet transitions should be accomplished in individual housing prior to moving to group pens. An example would be a transition from coarse-textured starter to a whole corn-pelleted supplement program. The growth target for the nursery phase is to double initial BW by 56 days of age, with hip height growth of 4 inches or more.

Post-Weaning Feeding Strategies

The gain efficiency of young dairy steer calves is very high. Expected (Chester-Jones and DiCostanzo, 1996) growth during the period up to 400 lb BW has been shown to be 2.51 lb/day with 7.50 lb DM/day intake and 0.33 gain-to-feed efficiency (**GF**). Since Holstein steers are weaned onto a high-concentrate diet, there is no need to offer them grass hay diets upon receiving them into a feedlot, as would be the case for recently-weaned native calves. Their initial diet should include some long forage to stimulate rumination, but the basal receiving diet can be 0.56 Mcal NEg/lb.

The preferred method for raising and finishing Holstein steers is to begin by weaning them onto a high-concentrate starter diet, followed by sustained feeding of this high-energy diet until the desired finished weight is achieved. This method results in finished Holstein steers that are referred to as "calf-fed" cattle. Advantages of this method are that yardage expense and interest expense on calf purchase cost are minimized, ADG and gain efficiency can be expressed to the full genetic potential of the cattle, and these steers at 1400 to 1450 lb BW result in high dressed yield, mainly Choice and Prime carcasses. There is no risk of carcass weight discounts for calf-fed Holstein cattle because there is no need to take them to heavier weights to achieve the necessary body condition score.

An important adjunct to the calf-fed finishing strategy was provided by Miller et al. (1986). They evaluated inclusion of 30% hay in the starter diet fed to 330 lb BW and found it to be beneficial to the starter phase and starter-grower-finishing ADG. Although gain efficiency was improved when an "all-concentrate" (80% rolled corn, DM basis) diet was fed during the grower and finisher phases, hay in the starter

diet was presumably beneficial to rumen development, and this benefit had a carryover benefit for ADG until harvest at 1,000 lb BW. Additional titration of hay inclusion percentage in the post-weaning, starter phase diet has not been reported in the literature in recent decades. This long forage particle stimulation of early rumen development should be incorporated into the nutritional design of the starter phase.

For the sake of organization, assume the starter phase spans from weaning until 330 BW. Thereafter, there could be a grower phase which spans 330 lb to 770 lb, followed by a finisher phase from 770 to 1450 lb. It is not essential that the diet fed during the grower phase be different than that which is fed during the finisher phase. In fact, this is the design of the calf-fed program that has been implemented in recent decades in the U.S. desert Southwest. In the calf-fed system of the Southwest (Zinn, 2015), Holstein steers enter the feedlot at 300 lb BW at 100 to 120 days of age, remain on feed for 349 days, have ADG of 2.88 lb/day, and are harvested at 1294 lb BW (which reflects 4% shrink). Forages are in short supply in the Southwest, unlike the Midwest. Current representative production numbers in Midwest and Northern Plains feedlots are as follows (T.M. Peters, DeKalb Feeds, Rock Falls, IL 61071; 2016; personal communication). Holstein steers enter at 475 lb BW and are on feed for 330 days consuming 20.9 lb DM/day, gaining 2.88 lb/day, and resulting in GF of 0.138 with harvest occurring at 1425 lb BW. Finishing diets may include 25% corn distillers grain, 12.5 to 15% as hay or forage, 5% commercial supplement, and 55% corn. The corn is either dry and/or high-moisture that has been coarsely processed. Wet or dry coproducts from the ethanol industry are utilized. When they contribute energy in the form of corn oil rather than starch, they support industry standard feedlot performance while diminishing the risk of acidosis.

The chosen energy density of the finishing diet ($\geq$ 0.62 Mcal NEg/lb DM) is based on balancing rumen health (which is a function of dietary energy sources, cost of effective fiber sources, feedbunk management, and duration of feeding the finishing diet) and carcass characteristics at harvest (which are a function of weight, implant program, and marbling score). High Plains feedyard consultants most commonly recommend an energy density for commercial feedlot finishing diets (Samuelson et al., 2016) of 0.68 to 0.70 Mcal NEg/lb. Their NEg concentrations are made possible by the inclusion of steam-flaked corn which has 0.76 Mcal NEg/lb, whereas high-moisture corn has 0.71 Mcal NEg/lb (NASEM, 2016). Since forage to concentrate ratios have been referenced in the Midwest, equivalencies between forage to concentrate ratios and dietary NEg concentrations are presented in Table 3. This author has finished calf-fed Holstein steers using 10% corn silage diets calculated to provide 0.65 Mcal NEg/lb DM. With the advent of kernel processors on corn silage harvesters, 10% seems to be the minimal advisable level of corn silage inclusion. Peters (2014) contends that continuous feeding of high-energy diets with 10 to 12% forage from light feeder BW to harvest BW may result in a stall-out period of slow growth, presumably due to metabolic complications related to sub-clinical acidosis, which arises in connection with the long duration of this finishing diet. This has not been observed in 6-head pen studies at UW-Madison.

Feedbunk management is a critical skill that must be implemented perceptively and on a consistent basis for Holstein steer feed intakes and growth rates to be sustained at a high level. Pens must be fed: 1) a diet which has a consistent composition from day to day, 2) at a consistent time(s) of day, 3) with a consistent manner of diet distribution, and 4) to allow equal access to the diet for all cattle in the pen. The feedbunk

for each pen should be viewed at a consistent time of day. Based on this bunk reading, an amount of diet should be offered that will be eaten by the pen of cattle within the succeeding 24 hr, with only crumbs of diet remaining. Preferably, all cattle adopt the habit of coming to the bunk to eat fresh feed when it is offered because appetite is an easy, meaningful method for daily assessment of cattle health. The goal of bunk management is to provide a ration that satisfies appetite without underfeeding, which restricts performance or overfeeding, which results in feed wastage. The assertion here is that skillful, consistent bunk management will circumvent the stall-out period referenced by Peters (2014). Daily provision of a total mixed ration (**TMR**) allows for greater control of feed additive intake, greater ability to recognize pen feed intake fluctuation, opportunity to integrate byproduct and/or moist feeds, ability to utilize forage more effectively, ability to decrease NEg concentration in diet promptly in response to incoming severe weather, and greater ability to notice sick animals.

When forages are readily available due to the cropping system necessitated by the farmland landscape, they may be fed in the 330 to 770 lb BW range. Forage-to-concentrate ratios can be adjusted whereby home-grown forages can be included in this grower period at up to 55% of the diet DM, followed by a high-energy finishing diet (DiCostanzo, 2005). When high forage diets of 0.34 and 0.39 Mcal NEg/lb were fed to Holstein steers beginning at 305 lb for 153 days to 625 lb BW and then followed by feeding a high-moisture corn diet (0.66 Mcal NEg/lb) until 335 days on feed, these steers displayed compensatory growth during the finishing phase (3.7 lb/day) so that their slaughter (1282 lb) and carcass (757 lb) weights, yield grades, and marbling scores were not different from steers continuously fed the high-moisture corn diet (Schoonmaker et al., 2004). Again, the constraint is to initiate the finishing diet so that Holstein steers can be finished at a desirable slaughter weight, by 1450 lb.

The self-fed, dry, whole corn and pelleted supplement program for finishing Holstein steers is used by small feedlots that do not have TMR mixing equipment and wish to capitalize on the low input of labor. Acidosis may result from inconsistent feed intake; though Eng (2005) surmised that Holstein steers are less likely to founder than native steers. The occurrence of this disorder has been attenuated by providing a palatable bedding source such as corn stalks or free choice long or chopped hay. In addition, a roughage level of 5 to 10% incorporated into the pellet has been successful (Traxler et al., 1995).

Apart from their higher energy requirement for maintenance (NASEM, 2016), the fulfillment of protein, mineral, and vitamin requirements for dairy steers can be guided by the recommendations in NASEM (2016). Yet, the ability to manage Holstein steers at light weights when their growth rate is rapid and gain efficiency is high affords an additional opportunity to enhance their performance via balancing the dietary supply of metabolizable amino acids to meet their metabolizable amino acid requirements.

Zinn et al. (2005) noted that calf fed Holstein cattle can increase BW by 1% daily and well-managed steers can attain ADG of 3.74 lb/day during their first 112 days on feed. They expressed concern that lysine, methionine, and threonine are growth-limiting amino acids for calf-fed Holstein cattle during this period. Salinas-Chavira et al. (2016) have since shown that balancing the diet to meet the metabolizable amino acid requirements of the calf-fed Holstein steer during the period from 285 to 625 lb improved ADG and GF, and the benefit on GF was sustained to 1275 lb. Fat inclusion at 5%

increases energy density of the diet and may be most beneficial to ADG in this early period of rapid growth that coincides with a constraint on gastrointestinal tract capacity.

Holstein steers have increased susceptibility to liver abscesses compared to native steers, and heifers (Amachawadi and Nagaraja, 2016). The 10-yr average incidence of liver abscesses in native heifers, native steers and Holstein steers was 13.9, 16.0, and 28.3%, respectively. The reason for this Holstein susceptibility is unknown. Liver abscesses result in liver condemnations as a human food source and account for additional carcass trim loss when they adhere to the diaphragm. Fusobacterium necrophorum and Trueperella pyogenes are considered to be the primary and secondary causative pathogens; however, Amachawadi and Nagaraja (2016) point out that bacterial isolations from abscesses of Holstein cattle have not been conducted. Dietary tylosin administered at 60 to 90 mg/head daily reduced the incidence of liver abscesses from 30 to 8% (Wileman et al., 2009).

Additional Management Considerations

Holstein steers apparently have greater water consumption than native steers. Although there is no known publicly available data to support this report, Eng (2005), Peters (2014) ,and Zinn (2015) have all made this comment. Consequently, pens of Holstein cattle are wetter and bedding requirements would be greater. It is also relevant that dietary salt inclusion not be excessive since this would exacerbate water consumption and urination. This author formulates diets for Holstein steers to contain 0.2% salt (DM basis).

The use of anabolic implants has not been been described in this paper, though they should be used in dairy steers. The choice of which potency of anabolic implant product and the frequency of their implantation must be considered in light of the arrival BW and duration of the grower and finisher phases. Chester-Jones (2010) has reviewed the literature and provided recommendations.

Conclusions

Holstein steers account for a substantial proportion of beef production from finished steers and heifers. It is important that these animals as neonatal bull calves receive an adequate dosage of colostrum, equivalent to that administered to their heifer mates. While consequences of inadequate colostrum provision have not yet been quantified, the long-term consequences for steer health are considered to be significant. Complete castration of bull calves is equally important because failure to do so has expensive consequences in terms of carcass value discounts. Holstein steers are large frame cattle which need to receive a high-energy finishing diet so that they will have adequate carcass fatness at a desirable carcass weight. This endpoint allows the inclusion of some forage in low-energy diets, provided the high-energy finishing phase begins in a timely manner so as to enable the steer to finish at an acceptable carcass weight. Since these steers may receive a high-energy diet for 11 mo, it is also essential that bunk management be consistently accurate in making the daily ration allocations. Holstein steers are susceptible to development of liver abscesses. While the reason for this susceptibility has been ascribed to the duration of the feeding the finishing diet, it is not clear whether the susceptibility is rooted in management or animal genetics.

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Table 1. Contribution of steers, heifers, and culled cows from U.S. dairy herd to U.S. commercial beef production in 2015[1].

Assumptions	Value	Reference
Calving interval of 13.1 mo; cows calving annually	91.6%	NAHMS, 2016
Dairy calves from U.S. calf crop	26%	-
Heifer component of calf crop to account for replacement heifer need and 1% for slaughter	53%	-
Calf death loss weighted for singletons vs twins	8.08%	Silva del Rio et al., 2007
Cow and replacement heifer death loss	6.8%	Shahid et al., 2015
Feedlot death and realizer[2] loss	3.77%	Peters, 2014
Commercial slaughter relative to federally inspected (FI) slaughter	1.01%	-

Components from USDA Agricultural Marketing Service for 2015	Value
Dairy cow inventory, thousands	9,307
Heifers for dairy cow replacements, thousands	4,710
Replacement heifers expected to calve within year, thousands	3,051
U.S. calf crop, thousands	34,302
FI dairy cow slaughter, thousands	2,915
FI cow carcass weight, lb	644
Steer dressed weight, lb	892
Heifer dressed weight, lb	818
Veal calf slaughter, thousands	453
U.S. commercial beef production, billion lb	23.698
U.S. beef production from FI steers and heifers, billion lb	19.697

Results of calculations as they pertain to dairy cattle	Value
Calves born after accounting for calving interval, thousands	8,905
Bull calves born, thousands	4,150
Heifer calves born, thousands	4,755
Surplus heifers, thousands	45
Heifers to beef sector after feedlot death and realizers, thousands	43
Steers and veal bull calves for slaughter after feedlot death and realizers, thousands	3,993
Steers to beef sector, excludes veal, thousands	3,565

Contribution of dairy cattle to U.S. commercial beef production	
Steer beef, billion lb	3.18
Heifer beef, billion lb	0.0354
Cow beef, billion lb	1.90
Steers, %	13.4
Heifers, %	0.1
Cows, %	8.0
Total dairy sector, %	21.5

Contribution of dairy steer and heifer beef production to U.S. FI steer and heifer beef production	
Steers, %	16.0
Heifers, %	0.2
Total dairy steers and heifers, %	16.2

[1]Boetel, B. 2016.

[2]A realizer is an animal that requires repeated veterinary treatment while hope remains for a full recovery, but later the

Table 2. Measurements of finished dairy beef steers pictured in Figure 2.

	Holstein (Figure 2A)	Jersey (Figure 2B)	Brown Swiss (Figure 2C)
Body weight, lb	1388	1150	1260
Dress, %	58.6	59.0	60.2
Carcass, lb	814	679	759
Fat thickness, in	0.28	0.28	0.25
Loin muscle area, in^2	12.2	10.5	12.2
Kidney, pelvic, heart fat, %	3.0%	3.5%	3.0%
USDA Yield Grade	3.0	3.1	2.7
USDA Maturity	A	A	A
USDA Marbling	Modest[20]	Moderate[60]	Modest[10]
USDA Quality Grade	Choice	Choice-Plus	Choice

Table 3. Equivalencies between corn silage:high-moisture corn ratios and net energy for gain concentrations[1,2].

Corn silage Proportion (%)	Corn, high-moisture Proportion (%)	Net Energy Gain (Mcal/lb)
10	60	0.653
15	55	0.640
20	50	0.626
25	45	0.612
30	40	0.599
40	30	0.571
50	20	0.544

[1]Based on diet DM formula as follows: corn silage proportion; high-moisture corn proportion; modified wet distillers grain with solubles, 25%; and supplement, 5%.
[2]NEg values for diet ingredients (NASEM, 2016) were corn silage, 0.44 Mcal/lb; high-moisture corn grain, 0.71 Mcal/lb; and modified wet corn distillers grain with solubles, 0.74 Mcal/lb. Supplement was considered to be only minerals, vitamins, and additives with zero NEg value.

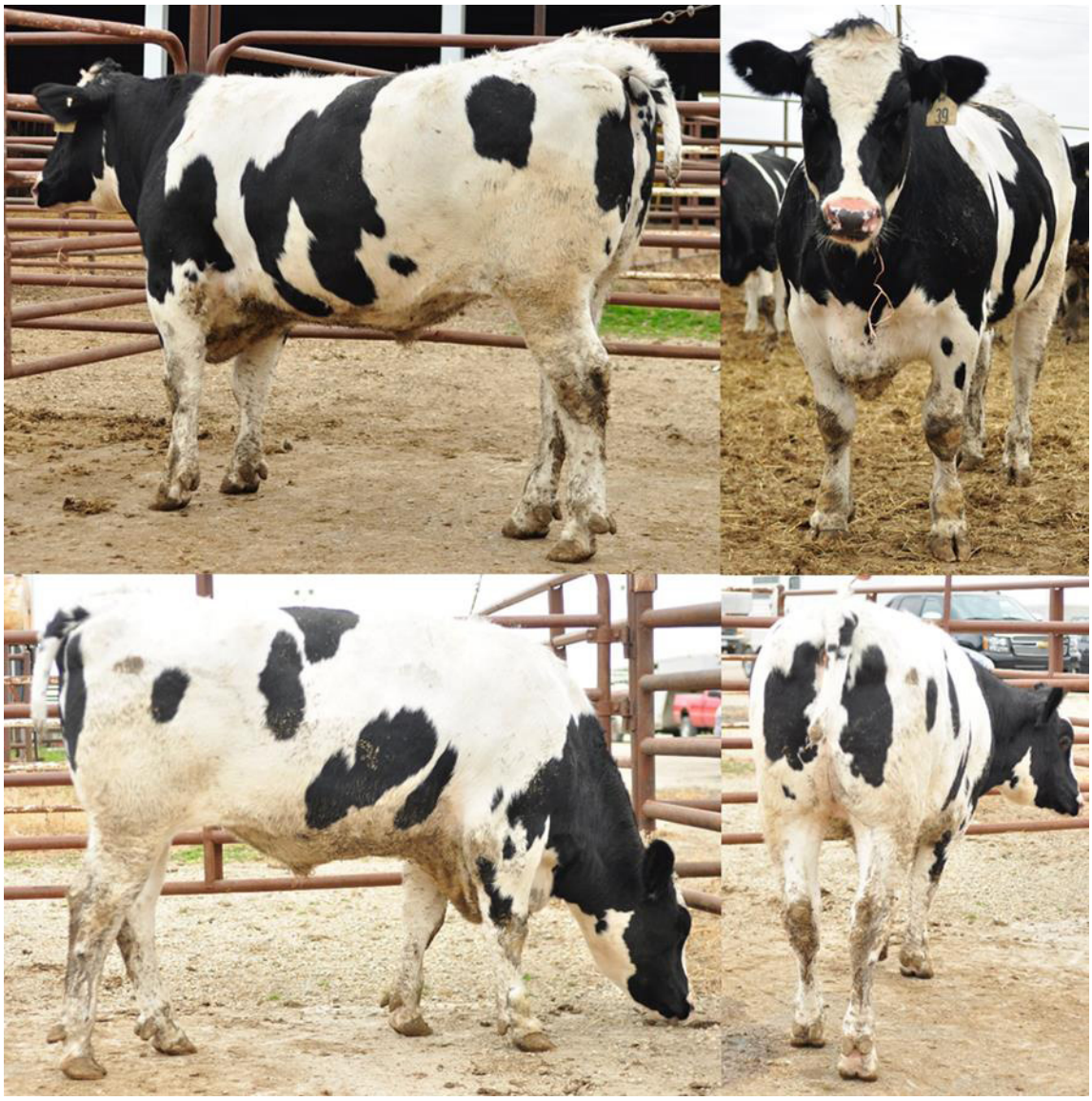

Figure 1. Appropriately finished Holstein steer that displays uniform fat coverage over the ribs, brisket fullness, and modest fat pones on both sides of the tailhead, characteristic of body condition score 7. Live weight of this steer is 1415 lb with dressing percentage estimated to be 61.5%. An ideal kind of steer that displays youthfulness and finish to be USDA yield grade 3 and high Choice with desirable muscle:bone ratio. (photos courtesy of Ron Mayer, JBS-Packerland).

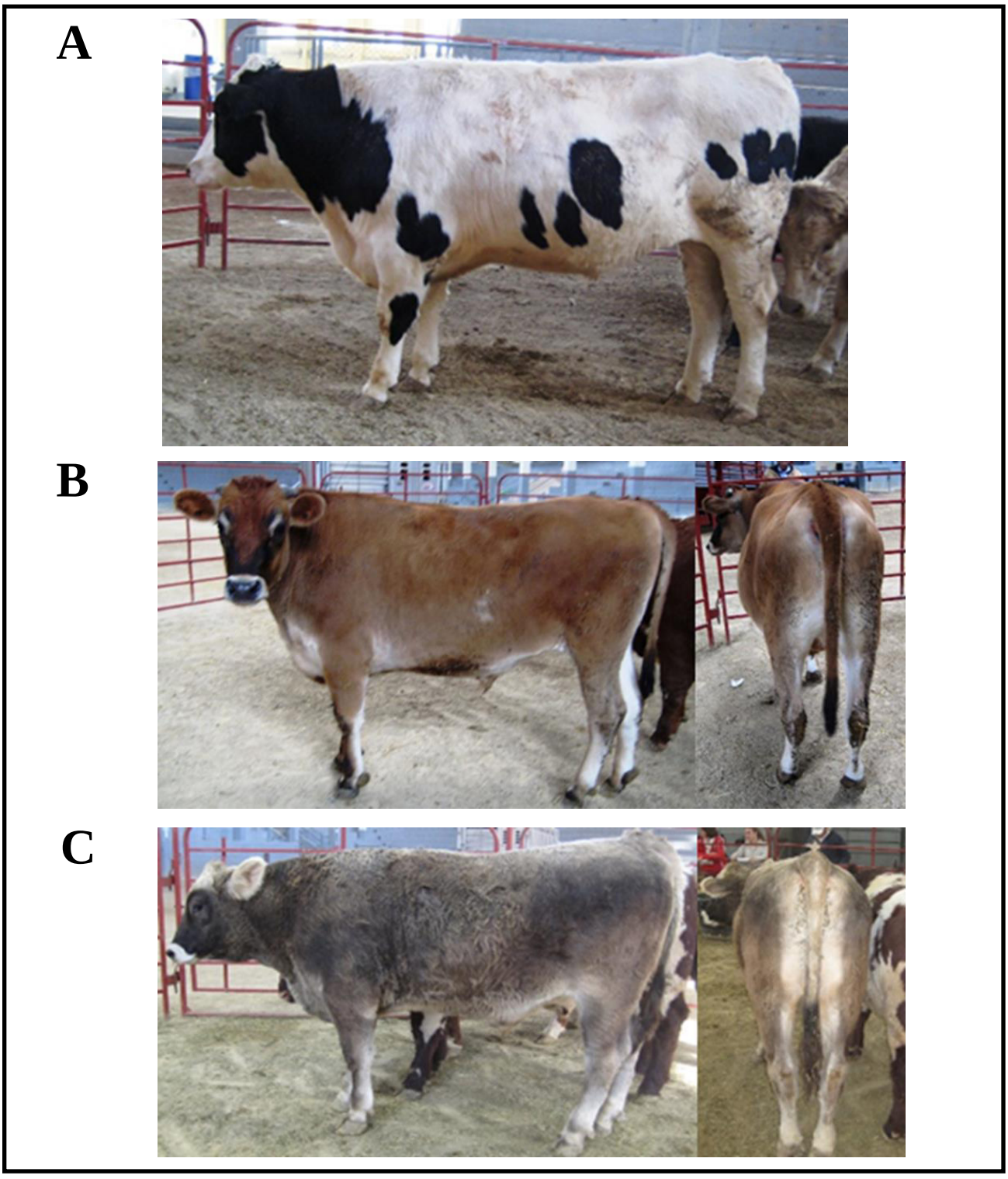

Figure 2. Appropriately finished dairy steers should display a body condition score of 7, on a scale of 1to 9, and weigh no more than 1550 lb and no less than 1200 lb BW, to avoid carcass weight discount. A) finished Holstein steer , B) finished Jersey steer, and C) finished Brown Swiss steer (photos courtesy of Ron Russell, UW-Madison). Weight, dressing percentage, and carcass yield and quality data for each steer are shown in Table 2.

Variation in Feed Costs Among Dairy Farms

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Introduction

The majority of milk marketed by dairy farmers in the United States is sold as a commodity, with dairy farmers acting primarily as price-takers in the marketplace. With the shift of the industry from a system of stable and predictable prices dictated by legislation, to prices driven by market supply and demand, milk prices are now subject to wide fluctuations characterized by intermittent highs followed by lingering lows. In the last 10 years (2007 to 2016), the Class III milk price averaged $16.81/cwt, ranging from a high of $22.34/cwt in 2014 to a low of $11.36/cwt in 2009, a range of $10.98/cwt. Monthly Class III prices exhibited an even wider range, from a low of $9.31/cwt in February of 2009, to a record high of $24.60/cwt in September 2014.

This volatile business environment has caused increased scrutiny of costs of production at the farm level, intensifying when milk prices are in the bottom of the price cycle. With feed costs for many Ohio dairy farms comprising at least 50% of total direct and indirect costs (Table 1), they are under constant scrutiny. Evaluation of feed costs frequently includes comparison to other farms or industry benchmarks. Many states have dairy farm business analysis programs that publish feed cost data. Average 2015 feed costs reported in the Summary of Illinois Farm Business Records (Krapf et al., 2016), New York Dairy Farm Business Summary (Knoblauch et al., pending), the Northeast Dairy Farm Summary (Laughton, 2016) and the Ohio Dairy Farm Business Summary (Shoemaker, 2016) were $9.18, 8.25, 8.51, and 11.88/cwt, respectively. Does this mean that New York dairy farmers are better at controlling feed costs than the Illinois, Northeast, and Ohio dairy farmers? Not necessarily. To use these numbers to help dairy farmers, it is important to understand why they are different.

Evaluating Feed Costs

What is being measured?

The term "feed cost" has many potential meanings in the dairy industry. In any given discussion, it might be referring to the total cost of a diet, or it might include only a fraction of the cost of the diet, such as the supplement portion, purchased feeds, forages, raised feeds, or some combination of ingredients. To be meaningful, it must be clear what costs are included in the measurement being discussed.

What animal groups are included?

Feed costs might be for a specific diet for one group of animals or could include multiple diets for multiple animal groups. Not understanding which diets are included in stated costs of production can result in comparison of

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one farm's total feed cost to another farm's cost of feeding lactating cows, resulting in frustration and potentially bad decisions for all involved. In the Illinois, New York, Northeast, and Ohio dairy summaries, reported feed costs represent all feeds fed to the adult and replacement animals by the farms. However, it should be noted that in the case of animals that are provided feed through a custom raising arrangement, that animal group's feed costs are most likely included in the total cost of production as a contract production expense but not as part of the total feed cost.

How are costs measured?

When a nutritionist formulates a diet, the cost of the diet should also be calculated. How should the feed ingredients be valued? Purchased feeds are the most straightforward and should be valued at their purchase price plus any associated transportation and storage costs. If the diet includes forages or grains grown on the farm, how should those feeds be valued? There are 3 options. Raised feed can be valued at the farm's cost of producing the feed ingredient, they can be valued at a local market price, or they can be valued at a number that represents neither. If the feeds are valued at the farm's cost of production, is it a cash cost of production, an accrual adjusted direct cost, or a total cost of production (accrual adjusted direct and indirect costs) with or without a charge for the value of labor and management? While cash costs of production (typically seed, fertilizer, chemicals, and perhaps other crop supplies) are more readily available, they will under-represent the actual cost of the feed. When market prices are used to value homegrown feeds, they are highly likely to under or overstate the farm's true cost of production. When randomly picking a number to represent an ingredient cost, the resulting feed cost has no value and can harm the farm's ability to make effective management decisions.

These are very important decisions as trying to compare feed costs within and between farms will only be useful if comparisons are made using similarly calculated costs. Valuation of feeds explains some of the differences in feed costs reported by the different summaries. It is important to understand how each state gathers and summarizes information so that comparisons between summaries or with other farm's data is done using costs calculated the same way, or at least recognizing and adjusting for the differences.

Illinois, New York, Northeast, and Ohio summaries report feed costs using accrual-adjusted expenses, meaning the total cost for an expense item is included, not just the cash paid in the reporting year. For example, all seed costs for corn harvested in 2015 would be charged to the corn enterprise whether they were prepaid in 2014, paid in 2015, or not paid until 2016 (or a combination thereof). Only including cash paid in the production year being evaluated can be very misleading and lead to over or under-stating actual production costs.

How state summaries report feed costs

The Illinois Farm Business Records Summary reports dairy farm data broken out by herd size (Table 2). From 2011 to 2015, data was reported for herds with 40 to 79 cows and herds with 80 or more cows. Their feed cost per hundredweight calculation includes purchased feed at purchase price. All raised feed is valued at a set market price per unit representative of Illinois markets. While this method allows a "level playing field" comparison among farms, it does not give participating farms a true cost of production based on their ability, or lack of ability, to grow quality dairy feeds cost-effectively. It is also easier than calculating the cost of production for homegrown feeds.

Cornell publishes several New York dairy farm business summaries, including a summary of all farms and a summary of large herd farms with 300 or more cows. Within summaries, data are broken down by profitability group. The summary of all farms reports average data for all farms and for the high 10%, while the summary for farms with 300 cows or more includes averages for all farms and for the high 20% of farms. High performing farms are sorted by rate of return to all assets without appreciation (Table 3). New York feed costs include dairy grain and concentrate, purchased dairy roughage, purchased non-dairy feeds (heifers and dry cows), fertilizer, lime, seed, spray, and other crop supplies. New York's reported feed costs do not include a charge for crop related machinery, labor, and other costs of producing crops.

The Northeast Farm Business Summary reports data for all farms and for the high 25% of farms sorted by rate of return on assets (Table 3). Their feed cost calculation includes purchased feed, seed, plants, fertilizer, chemicals, and spray. Like the New York data, the Northeast summary data does not include the total costs of crop production.

The Ohio feed costs are the most representative of total feed costs of all the states. Data are reported for all herds and for the high 20% sorted by net return per cow (Table 3). Purchased feed is included at purchase price. All raised feed is included at total cost of production including direct and overhead costs, as well as a return to the farm's labor and management. Direct costs include seed, fertilizer, chemicals, crop insurance, drying, storage, fuel and oil, repairs, custom hire, hired labor, land rent, machinery leases, operating interest, and miscellaneous expenses. Overhead costs include farm insurance, property taxes, utilities, dues and professional fees, machinery, and building depreciation expenses.

Ohio's feed costs also capture the cost of shrink as the amounts of feed fed are calculated for each feed as follows: Feed Fed = Beginning Inventory + Quantity Purchased + Quantity Raised – Quantity Sold – Ending Inventory. While any feeds purchased are valued at the purchase cost, the amount that was raised will be valued at the total cost of production divided by the amount fed. If shrink is an issue before feeding, the total volume of feed fed will have a higher cost per unit as the total costs of production will be divided among the volume of the crop actually making it into the inventory as raised feed. If shrink is an issue between storage and the bunk, the cows will be charged for volume of feed that was available to be fed, whether they actually received and ate it or it was lost to shrink before they were able to consume it. It is important that farms carefully track yields and take accurate inventories for the beginning and ending inventories.

Impact on profitability

There is not a specific feed cost benchmark that will guarantee a farm's profitability. With total feed costs averaging 50% or more of total direct and indirect costs of production (Table 1), feed costs should be evaluated in the context of the dairy enterprise's profitability (Figure 1). While there is a trend indicating that lower feed costs are related to increased net returns, lower feed costs do not guarantee profitability. Ohio's feed cost averaged $11.88/cwt of milk in 2015 (37 conventional and 3 organic herds); it is important to note that achieving a feed cost at or below the average does not guarantee that a farm will achieve a high or even a positive net return per cow. Each diamond in Figure 1 represents one of the 37 conventional dairy farms participating in the 2015 analysis program. There were 8 farms with a feed cost near $11.50/cwt. Three of the farms experienced a negative net return per cow, while 5 realized positive net

returns ranging from less than $200 to around $650 per cow. The same is true if we look at farms with a positive net return per cow. Five farms achieved a net return between $250 to $300 per cow. There was a difference of more than $5/cwt in these farms' total feed costs, ranging from $11.50 to 16.90/cwt.

Conclusions

Today's dairy farms are operating in a volatile marketplace. The bottom line for a dairy enterprise is the net return generated per cow (Table 4). Feed costs make up at least half of the total direct and indirect costs of producing milk on most dairy farms and have the single biggest impact on net return per cow. Because feed costs are a major production cost, monitor it regularly, compare to goals, and evaluate at least once a year in relationship to the profitability of the dairy enterprise. Care should be taken when calculating ration costs and feed costs and comparing with benchmarks or other farms' performance. These comparisons are very useful if it is clearly understood what diets and animal groups are included in the feed cost calculations and how costs are determined for both purchased and raised feeds. Making comparisons and management decisions without clear knowledge of these factors can lead to wasted time and poor results. An individual farm's participation in farm business analysis programs provides excellent data for monitoring and comparison as all participating farms' costs are calculated in the same manner.

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Table 1. Average expenses ($/cwt) and percent of total direct and indirect expenses, for 39 Ohio farms, and high 20%[1] of farms, Ohio, 2015[2].

	All Farms	%Total Expenses[3]	High 20%	% Total Expenses
Feed	$11.88	55.46	$10.42	57.88
Hired labor	2.44	11.40	2.09	11.61
Breeding fees	0.41	1.91	0.31	1.72
Veterinary	0.62	2.89	0.49	2.72
Supplies	0.92	4.30	0.62	3.44
Contract production	0.20	0.93	0.22	1.22
Fuel and oil	0.25	1.12	0.23	1.28
Repairs	0.48	2.24	0.24	1.33
Custom hire	0.69	3.22	0.17	0.94
Utilities	0.48	2.24	0.51	2.83
Hauling and trucking	0.52	2.42	0.46	2.55
Marketing	0.29	1.35	0.28	1.55
Bedding	0.42	1.96	0.40	2.22
Total Direct Expenses	$19.60		$16.42	
Depreciation	0.92	4.30	0.95	5.27
Interest	0.38	1.77	0.24	1.33
Miscellaneous	0.52	2.43	0.38	2.11
Total overhead expenses	$1.82		$1.58	
Total direct and overhead expenses	$21.42		$18.00	

[1]Farms sorted by net return per cow.
[2]Shoemaker, 2016.
[3]Percent of total direct and overhead expenses.

Table 2. Average dairy feed cost, number of herds, and average number of cows, 2011 to 2015, Illinois Farm Business Records[1].

Year	2011		2012		2013		2014		2015		5 Year Avg.	
Herd size (Cows)	40 to 79	80+	40 to 79	80+	40 to 79	80+	40 to 79	80+	40 to 79	80+	40 to 79	80+
Number of herds	9	21	12	24	9	30	9	27	7	29		
Number of cows	62	231	64	232	69	210	64	217	58	210		
Feed cost ($/cwt)	15.10	10.57	16.85	12.35	14.81	13.06	12.73	11.06	10.70	9.09	14.11	11.23

[1]Krapf et al. (2016).

Table 3. Feed costs ($/cwt) as reported by Ohio[1], New York,[2,3] and Northeast[4] dairy farm business summaries, average of all herds, average of high performing herds, 5-year average, and average number of farms.

	Ohio		New York (All Farms)		New Y ork (>300 Cows)		Northeast	
Year	All Farms	High 20%	All Farms	High 10%	All Farms	High 20%	All Farms	High 25%
2015	11.88	10.24[5]	8.25	7.55	8.24	7.75	8.51	8.25
2014	13.03	11.36	9.12	8.83	9.09	8.80	9.54	8.88
2013	12.10	11.31	8.17	7.59	8.89	8.56	9.36	8.68
2012	11.78	10.45	8.52	7.86	8.53	8.01	9.01	8.42
2011	10.88[6]	9.55[6]	7.62	6.84	7.56	7.19	8.07	7.52
5 year average	11.93	10.58	8.34	7.73	8.46	8.06	8.90	8.35
Number of farms	37		174		109		481	

[1]Shoemaker et al. (2012 to 2015). High 20% sorted by net return per cow.
[2]Knoblauch et al. (2012 to 2015). High 10% sorted by return on assets without appreciation.
[3]Karszes et al. (2012 to 2016). High 20% sorted by return on assets without appreciation.
[4]Laughton et al. (2012 to 2016). High 25% sorted by return on assets without appreciation.
[5]Conventional (non-organic) herds only.
[6]Homegrown feeds valued at Ohio market prices.

Table 4. Net Return ($/cow) as reported by Ohio[1], New York[2], and Northeast[3] dairy farm business summaries, average of all herds, average of high performing herds, 5-year average, and average number of farms.

	Ohio		New York (All Farms)		New York (>300 Cows)		Northeast	
Year	All Farms	High 20%	All Farms	High 10%	All Farms	High 20%	All Farms	High 25%
2015	36	1,046	235	833	227	744	138	448
2014	1,266	1,976	1,676	2,330	1,701	2,259	1,314	883
2013	544	1,501	911	1,488	915	1,489	613	989
2012	231	1,145	663	1,273	669	1,175	765	1,294
2011	317	1,290	1,139	1,834	1,207	1,790	1,185	1,756
5 year average	479	1,392	925	1,552	944	1,491	803	1,274
Average number of farms	37		174		109		481	

[1]Shoemaker et al. (2012 to 2015). High 20% sorted by net return per cow.
[2]Knoblauch et al. (2012 to 2015). High 10% sorted by return on assets without appreciation.
[3]Karszes et al. (2012 to 2016). High 20% sorted by return on assets without appreciation.
[4]Laughton et al. (2012 to 2016). High 25% sorted by return on assets without appreciation.

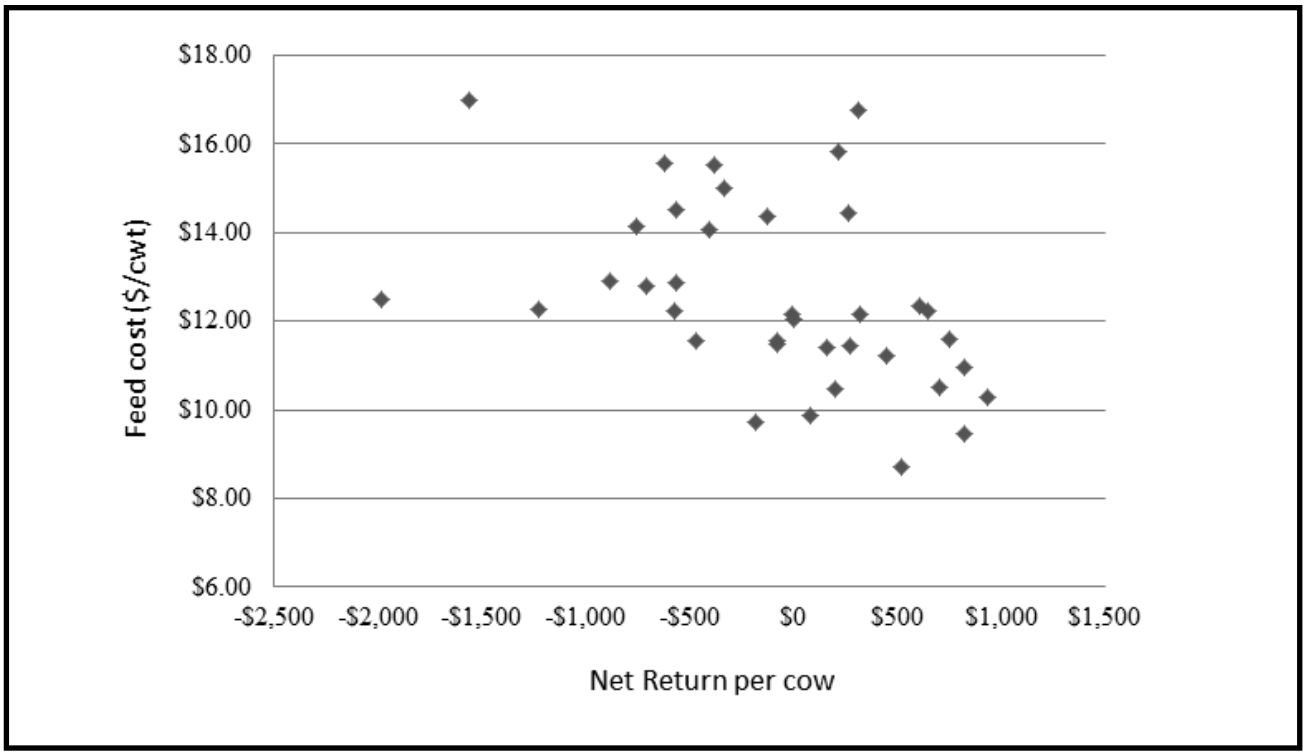

Figure 1. Feed cost versus net return per cow, 37 conventional Ohio dairy farms, 2015 (Shoemaker, 2016).

Agronomic and Nutritional Attributes of Reduced Lignin Alfalfa

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Abstract

Alfalfa (*Medicago sativa*) growers are faced with the recurring dilemma of having to balance yield and forage quality when harvesting their alfalfa crop. Yield increases while digestibility decreases as the plant matures, primarily because of increasing lignin content in the stems. A consortium of scientists at Forage Genetics International, The Samuel Robert Noble Foundation and U.S. Dairy Forage Research Center collaborated to alter the lignin content in alfalfa through genetic modification, resulting in the recent commercial release of the HarvXtra® alfalfa brand. A number of alfalfa varieties having the reduced lignin HarvXtra® trait are being marketed. Reducing the lignin content in alfalfa should extend the time interval when forage can be harvested and still maintain adequate nutritive value for ruminants with high nutritive requirements. Field trials were established in 6 states (KS, MI, OH, PA, CA, and WI) in spring 2015 to evaluate yield and nutritive value over time of the transgenic HarvXtra-008 alfalfa variety compared with 2 other varieties (one selected for high quality and one for high yield). Forage samples were collected over time during 2 growth cycles in 2015 and analyzed for nutritive value. Forage yield and nutritive value were also evaluated under 28, 33, and 38-day cutting intervals in 2015. Across all 6 states in the seeding year, HarvXtra-008 forage had consistently lower neutral detergent fiber (-2 to -3.8 units of **NDF**), lower acid detergent lignin (-1 unit of **ADL**), and higher NDF digestibility (+4.2 to +5.4 units of **NDFD**) compared with the other alfalfa varieties. This represents a 7 to 10 day advantage in nutritive value for HarvXtra-008. When cut on the 38-day schedule, HarvXtra-008 yielded similarly or more and often had higher nutritive value than the other varieties cut more frequently on 33- or 28-day schedules. Results with HarvXtra-008 from the first year are promising for alfalfa growers who want to maintain high forage nutritive value while increasing forage yields with less frequent harvests. More years of data will show how harvest interval affects nutritive value, yield, stand persistence, and profitability of alfalfa with the reduced lignin transgenic trait.

Introduction

Alfalfa is a high-yielding forage legume with nutritional attributes that complement those of corn (*Zea mays L.*) silage when used in dairy rations. Morphological and physiological changes occur in the plant as it matures that increase yield of DM per acre but decrease the nutritional value of the forage. As alfalfa approaches the ideal time for harvest, its nutritional value declines on a daily basis due to the accumulation of indigestible plant constituents in the cell walls. The yield

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increase versus nutritional value decrease is generally greater in the spring and early summer growth cycles than in late summer in humid environments (Brink et al., 2010), corresponding with the growth cycles that produce the largest proportion of the annual DM yield per acre. As a consequence, alfalfa growers are faced with the recurrent dilemma of having to balance forage yield and quality when harvesting their alfalfa crop. Weather conditions in humid environments can delay harvesting of alfalfa so the optimal window of time is often missed, resulting in high forage yield with less than ideal nutritive value for animals with high nutritional requirements. This factor has limited the use of alfalfa on many dairy farms, resulting in corn silage use being more strongly favored due to the ease of one harvest with a more consistent nutritive value content.

Leaves contribute significantly to the nutritive value of alfalfa, while stems contain higher concentrations of compounds that are highly indigestible by ruminant animals. The most important indigestible constituent in stems is lignin, which occurs in association with the thickening of secondary cell walls during the maturation process (Albrecht et al., 1987). Highly lignified plant tissue passes through the animal's digestive system and is not utilized for animal growth and development. Therefore, lignin limits ruminant digestibility, feed intake potential, and energy availability, all of which ultimately result in limiting animal production and performance. In order to significantly alter the potential forage quality of alfalfa, the nutritive value of stems must be improved because that is where most of the lignin is found.

For the past decades, breeders and geneticists have focused particularly on reducing the overall lignin content in alfalfa forage as a means of improving its nutritive value as the plant matures. A consortium of scientists at Forage Genetics International, The Samuel Robert Noble Foundation and U.S. Dairy Forage Research Center collaborated to alter the lignin content in alfalfa through genetic modification, resulting in the recent commercial release of the HarvXtra® alfalfa brand. Reduced lignin concentration in the plant was achieved by genetic modification using RNA interference to down regulate the Caffeoyl coenzyme A O-methyltransferase (**CCoAOMT**), a technique that essentially suppressed genes that code for specific enzymes in the lignin biosynthesis pathway in alfalfa (McCaslin et al., 2014).

A reduction in lignin content in alfalfa and the associated improvement in digestibility should enable growers to lengthen the time period when alfalfa has acceptable forage quality for animals with high nutritive requirements. Thus, growers would have a wider 'optimal' harvest window of opportunity, making it possible to possibly achieve higher yields by harvesting alfalfa later, while also maintaining acceptable forage nutritive value. One question in particular is whether a reduced lignin content will make it possible to harvest later, with less frequency, in order to obtain higher forage yield with similar forage quality as standard varieties that must be harvested earlier and more frequently to maintain adequate nutritive value. Collaborative field evaluations among 6 universities were initiated in 2015 to address those management questions. The specific objectives were: 1) to determine if the change in nutritive value over time of HarvXtra® alfalfa differs from conventional alfalfa varieties, and 2) to provide information that will help alfalfa growers determine appropriate harvest schedules for reduced lignin alfalfa that maximizes yield and maintains adequate forage quality for the class of livestock being fed.

Experimental Approach

Three alfalfa varieties ('HarvXtra-008' with the reduced lignin trait, '54R02' selected for high yield, and 'WL 355 RR' selected for high forage quality), were sown at 18 lb/acre of pure live seed in spring 2015 in 6 states (CA, KS, WI, MI, OH, and PA). Fertilizer applications were made at each location according to state recommendations based on soil test results. Herbicide, insecticide, and fungicide treatments were applied as needed to control weeds, insects, and foliar diseases, respectively. Two experiments were established using a randomized complete-block design with a split plot restriction on treatment randomization, with 4 replications.

The first experiment was designed to focus on the change in forage nutritive value over time within a growth cycle for the 3 varieties. Plots in Experiment I were arranged so that a given growth cycle was the main plot factor and alfalfa varieties were the subplot factor. The first growth of the seeding year was clipped off and discarded to avoid differences in development during establishment. Beginning with the second growth cycle in the seeding year, one main plot (containing all varieties) in each replication was sampled by hand clipping forage samples to 2-inch stubble on day 20, 23, 27, 30, 34, and 37 of regrowth from the previous date of cutting. A different whole plot, not sampled previously, was used in the third growth cycle of the seeding year to avoid any variation in alfalfa regrowth caused by variable clipping dates within previously sampled plots. The forage samples were dried in a force air oven, ground, and analyzed for nutritive value using calibrated near infrared reflectance spectroscopy (**NIRS**) equations. The following nutritive value traits are reported here: ADL, NDF, NDFD, relative forage quality (**RFQ**), and crude protein (**CP**) concentration.

The second experiment evaluated harvest schedule effects on yield and nutritive value of the 3 alfalfa varieties. As in the first experiment, the first growth of the seeding year was clipped off and no data were collected. For the second and third growth cycles in the seeding year (2015), plots were arranged so that harvest schedules (28-, 33-, and 38-day intervals) were the main plots and alfalfa varieties were the subplots. Before each harvest, a 0.6 to 1.0 lb sample was hand clipped from plots to be harvested and the fresh weight was recorded. The samples were dried and weighed to determine DM percentage, then ground and analyzed for nutritive value using calibrated NIRS equations. Plots were clipped to a 2-inch stubble and DM yields were calculated. A forage plot harvester was used to cut and weigh plot fresh weights that were converted to dry weights for determination of DM yield.

Results

The reduced lignin variety HarvXtra-008 was consistently higher in forage nutritive value (lower ADL and NDF; higher NDFD, RFQ, and CP) than the other 2 varieties across all states and both growth cycles measured in 2015 (Table 1). HarvXtra-008 had about 20% less ADL and 12% higher NDFD compared with the 2 other varieties.

As expected, nutritive value declined for all varieties during regrowth in both growth cycles sampled (Figure 1). Differences among varieties for NDFD were relatively consistent over the periods sampled. HarvXtra-008 maintained about a 7 to 10 day advantage in NDFD compared with the 2 other varieties. In other words, HarvXtra-008 harvested with 37 days of regrowth had the same NDFD level as the other varieties harvested on day 27 to 30 of regrowth.

Nutritive value data from the harvest schedule study (Figure 2) confirmed what had been observed in Experiment 1. HarvXtra-008 contained lower ADL and NDF concentrations than 54R02 and WL 355 RR averaged across sites, harvest intervals, and cuttings ($P < 0.05$, Figure 2). Consequently, NDFD was greater for HarvXtra-008 than for the other varieties ($P < 0.05$). Average ADL, NDF, and NDFD of HarvXtra-008 cut on a 38-day interval were equivalent to or better than values for the other varieties cut on a 28-day interval ($P < 0.05$, Figure 2). These results support the idea that HarvXtra-008 has a longer harvest window for achieving excellent forage quality.

When HarvXtra-008 was compared with the average of 54R02 and WL 355 RR across all sites and cuttings in the seeding year harvest schedule study, it averaged 15% less ADL (4.3 vs. 5.1 percentage units, respectively, $P < 0.05$), 9% greater NDFD (52.4 vs. 48.2 percentage units, $P < 0.05$), and 5% lower NDF (29.6 vs. 31.5 units, $P < 0.05$).

Across sites and cuttings, total alfalfa yield in the seeding year general increased with harvest interval for all varieties, as expected (Figure 3). HarvXtra-008 yielded about 8% less ($P < 0.05$) than 54R02 and WL 355 RR when averaged across all harvest schedules, but the difference was most apparent for the 33 and 38-day schedules. HarvXtra-008 cut on the 38-day schedule yielded similarly to the other 2 varieties cut on the 33-day and more than the 2 other varieties cut on the 28-day schedules.

Summary

The transgenic reduced-lignin alfalfa variety HarvXtra-008 maintained lower lignin and NDF contents and greater NDFD than the 2 other varieties during the seeding year. The transgenic HarvXtra-008 reduced lignin variety maintained high nutritive value for 7 to 10 days longer than the other 2 alfalfa varieties. This trait represents a significant new tool for alfalfa growers. The results with HarvXtra-008 are very promising for alfalfa growers who want to maintain adequate forage nutritive value when harvesting less frequently, or when weather systems delay harvest. The results are also very promising for those who want to achieve higher forage nutritive value while harvesting on their normal harvest frequency, because HarvXtra-008 was consistently higher in nutritive value on any given harvest date than the other varieties (one of which was characterized as a "high quality" variety). The studies reported here were continued in 2016 (results are being processed and analyzed). The reduced lignin trait and forage yield levels will likely improve with continued breeding progress. More years of data from these and similar studies along with on-farm evaluations will demonstrate how harvest interval affects nutritive value, yield, stand persistence, and profitability of alfalfa with the reduced lignin transgenic trait and will clarify optimal harvest strategies for alfalfa growers using this new tool.

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McCaslin, M., P. Reisen, and J. Ho. 2014. New strategies for forage quality improvement in alfalfa. In: Proc. California Alfalfa, Forage, and Grain Symp., 44th, Long Beach, CA. 10-12 Dec. 2014. UC Cooperative Extension, Davis, CA.

Table 1. Forage nutritive value of 3 alfalfa varieties averaged over 6 sampling dates during 2 growth cycles in the 2015 seeding year (average of 6 locations).[1]

Variety	ADL, %	NDFD, %	NDF, %	RFQ	CP, %
HarvXtra-008	4.0[b]	55.5[a]	26.7[c]	297[a]	26.4[a]
WL355 RR	4.9[a]	51.0[b]	28.7[b]	262[b]	25.8[b]
54R02	5.0[a]	50.1[b]	30.5[a]	243[c]	25.0[c]

[abc]Values followed by different letters are significantly different at P = 0.05.
[1]ADL = Acid detergent lignin, NDF = neutral detergent fiber, NDFD = NDF digestibility, RFQ = relative forage quality, and CP = crude protein.

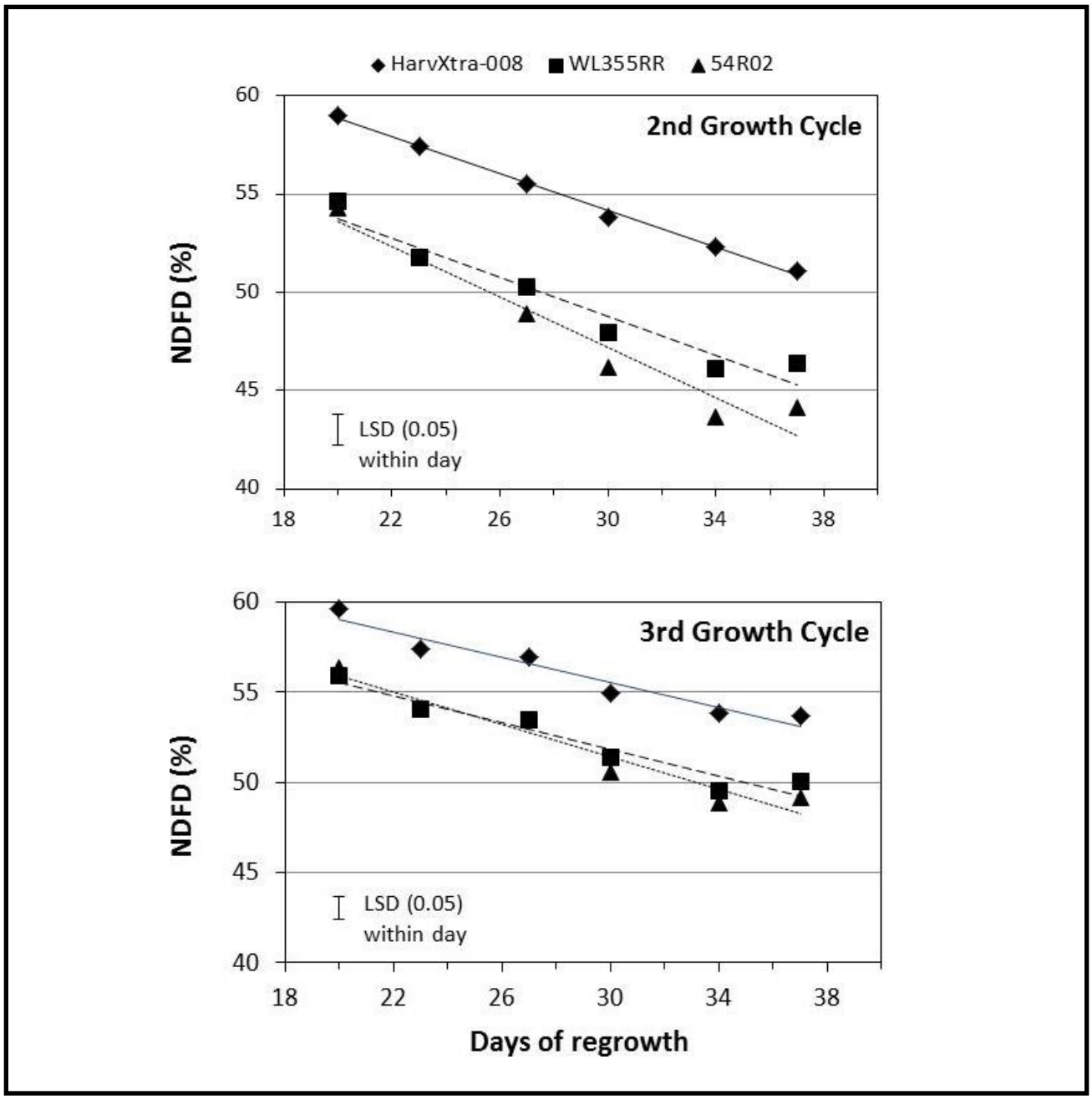

Figure 1. Neutral detergent fiber digestibility (**NDFD**) of 3 alfalfa cultivars during the second and third growth cycles in the 2015 seeding year (averaged over 6 locations).

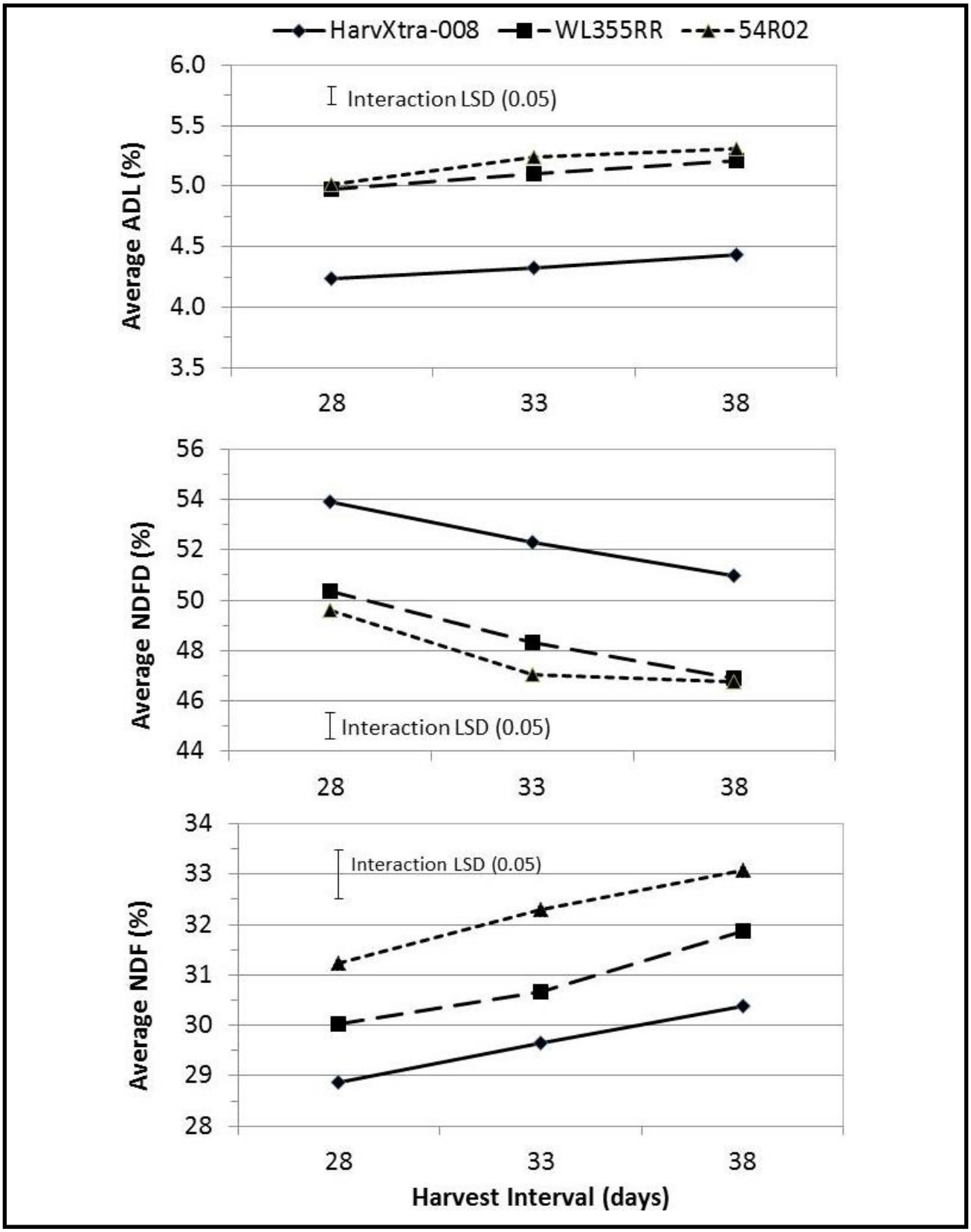

Figure 2. Average acid detergent lignin (**ADL**) and NDF concentrations and NDF digestibility (**NDFD**) of 3 alfalfa varieties harvested on 28, 33, and 38 day intervals in the 2015 seeding year (averaged over 2 harvests and 6 locations).

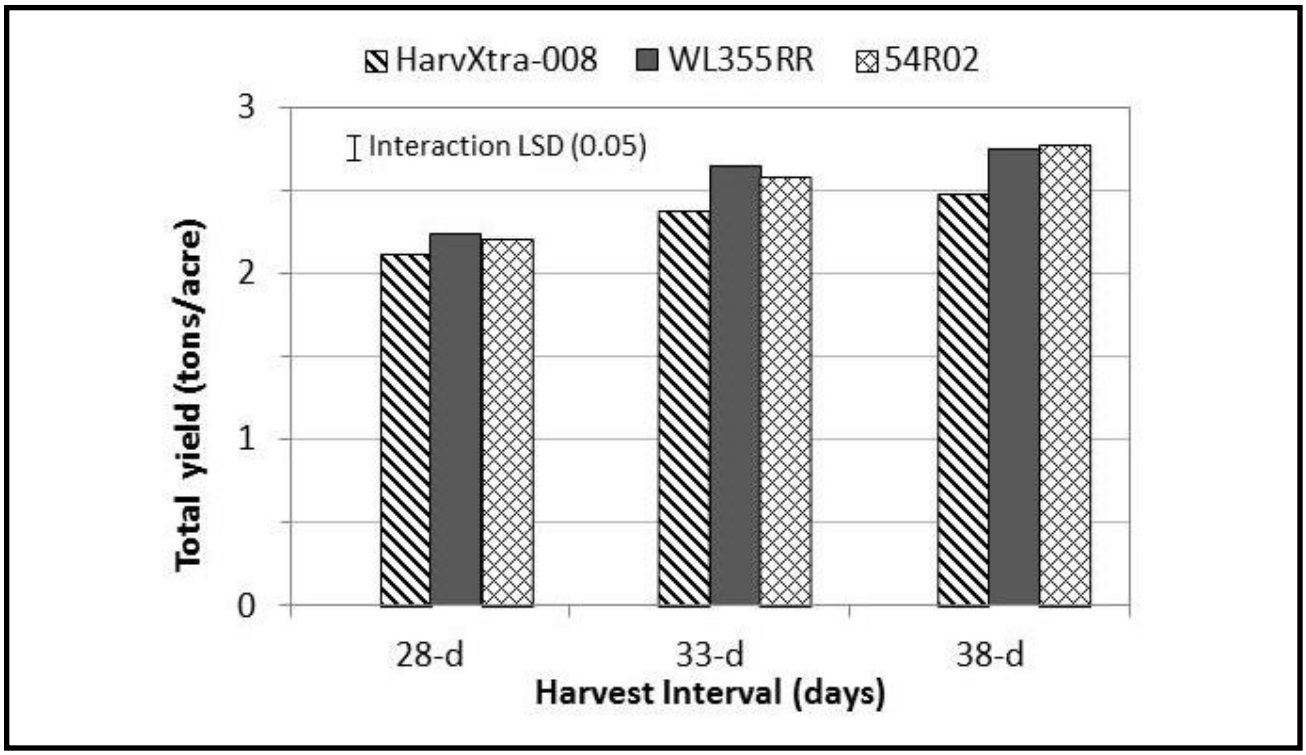

Figure 3. Total 2015 seeding year yield of 3 alfalfa varieties harvested on 28, 33, and 38 day intervals (total of 2 harvests, averaged over 6 locations).

"There's Nothing Like First-Hand Evidence" (Sherlock Holmes) The Cows Tell us What's Happening

Jim VanderSchuur[1]
Purina Animal Nutrition

First of all, I am honored and humbled for the opportunity to present a session at this 26th Tri-State Nutrition Conference. Over my 30+ years in the dairy feed business, I never imagined I'd be standing in front of you today. Many of my colleagues would agree. With that, I'll give it my best shot!

Over the past 3 years, as Tri-State Conference board member, we had numerous comments and / or suggestions requesting more information to take back to the field. To address these requests, I'll focus my session on field observations. "THE COWS TELL US WHAT'S HAPPENING!"

From the "Baby Boomer" generation to the "Millennials", we have seen vast changes in communic ation, technology, and accessibility of information. Oh yes, can't forget those "Generation X'ers"! However, for this presentation, we will use the wider generation gap. Each generation and individual has their own life history of events and environmental surroundings (history) around them, which contributes to your own individual "tool box". Dairy producers have transitioned from station barns and upright silos to parlors, robotic milker systems, bunker silos, and TMR rations. The younger generations today are very comfortable with all the new technology available (cell phones/computers/etc.), utilizing and depending on them 24/7/365. Debatable, maybe too much!

Years ago, Dr. Herb Bucholtz and myself had a brief discussion after spending an entire morning on a farm walk thru and herd evaluation with his MSU dairy nutrition class. I asked, "Herb should I take new forage samples and reformulate the ration?" Herb replied, "You can if you want to, but the cows will tell ya!" Lesson learned! Balance ration, then look and listen to the cows.

Three rations exist on the farm:

1. Ration on paper – computer,
2. Ration fed to cows, and
3. Ration that cows eat.

For this presentation, let's assume ration one is properly balanced. We'll focus our discussion on rations two and three. Daily, we work with owners, employees, cows, equipment, forages, facilities, weather, etc. If there is one constant on dairy operations, it's change! Sherlock Holmes is a perfect analogy for detective work, fact finding, and trouble-shooting in deducing on-farm evidence - the real problem. There is a short list below, which covers some of the day-to-day herd dynamics. We could spend an entire presentation on just a couple of these items.

- Producer goals
- Communication
- Employees
- Bunker/Forage management
- Feed bunk space/Push ups
- TMR access
- Equipment/Proper mixing
- Clean water and access
- Over crowding
- Group changes
- Production records
- Milking equipment/Milk components

However, to demonstrate the "Sherlock Holmes" detective approach, here are a few true stories from fellow colleagues and myself to illustrate what can/does affect cow behavior and performance.

Included is a checklist from a longtime friend and colleague titled, "When few and/or many cows are down" (Appendix A). It might be a little outdated, but it is still a good list for troubleshooting, observations, and detective work. Maybe it's not so elementary, my dear Watson!

Conclusion

We spend hours on the computer balancing and re-balancing diets. Maybe rightfully so. My challenge is, "Are we allocating enough time for monitoring individual farm and cow herd dynamics?" Utilizing technology, such as video cameras, cell phones, and photos are excellent tools for on-farm detective work. LOOK AND LISTEN!

Always remember Dr. Herb Bucholtz's comment: "THE COWS WILL TELL YA!"

References and Contributors

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Appendix A

When Cows Are Down -- Look For:

1. Mastitis
2. Group change - since last test
3. Lame cows - trimmed feed too short on some cows or some need trimming
4. Added cows - no more bunk space
5. Late state lactation - skipping milkings - drying off these cows
6. Highest producing cows - lacking nutrition - not challenge feeding
7. Cows in heat on test day
8. Start of disease problem - dysentery - foot rot - pink eye, etc.
9. Early stage lactation cows dropping off - too short dry period - too long dry period - poor dry cow feeding program
10. Poor quality heifers added to milking herd
11. Had cows on show circuit - just returned home - upset cows
12. Poor body condition
13. Rumen upset: slug feeding - fine chopped forage - low fiber, etc.
14. Computer Feeder Grain Information not updated
15. McDonald's disease

When <u>Many</u> Cows Are Down - Look For:

1. Mastitis
2. Drastic roughage changes - (quantity - quality - kind - moisture)
3. Disease present - I.B.R., dysentry, lepto, etc.
4. Change of milking personnel
5. Change of feeder personnel
6. Too small milk lines or milking procedure - or equipment change
7. Added cows - did not increase total pounds of feed
8. Drastic weather change - hot or cold - heat stress
9. Lack of water
10. Lack of salt
11. Electric short or stray voltage
12. Improper weighing of feed - inaccurate or broken scales - weak scales
13. Computer or magnetic feeder ran out of feed - or not working properly - bad tags
14. Change from dry corn to high moisture corn and did not increase amount fed
15. Started feeding green chop or unfermented feed - direct cut - no wilting
16. Added cows - no more bunk space
17. Wrong vacuum on milkers - incomplete milking - poor ventilation
18. Ran out of concentrate
19. Reduced amount of concentrate fed - due to an increase in concentrate price
20. New man cleaning yards - disturbs cows for too long a time - less time to eat
21. Not consistent on milking times or interval - busy in fields, etc.
22. Not consistent on feeding times - busy in fields, etc.
23. Change in sequence of feeding
24. Eliminated one or more feedings per day
25. Lack of good fly or pest control program
26. Lack of water in holding pens during milking - in extremely hot weather
27. Change in high moisture corn - now buying <u>poor quality</u> high moisture or using up last of grain in silo
28. Turned cows out on pasture - did not provide hay bunks - salt - mineral or water out on pasture (even if he did make these provisions, cows may still drop because we cannot <u>control</u> amount of pasture consumed and they eat less milking ration)
29. Feed bunk empty for more than 4 hours/ day
30. Feed bunks not cleaned regularly - full of old feed
31. Improper body condition
32. Unpalatable ingredients or additives.

33. Drop in intake
34. Level of fat in diet
35. Moldy feed
36. Herd or group composition change - more heifers - staler cows - new bull
37. Too much grain in manure - check effective fiber - grain processing - level of grain feeding
38. Hard fiber stools - check grain levels
39. No feed in bunk after milking
40. Check cud chewing
41. Check for a busy barnyard and nervous cows
42. Unbalanced nutrition