Achieving Excellence in Dairying

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If you want cows that product more than 100 pounds (45L) of milk a day "fill them up and lay them down."

Many factors determine milk yield besides just rations. Non-dietary factors such as feed push-ups, feeding for a refusal rate of five percent, stall design and management and age at first calving are have a major influence.

There are three things a cow should be doing: She should stand to be milked, stand to eat and drink, and lay down. If she's doing one of these things she's making you money.

The Three Circles of Excellence

A simple thought to help dairy operations to be as efficient and profitable as possible, is to break them down into "circles." Understanding the cycles and circles of dairy farming on any size operation can find the bottlenecks in the operation. A bottleneck is a point of congestion, the limit of constraints or blockage which keeps an operation from its highest potential.

There are three circles on every dairy farm that need to be understood for bottlenecks to become apparent.

The Daily Circle. The first cycle is the 24 hour circle, or what does a cow does during the course of a day. When planning facilities the designer should consider a cow's daily life (Figure 1.)

- When and how often is she milked?
- How long does she spend in the holding pen and parlor?
- How long is she locked up for breeding?
- When is she fed? When does her feed arrive and how long is the manger empty?

All of these questions are easy to answer when we know the 24 hour circle of a herd or pen of cows. Also, take a close look at what 24 hours look like in the life the dry cows and heifers. LDHM 2017

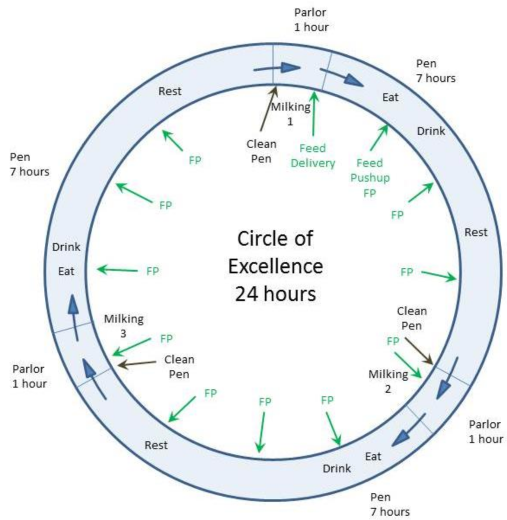

Figure 1. Circle of Excellence 24 hour Time Budget of a Milking Cow, FP = feed push-up

The Annual Circle. In addition to looking at the cows' typical day, consider what her year looks like (Figure 2.) This second circle starts at the maternity pen. Another way to ask about the circle is how does the recently freshened cow get back to the fresh pen a year later? The questions about the annual circle might look like these:

- Where does she freshen, when is she moved into the fresh pen, how long is she in the fresh pen, when is she moved into the breeding pens, when does breeding start, when does breeding stop, how many rations does she get fed?
- When is she dried off, how long is she dry, how many dry cow rations is she fed, what are the rations?
- How is the beginning of labor detected, when is she moved to be by herself to calve?
- How often does she experience pen/ group changes? Cows lose up to six pounds of milk a day for two to three days every time they change social groups. (Shaver & Zwald, 2012)
- How often is her milk cow ration changed?
- When is she bred?
- How long is she dry?

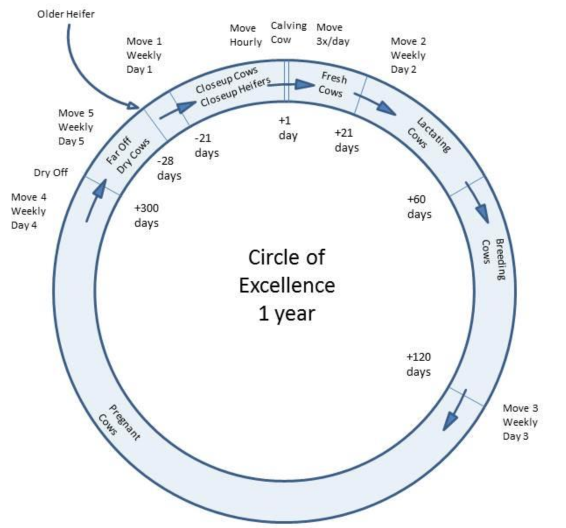

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Figure 2. Circle of Excellence Annual Cycle of a Cow's Life

Calf to Fresh Cycle. The third circle also starts at the maternity pen and belongs to the calf. (Figure 3) Instead of looking at a year, this circle looks at the first two years of life, beginning at calving. Questions include:

- When is she fed colostrum, how much colostrum is she fed, where is she housed and fed until weaning, how many calves are together in the weaning pens?
- What is she fed, when is grain introduced, how many heifer rations is she fed, where is he housed until breeding age? When are water, forages and fermented forages introduced?
- When is she bred, is she bred by size or age or both?
- When does she move into the close up pens, how is she handled at calving for the first time?

Think about those three circles on all sizes of dairy farms. If the circles are fully understood, bottlenecks blocking the operation's potential can be identified and corrected. Any size dairy farm can be more easily understood when analyzing the circles of excellence, and large operations may not seem as overwhelming.

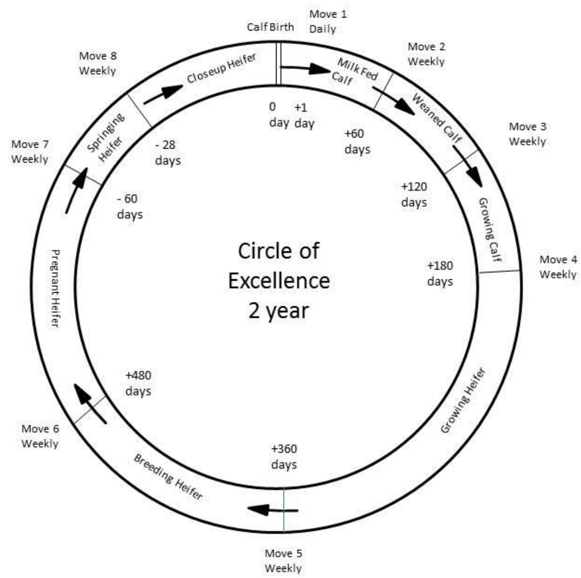

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Figure 3. Circle of Excellence 24 month Cycle of the Replacement Calf

Common problems. She should not be spending more than four hours a day away from food. The producer gets four hours a day; the cows get the other 20. The four hours away from feed also needs to include such things as sorting pens, holding pens, breeding time, hoof care, palpation rail time and other herd health.

One of the most common failures on farms is not making sure that cows have at least half of their dry matter intake when they exit from morning milking. And it is very important to feed the best feed to your best cows. Silage loses quality when exposed to the air, so the first feed mixed in the morning should go to the low production pen, then, the fresh cows can have the freshest feed that morning.

The ancestors of the modern cow were prey. Cows are designed to eat as much as they can first thing in the morning, and then moved to a safe location to lie down and chew her cud.

Another common mistake is not having enough waterers in freestalls; many freestall designs have three waterers when there really should be four. If there are more than 100 cows in a barn they typically divide into two social groups and each social group should have two waterers.

Freestall design is crucial. The main four reasons for “freestall fails” are lack of cushion, neck rail placement, lunge and bob space limitations, and lack of fresh air/ vision.

Freestall design include 48” (122cm) wide stalls, neck rail 48” (122cm) above the height of the back curb, neck rail that is 68” (172cm) from back curb to contact of neck rail, 16’ (5m) from curb to curb “nose to nose,” 68” (172cm) to brisket board, and two inches (5cm) above back curb for brisket board.

Wider stalls are often not better because cows lie diagonally in the stalls. They then defecate on the stall instead of the alley and lie in their own waste.

If the cows are lying diagonally, the set up can sometimes by corrected by putting 2x4s on the side rails to prevent the cow from putting her head through.

If a 30” (76cm) loop is used with forward lunge, width is not as important, but a 39” (100cm) loop from top to bottom, lets the cow lay diagonally and may need some modification.

Bedding must be maintained level with the curb for the curb width to be “useable.” Once the bedding drops below the curb and useable bed length becomes 8 to 10” (25cm) shorter, which is unacceptable to the cow.

A person should be able to fall to their knees in the area where the cows lie down and not experience pain. If it hurts to do that then the cow needs more padding and/or bedding.

Lack of fresh air can also be an issue. Something as simple as weeds being allowed to grow tall alongside of a building can disrupt air flow.

Do not underestimate the value of standard operating procedures (SOP). Everyone should know and understand their job, and everyone should be required to pass an exam (oral or written) about their job and how to do it. When people know their jobs they will be happier at their jobs.

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The U.S. and World Milk Price Outlook: An Improving Prospect?

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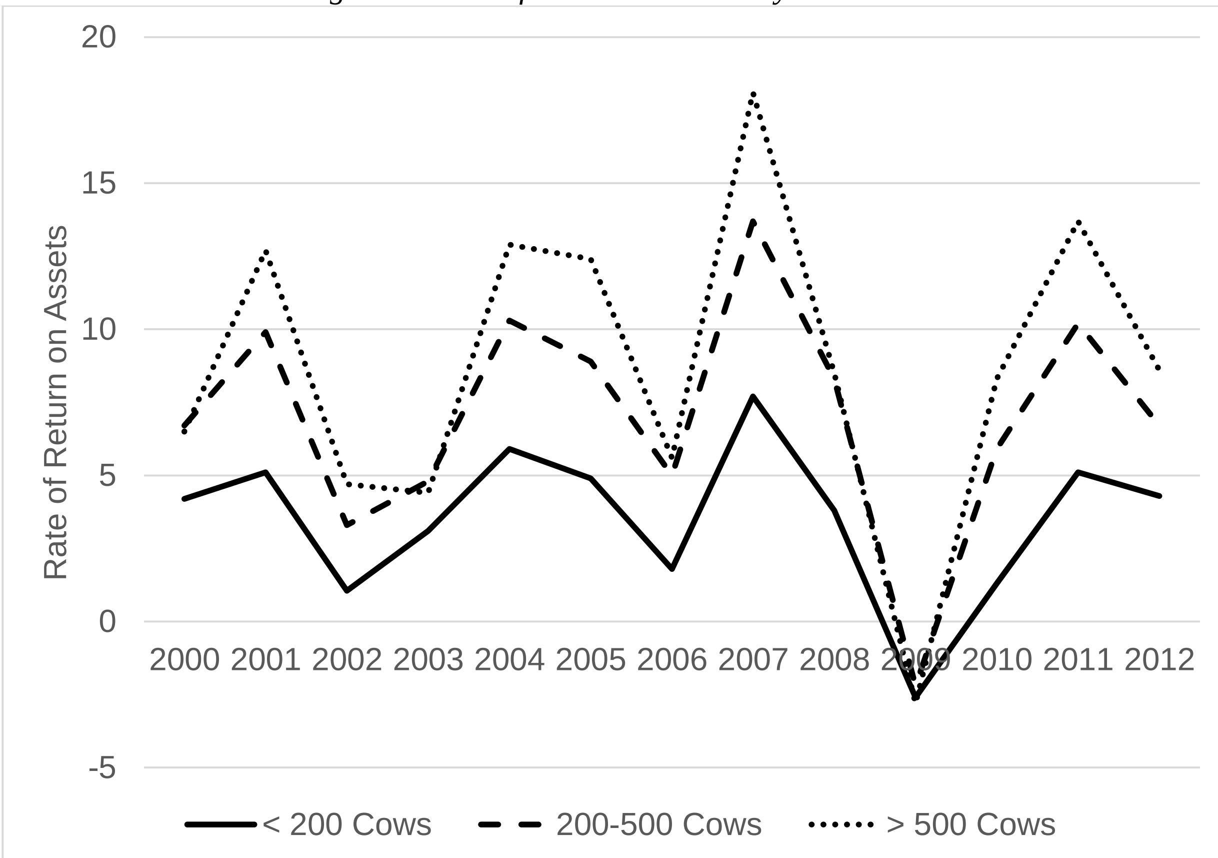
There is an unending curiosity about milk price forecasts, and I think, rightly so. Having some knowledge about income in the year ahead may help to plan production targets for your operation and certainly, cash flow projections will help with investment decisions.

Before about 2005, the U.S. was relatively isolated from imports and export opportunities of dairy products—both represented about 3-4 percent of U.S. production. An active price support program also suppressed milk price volatility through the mid-1990s until that program was first diminished in effectiveness and later repealed. Prior to this time milk price forecasting was both easy to do and relatively uninteresting.

The volatility of milk prices and the uncertainty of profitability have created much more risk in the dairy industry, but with the additional risk also comes the possibility of greater rewards for those who manage the business well. My colleagues and I have recently conducted a study of farm level financial data from three major dairy states—Wisconsin, New York and Michigan. These states have a diversity of farm sizes and business models and we tracked about 12,000 annual data records of the same farms over more than a decade of observations. One of the interesting conclusions was that all farms suffered similar low rates of return on their businesses during low profit years, but in years with high prices, larger farms tended to experience much better return on investments than smaller farms did. I.e., better management practices yielded better rewards in the good years (Figure 1).

Figure 1. Rate of Return on Assets by Herd Size.



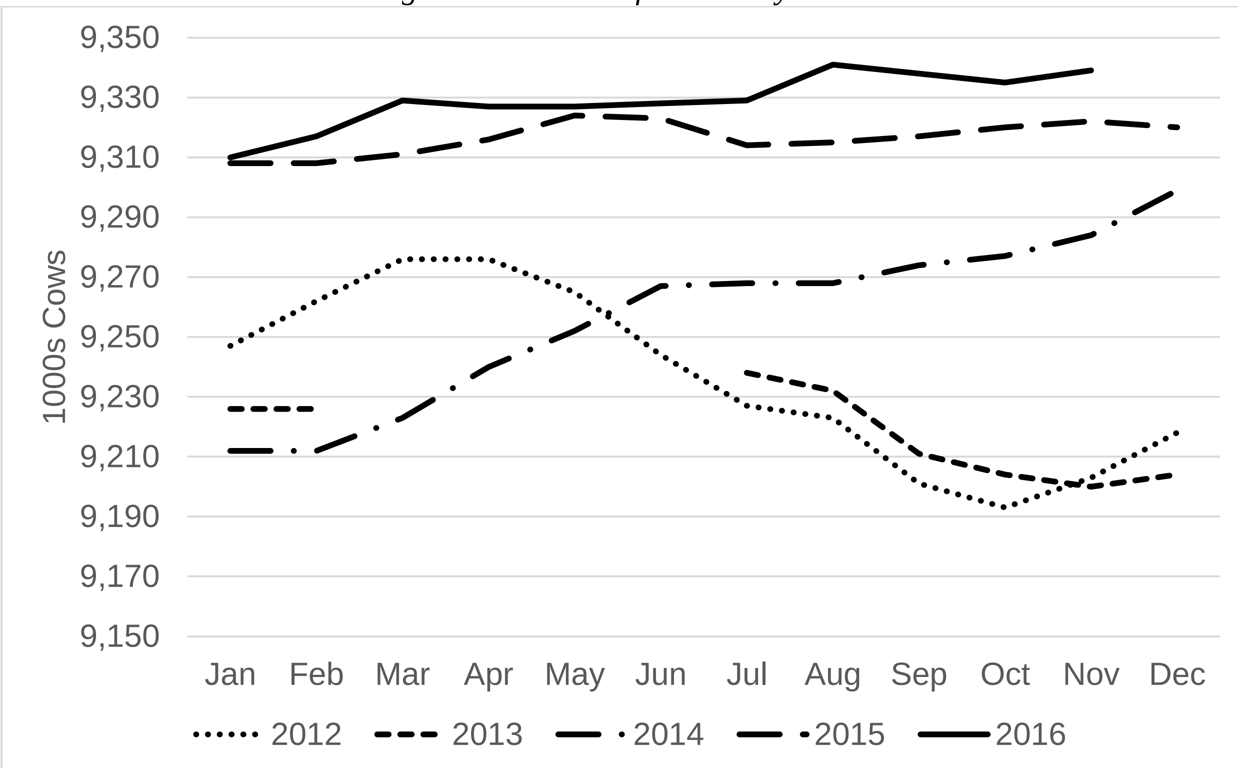
Milk Price Cycles

Milk price volatility has developed a cyclical nature. Spectral decomposition of the wave elements of price shows that there is clearly an annual cycle which corresponds to the continued seasonal nature of milk production and a seasonal demand that is almost counter-cyclical to milk production. I.e., milk production still has a spring flush and a fall short season while demand declines when schools recess for summer but accelerates in the fall from Thanksgiving through the Super Bowl. This basic annual pattern has been the same for about the last century.

The cycle that is newer and much more impactful is one that is about three years in length. The length has varied a bit from about 33 months to nearly 44 months over the last 15 years, but it has averaged close to 36 months from peak to peak or trough to trough during that time. While the causes of the seasonal cycle are well explained, the causes of the three year cycle are less well understood.

A big milk price, like dairy farms received in 2014, is a market telling producers that it wants more milk, and the price provides not only the signal but also the wherewithal to increase milk production. Some of the milk production happens because cows are fed a more concentrated diet and we get a bit more milk per cow, but we also tend to keep cows in the herd that we might have culled in other circumstances. We may also raise heifers from more marginal cows and generally, the U.S. herd size increases over several months. We can see this happening in the number of cows in the U.S. in 2014 (Figure 2).

Figure 2. Number of U.S. Dairy Cows.



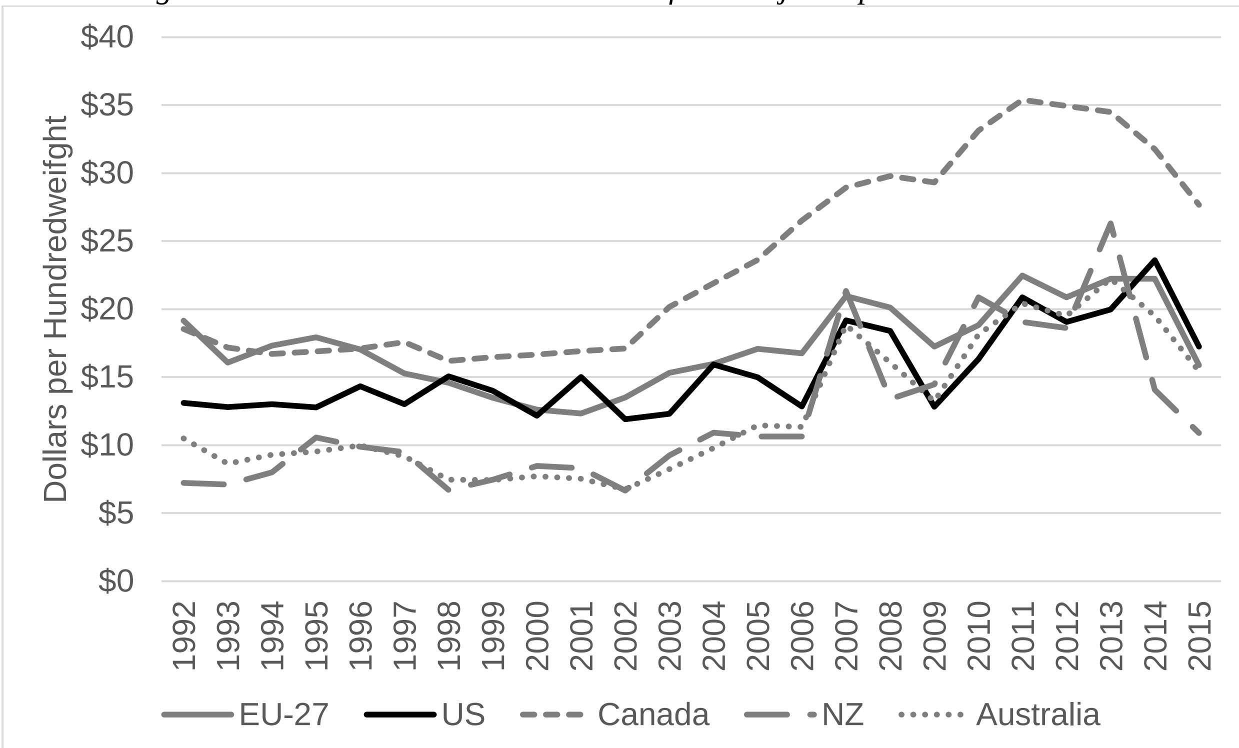
By the time the extra heifer calves are raised, bred and brought into the milking herd, the independent decisions of 40,000 U.S. dairy farms has a tendency to over-shoot the demand for dairy products. This then leads the market place to send the next signal to farms to reduce production by presenting them with a low milk price as was the case in 2012 (Figure 2).

These lags between the perceived need for product and the too-much, too-late delivery is a classic example of an uncoordinated supply chain causing price cycles and the volatility that we have seen in the last couple of decades. This has more recently been complicated by the emergence of the U.S. as a major exporter of dairy products.

Dairy Exports

When the U.S. imported and exported about 3-4 percent of its milk supply, we had the luxury of ignoring what was happening in the rest of the world. Our domestic dairy industry was a fairly closed system. But, we have grown to be the third largest exporter of dairy products after the European Union and New Zealand which brings new opportunities but also new complications. If we are going to export dairy products, then we must be price competitive with other exporting regions or else countries wanting to import dairy products will source them from other sellers. In 2007, the four major dairy exporters achieved convergence of farm gate milk prices and they have tracked closely together in most years since that time (Figure 3).

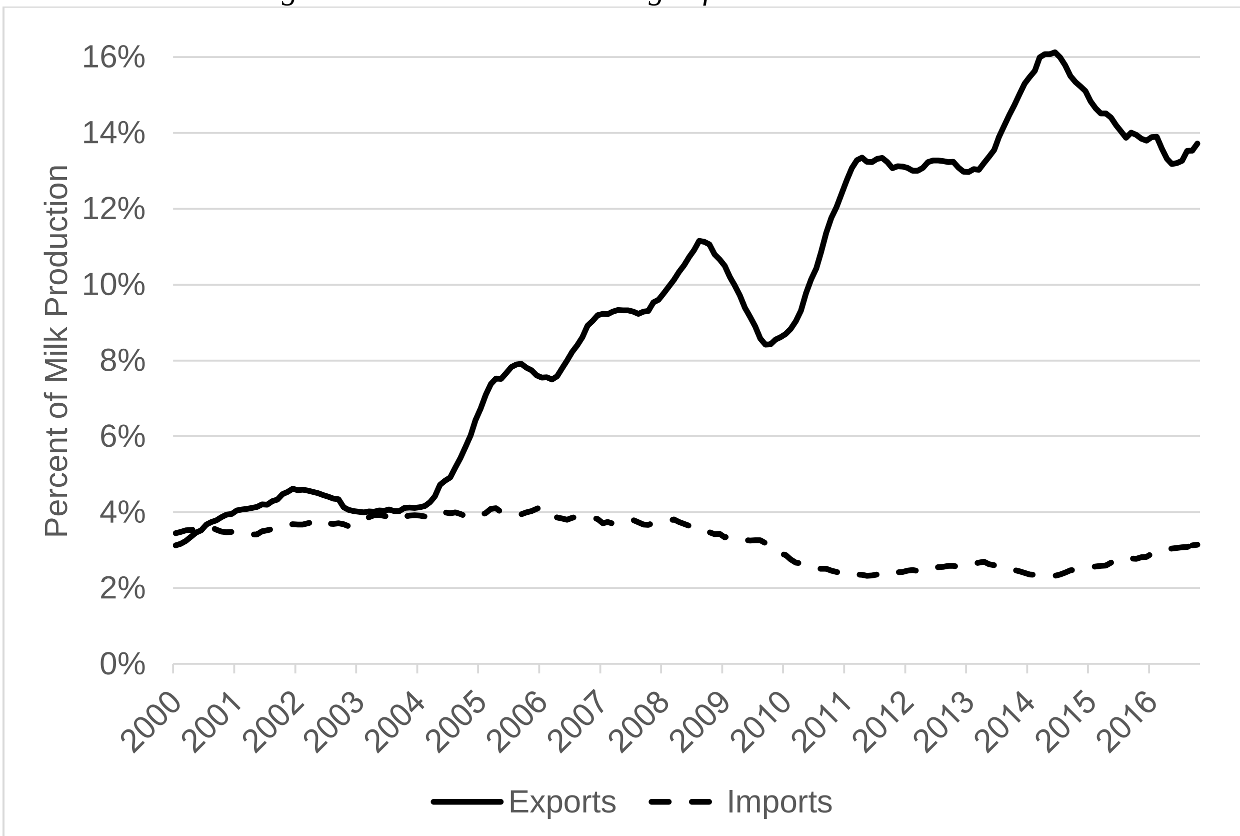
Figure 3. Annual Farm Gate Milk Prices from Major Exporters and Canada.



U.S. milk production per cow is a long and remarkable trend in increased efficiency. This very linear increase of about 284 pounds of milk per year shows no sign of either slowing down or speeding up to any significant degree. The highest yielding cows are now capable of producing more than 70,000 pounds of milk per year which is well above the U.S. average of about 23,000. Although there must be an upper limit to milk yield per cow, this difference suggests that there is still a good deal of room for the trend to persist. About half of the increase can be attributable to better selection of genetics and the other half to better management of the cow. However, this trend does have implications for dairy markets.

The average increase in milk per cow was outgrowing the average increase in per capita consumption of dairy products and our population growth. The implication is that we simply didn't need as many cows to support our domestic demand for dairy products. With the convergence of milk prices across the globe, we could find new demand for dairy products outside the U.S. and support continued higher levels of milk production.

Figure 4. Trade as a Percentage of U.S. Milk Production.



In about 2005 we began to export more significant quantities as our dairy product prices converged with the other exporting countries. Export trade has increased fairly steadily since that time reaching a high of about 16 percent of milk production. There have been a couple of notable exceptions during 2009 and the last two years.

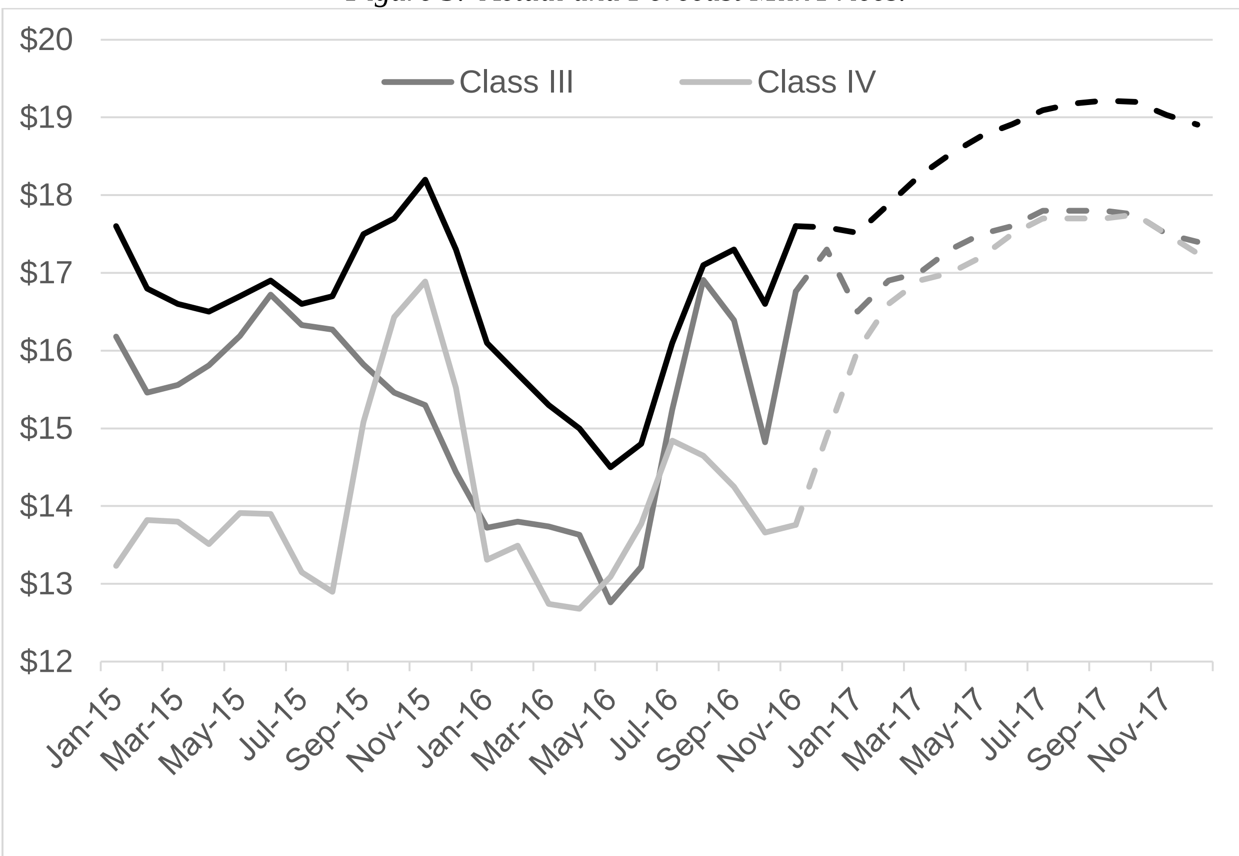
The world slipped into a global recession in the last quarter of 2008 and most of the countries where we had found export sales simply couldn't afford to purchase as much as they had been. The loss of export sales amounted to about 2 percent of our milk production and the extra product stayed in this country. The U.S. was also in recession and selling the extra dairy products into our relatively poor domestic economy only happened at the very low prices of 2009.

We also lost sales of exports over the last two years; in fact, about the same amount as in 2009. However this time the product stayed into what has been a recovering and almost robust domestic economy. Farm milk prices have been depressed in 2015-16, but not nearly by as much as they were in 2009. Per capita domestic sales of cheese hit all-time highs in 2016 and butter sales have been higher than they have been in decades. Even fluid milk sales have recently seemed to stop their decline and sales of whole milk have been particularly strong. The medical community has declared a truce in the war on butterfat.

Outlook for Dairy Prices

Milk prices hit their low point of the current cycle in May of 2016 and have been recovering since that time (Figure 5). I am forecasting continued price recovery through 2017 at a fairly steady pace with a plateau for the second half of the year. For your budgeting purposes, the 2017 U.S. All Milk price will average about $2.50 higher than the average for 2016.

Figure 5. Actual and Forecast Milk Prices.

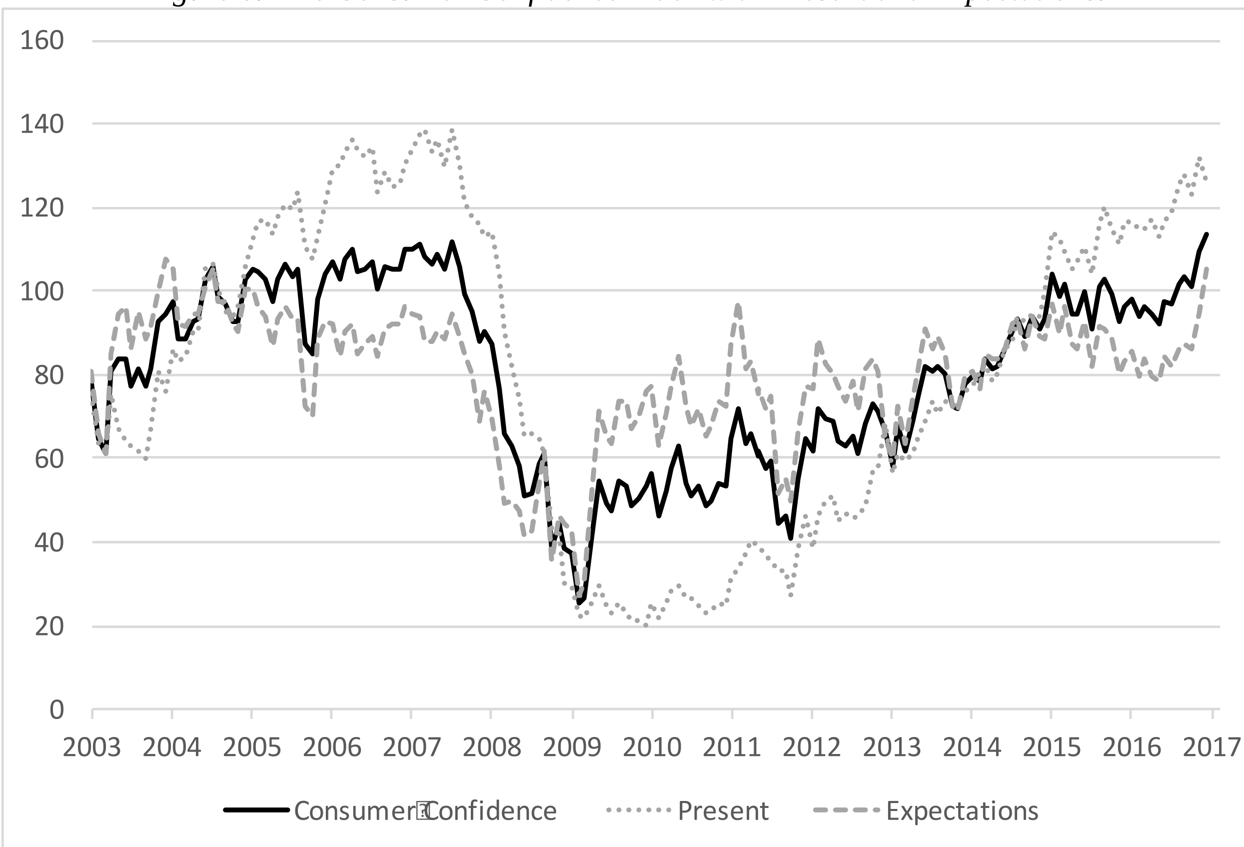


I come to this price forecast with the assumption that our domestic economy will continue to remain strong. The U.S. is basically at full employment now and other measures such as Leading Index for the United States, or the ISM Purchasing Managers Index are all indicating strength for the economy.

The Consumers Confidence Index is also supportive of a strong economy. This index is composed of two sets of questions that are asked of survey respondents monthly: one set is the Present Situation—"how are you feeling about the economy today", and the other set is the Expectations—"what do you think about the economy in the near future". The Confidence Index itself is just the average of the present and the expectations responses but we can often learn quite a bit by looking at the detail beneath the composite index.

Notice with the Confidence Index (Figure 6) that in 2008 consumers were saying two things: "the present situation is excellent but I'm concerned about the future". When this happens, consumers get conservative and begin to use caution with their spending—they put off buying a new car and they don't go out to eat as much, etc. In an economy that is largely driven by consumer spending, this begins to be a self-fulfilling prophecy about the future. This, and other circumstances drove the economy into the recession of 2009 which, as I've said, had implications for milk prices too.

Figure 6. The Consumer Confidence Index with Present and Expectations.



Through the depths of the recession in 2009-11, consumer response was basically saying "it's awful today, but I'm optimistic about the future". And this optimism began to pull us out of the recession and into the recovery that we enjoy today. Fast forward to 2015 and you can begin to see the divergence between the assessment of the present and the future that drove us into the last recession. I'm not forecasting recession in 2017, but I am urging that we keep our eyes on the consumer to make sure that we aren't caught unaware of consumer pessimism again.

What Could Change My Forecast?

Currently, the market appears to have optimism about the new Congress and the incoming Administration. I hope that optimism holds but it seems to me that there are more unknowns about what the actual changes in policy will be than in many past elections. If consumers begin to become pessimistic about the future, then we could well slide into a softer economy and one that doesn't support strong sales of dairy products.

I think that foreign markets hold more of the key to a different milk price outcome than our own domestic economy does. China seems to be showing signs of buying more dairy products again.

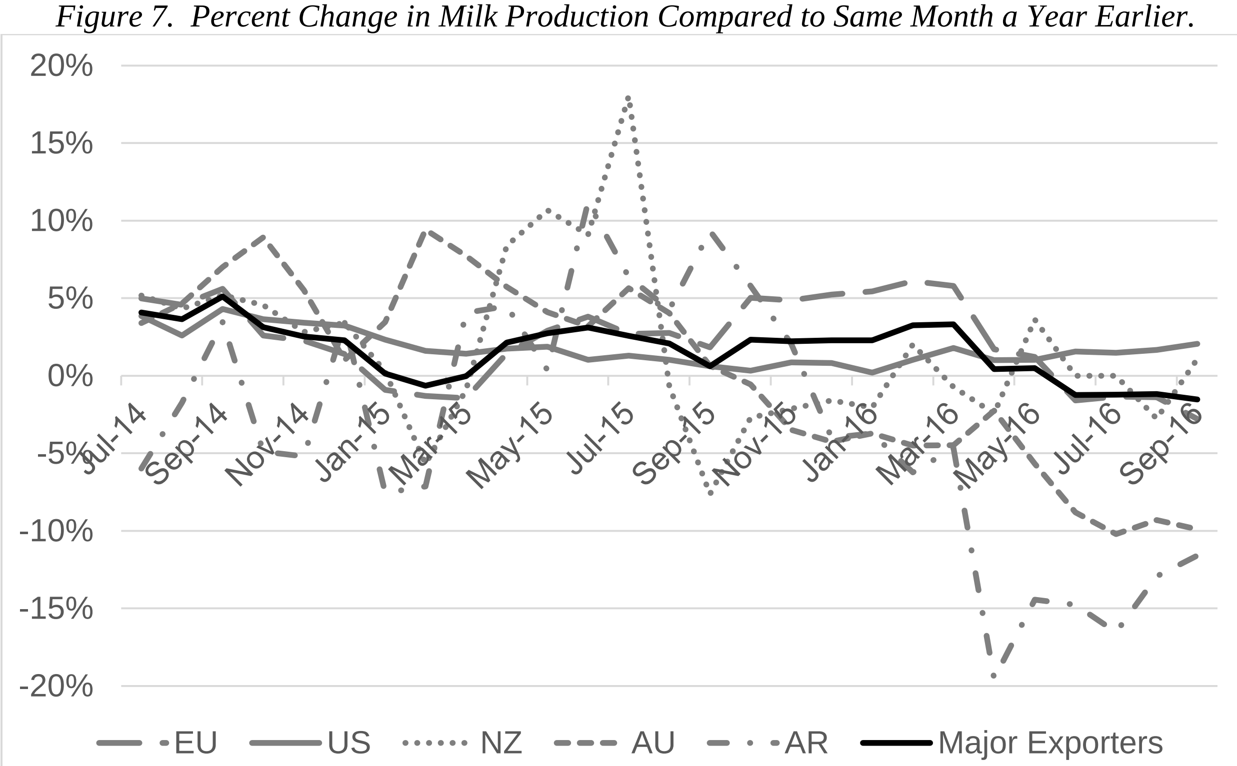
Their purchases of milk powder in late 2013 and early 2014 were primarily what led to the surge in milk prices for us in 2014. We also think that other Southeast Asian country demand will strengthen in the new year with India perhaps emerging as a new importer of dairy products. But to me, it is the exporting countries of the world that hold the key to the future of milk prices.

The European Union has been the largest exporter of dairy products for many years. The EU exports were surpassed by New Zealand for a recent few years but not by much. Europe's agricultural policy revoked long-standing milk production quotas in April of 2015. Many of the countries of Europe were under constraint in milk production because of the quotas and several of the countries exploded into growth when the quotas came off. Notably Ireland, the Netherlands and Germany—some of Europe's larger milk producers—increased production significantly throwing the world into a surplus of dairy products and the subsequent price depression we have recently been working our way through.

We began to see that low milk prices were having an impact on producer choices of output. In about April of 2016, growth in world milk production was less than the growth in demand for dairy products allowing the world to begin to pull down some of the surplus stocks that were weighing on prices. By May, it was obvious that world milk production would be negative and allow a faster draw-down of stocks. This was when we saw some of the first increases in product prices as buyers wanted to secure stocks at a time when prices were at their bottom.

By the end of 2016, only the U.S. had modest growth in milk production of the top 5 exporting countries (Figure 7). By June of 2016, the major exporters of the world were producing less milk and dairy products than in the previous year.

Figure 7. Percent Change in Milk Production Compared to Same Month a Year Earlier.



New Zealand, Australia and Argentina are all southern hemisphere countries with a predominant grazing and seasonal calving business model. All of these countries are well into their production season and will not make changes in stocking rates until the beginning of next year's production cycle. Europe may show some urge to grow as prices improve, but I think there are some other constraints that will hold them back.

The Netherlands has implemented a restriction on phosphorous application to their limited land mass. This is likely to reduce the dairy herd in that country by more than 100,000 cows. As milk prices declined, producers in several other countries of Europe bred dairy cows to beef bulls to search for profit in a different market. The calf crop of beef animals will play out over the next couple of years also limiting milk production potential. It is likely that milk production in the major exporting countries will be somewhat slow to respond to improved profitability in 2017.

The next major spike in milk prices will likely happen when dairy buyers around the world realize that stocks are getting tight. I believe that there is a chance that could happen by the fourth quarter of 2017 or possibility on into 2018. That would make our current cycle one of the longer cycles (from peak to peak) that we have seen but not out of the range.

In Summary

2017 will be a year of recovery for dairy farmers around the world. Milk prices have been low for the better part of two years and most producers have put off major reinvestment of their capital assets for those years. Milk prices for the year should average about $2.50 above the 2016 levels with greater price gains possible by the end of the year. This improved profitability will show up more markedly on the bottom line of the better producers across the country as a higher return on assets. I also expect that class III and IV milk prices will converge again, improving milk prices to western U.S. dairy producers where more butter and milk powders are manufactured.

As dairy buyers around the globe are looking for product, the U.S. will be in good position to supply some of those needs. This will put our export sales back on track to represent a greater proportion of our milk production. However, our competitors around the globe will not let us grab market share without a struggle. Expect them to chase a high price—the market signal that the world wants more milk. This of course will ultimately lead to over production and the cycle returns again.

Understanding Inflammation and Immunity to Improve Transition Management

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Take-Home Messages

- Impairments in immune function and a pro-inflammatory state coincide at the start of lactation in many dairy cows, and are associated with greater risk for disease.
- A growing number of feed and pharmaceutical products are offering a variety of means to attempt to enhance immune function in the transition period, and other tools are being tested for limiting inflammation during the transition period.
- Post-calving anti-inflammatory treatments can, in some cases, dramatically increase milk yield over the entire lactation.
- Inherent links between inflammation and immunity raise important questions about whether dairies can “have their cake and eat it, too”, by improving immunity while avoiding inflammatory condition. These questions are still being resolved; however, several studies point to the suggestion that net benefits on health and productivity can be achieved.
- It is likely that some herds may benefit most from anti-inflammatory strategies, while others may benefit most from immune promotion tools. To date, there has been essentially no research on combinations of these strategies.

Why worry about immunity?

Large-scale analysis of dairy herd records suggests that, around the globe, transition cow problems account for over half of mature animal health problems on a typical dairy farm. There are some factors that are obvious risks to cows immediately after calving, including the potential for latent mastitis cases to re-emerge at the onset of lactation and the tissue trauma from calving. However, there is also a well-documented alteration in immune function during the weeks around calving (Kerhli, 2015). In particular, the function of innate immune cells seems to be consistently impaired. Innate immune cells are those involved in quick recognition and clearance of pathogens, independent of pathogen-specific memory (antibodies).

Why is the immune system of transition cows suppressed? The exact reasons for decreased immune function during the transition period are complex. However, studies with mastectomized cows made it clear that the primary driver is not gestation and calving, but rather lactation and the metabolic changes that come with it (Nonnecke et al., 2003). Numerous large studies have demonstrated that metabolic diseases (e.g. ketosis) put cows at higher risk of contracting clinical infections; likewise, cows with infectious diseases (e.g. metritis) are also at higher risk of subsequent metabolic disorders. The inter-dependent nature of the immune and metabolic systems in the animal are only now becoming clear, but high blood ketone and non-esterified fatty acid concentrations as well as hypocalcemia are known to limit the responsiveness of immune cells to pathogenic signals. Cows with excessive body condition experience more dramatic drops in immune function at calving, possibly as a consequence of oxidative stress. As a result, nutrition of the transition cow can have a large influence on immunity during this time, even beyond the vitamins and minerals that have received focus in the past.

There is some direct evidence that poor immune responsiveness in the transition period is predictive for incidence of infections during this time. In one study, 5 of 31 cows were identified as poor immune responders 4 weeks before calving. All 5 of these cows developed clinical infections during the first 2 months of lactation, whereas only 3 of the other 26 cows did so (Catalani et al., 2013). It is likely that the high rate of infections in early lactation can be attributed in part to immunosuppression.

What does inflammation have to do with transition cows?

Inflammation is a key component of the immune response to infection or tissue damage. Immune cells that first sense pathogens or signs of traumatized cells release signals that activate pain sensors, promote blood flow to the local tissue, and cause fever, accounting for the traditional signs of inflammation. Additionally, the systemic effects of inflammation include an alteration of liver function, typically called the acute phase response. Most of these responses are beneficial for recruiting innate immune cells to the site of immune activation and for inhibition of bacterial growth, but they come at a cost to the animal. Importantly, inflammation can occur in the absence of a true pathogen challenge and can occur without the traditional signs of focal pain, swelling, and redness. When blood markers of inflammation are elevated in the absence of clinical signs, it is often referred to as sub-acute inflammation.

The presence of an acute phase response in postpartum dairy cows is well-established (Bradford et al., 2015). Although early studies focused on associations between inflammatory markers and diseases such as mastitis and metritis, numerous studies in the past decade have demonstrated that inflammatory and acute-phase mediators are elevated in the days after parturition, even in cows that are apparently healthy. This growing body of evidence suggests that either the processes of parturition and galactopoiesis induce inflammation directly or that infections or endotoxin affect far more fresh cows than is currently recognized. Whatever the explanation, the prevalence of post-calving inflammation raises important questions about the implications for early lactation cows.

Although most transition dairy cows apparently experience a period of inflammation, the magnitude of this inflammatory condition varies greatly between cows. Bertoni et al. (2008) assessed the importance of this variation by measuring a panel of inflammatory markers and separating transition cows into quartiles for degree of inflammation. Cows in the highest quartile had significantly lower milk yields than those in the lowest quartile throughout the first month of lactation, differing by 20% on day 28 of lactation (Bertoni et al., 2008). One metric that has been used in this respect is paraoxanase, a plasma biomarker that is potently suppressed by a variety of inflammatory stimuli. Transition cows with high paraoxanase concentrations, in addition to having lower concentrations of acute phase proteins and reactive oxygen metabolites, produced 4,346 lb more milk (24%) over 305 days than those in the lowest quartile for paraoxanase (Bionaz et al., 2007). Other findings suggest that stronger inflammatory responses in the first week of lactation are associated with decreased whole-lactation milk yield (Huzzey et al., 2015). Plasma concentrations of haptoglobin (an acute phase protein) greater than 1.1 g/L were associated with a 2,088 lb decrease in 305-day mature equivalent milk yield, and elevated haptoglobin was also associated with a 19% decreased risk of conception. Abnormally high markers of inflammation are associated with poor production, health, and fertility outcomes.

Immune promotion tools

With the growing interest in animal characteristics influencing infection risk, a number of factors have emerged as important for supporting strong immunity. Data currently available suggest that cows have improved transition immune function when: 1) they are not exposed to significant heat stress during the dry period; 2) they calve with a BCS ≤ 3.5; 3) they are supplemented with antioxidants during the dry period; 4) total serum calcium concentrations are maintained near 9 mg/dL, and 5) blood BHBA and NEFA concentrations stay below 1 mM during the transition. Considering the immune system of the transition cow does not necessarily require a change in recommendations for management during this period, but can provide additional motivation to prevent heat stress, provide sufficient access to feed, manage body condition, support calcium homeostasis, and monitor oxidative balance.

Beyond these best practices for transition cow management, a variety of dietary and pharmaceutical products are being marketed for the explicit purpose of improving immune function. Vaccines have obviously been a very useful tool in promotion of adaptive immunity for decades, and the ongoing development of a vaccine against metritis-causing pathogens may soon bring a new weapon to bear on a frustrating problem (Machado et al., 2014). On the other hand, pharmacological tools for promotion of innate immunity have not been available for livestock until very recently. Granulocyte colony-stimulating factor (GCSF) is a signal used by the immune system which has been adapted into an injectable prophylactic treatment used prior to the period of immunosuppression. The GCSF treatment stimulates the development and maturation of neutrophils, resulting in a fairly dramatic increase in the population of these key innate immune cells in circulation. In conditions favorable to environmental mastitis, the administration of GCSF significantly decreases the incidence of clinical mastitis (Hassfurther et al., 2015).

Dietary agents are also being used as immune stimulants, although the exact modes of action for these feed additives are more elusive. We recently reported that a dietary yeast product enhanced antibody response to vaccination and stimulated greater gut release of IgA, which is able to bind to and carry pathogens out of the gut (Yuan et al., 2015). A large-scale analysis of commercial farm responses (off-on) to a different feed supplement was presented recently, suggesting beneficial effects on farm-recorded mastitis and mortality (Chapman et al., 2016). Such dietary components can likely alter the responsiveness of the immune system by interacting with immune sentinels lining the gut and/or by altering gut epithelium function, but other mechanisms cannot yet be ruled out.

Responses to anti-inflammatory treatments

Motivated by evidence linking early lactation inflammation to decreased health and productivity, we conducted a study with 78 cows assigned to either control or sodium salicylate delivered via drinking water (2 g/L) for the first 7 days of lactation (Farney et al., 2013). Sodium salicylate is a member of the non-steroidal anti-inflammatory drug (NSAID) class, and is the parent compound of aspirin. At first the results did not look very promising, with no improvement in metabolic health and no increase in early milk yield. However, as lactation progressed, the oldest cohort of cows treated with salicylate (those in parity 3 and greater) responded by producing 21% more milk over the full lactation, and fully 30% more milk fat, than parity-matched controls. On the other hand, primiparous cows treated with salicylate tended to produce less milk, suggesting a potential parity difference in either baseline inflammatory status or response to inflammatory signals.

We subsequently completed a follow-up study to evaluate whether postpartum treatment of multiparous cows could increase whole-lactation productivity of cows on a commercial farm. To facilitate treatment in a commercial setting, we shortened postpartum treatment to 3 days (sodium salicylate) or 1 day (meloxicam) and compared them to placebo treatments (Carpenter et al., 2016a) across 153 cows. Despite this very limited treatment window, cows treated with either NSAID produced about 10% more milk over the whole lactation compared to placebo. Over the 365 days following treatment, meloxicam also tended to delay removal from the herd based on survival analysis ($P = 0.06$; 30, 35, and 38 of 51 cows remained at 365 d postpartum for control, salicylate, and meloxicam, respectively). Meloxicam primarily affected early-lactation culling, and health records recorded by the farm suggested that metabolic disorders accounted for most of this decrease.

Several other groups in a variety of countries have failed to observe significant impacts of postpartum anti-inflammatory treatment on milk yield, and it remains to be seen whether a treatment paradigm can be found that is consistently effective. However, we believe that impacts on long-term milk yield likely require treatment relatively early after calving (though not before the placenta is cleared); that treatment responsiveness is not limited to cows with calving difficulties; and that milk yield must be monitored for at least 60 days into lactation to have a good chance to observe the impact of anti-inflammatory treatment.

The use of anti-inflammatory drugs to treat nonspecific postpartum inflammation is not currently approved. Therefore, it is worthwhile to consider whether some feed ingredients might offer the same anti-inflammatory benefits without the use of regulated pharmaceuticals.

Polyphenols are a diverse class of compounds found in nearly all plants in varying concentrations. Some polyphenols have been clearly shown to have potent anti-inflammatory effects, and a recent study demonstrated some exciting responses in dairy cattle during the transition period. Winkler et al. (2015) reported that cows supplemented with a feed supplement containing green tea and curcuma extract for the close-up period through 9 weeks in milk had decreased plasma NEFA concentrations after calving and produced approximately 10 lb/day more milk in weeks 4 – 8 of lactation.

A different nutritional approach to limiting inflammation is to use omega-3 fatty acids. These polyunsaturated fatty acids have well-described mechanisms underlying their anti-inflammatory effects, although efficiently delivering them to the small intestine is a challenge in ruminants because of ruminal biohydrogenation of dietary unsaturated fatty acids. Nevertheless, feeding whole flaxseed (omega-3 source) compared to sources of omega-6 fatty acids increased plasma glucose and decreased plasma ketones in fresh cows; more surprisingly, the anti-inflammatory omega-3 source resulted in greater phagocytic activity of circulating leukocytes (Gandra et al., 2016). Although this finding of improved metabolic and immune function is exciting, previous studies have reported indications of less responsive immune systems in cows fed omega-3 sources (Lessard et al., 2003;

Silvestre et al., 2011), and such findings are more in line with research in rodents. Perhaps the key to beneficial impacts of omega-3 fatty acids on both inflammation and immunity is an improvement in metabolic profile.

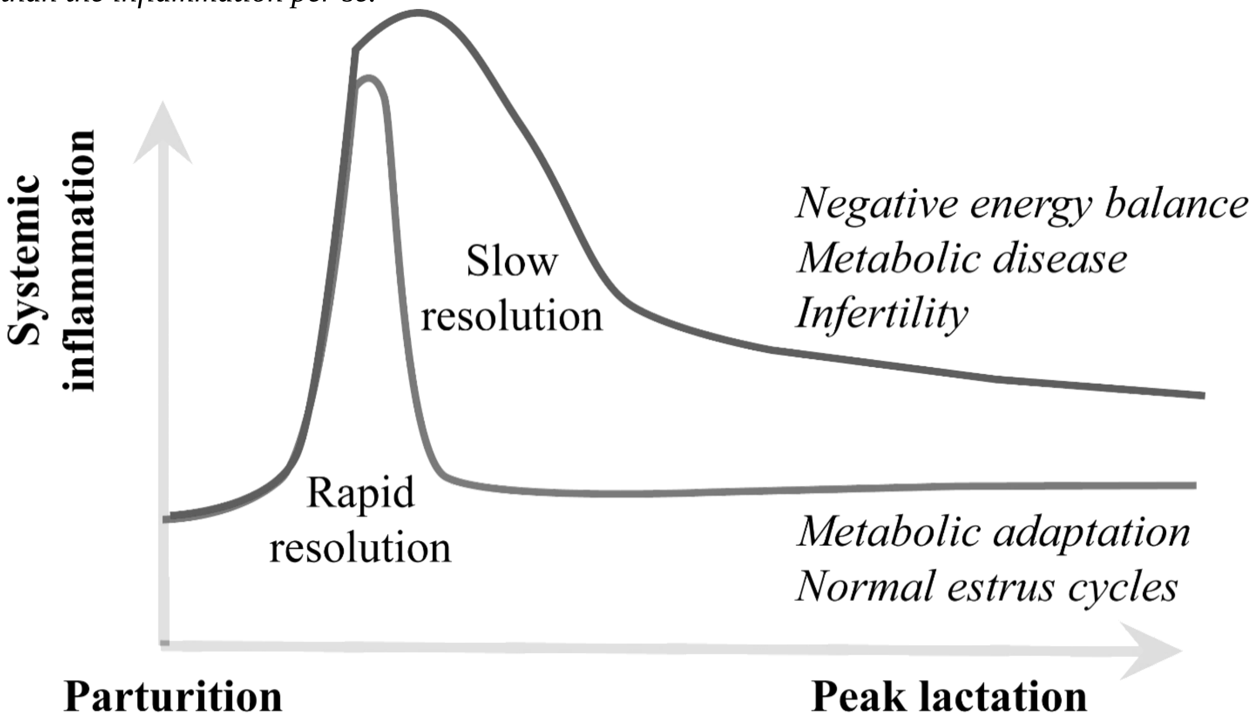
Is there an inherent conflict between promoting immunity and preventing excessive inflammation?

Because inflammation is a core component of the immune system's response to an infection, it is logical to ask whether anti-inflammatory strategies may worsen the immunosuppression that is already recognized as a problem in transition cows. In fact, Nightingale et al. (2015) demonstrated that transition cows with the most dramatic inflammatory profiles also had the most potent measures of neutrophil function. One interpretation of these findings is that transition cows are adapted to respond to immunosuppression with a compensatory inflammatory state.

Inherent conflicts between anti-inflammatory strategies and potent immune responses are also suggested by findings of increased infection rates following NSAID treatments in some small studies and greater mortality rates following pathogen challenges in mice genetically engineered to allow for endogenous omega-3 synthesis (Bradford et al., 2015). Likewise, dietary supplementation of an immune stimulant resulted in an increased acute phase response to endotoxin (Brandão et a., 2016), suggesting that at least some means of enhancing immunity will likely promote inflammation as well. Still, these results do not necessarily mean that a more appropriate balance cannot be achieved. In fact, the immune stimulant described above resulted in increased milk yield (Brandão et a., 2016), and as mentioned before, post-calving meloxicam treatment increased both milk yield and herd retention (Carpenter et al., 2016a).

One question that has not yet been addressed in observational studies is whether the pattern of inflammation impacts long-term outcomes. We hypothesize that brief spikes in inflammatory signals that are resolved in the first 3-4 days of lactation may support immunity and physiological adaptations to lactation. However, failure to rapidly resolve these signals may lead to a variety of adverse impacts that ultimately impair productivity, health, and fertility (Figure 1). We hope that new data will begin to address this question in the coming few years.

Figure 1. *Hypothetical impacts of brief, rapidly resolved postpartum inflammation versus sustained inflammation. It is proposed that lack of resolution leads to impaired health and productivity rather than the inflammation per se.*



Choosing the right strategy for each herd

In research with anti-inflammatory agents, there have been some marked differences across studies that, while not allowing strong conclusions, hint at predictors for success with these tools. First, treatment with Banamine shortly before and shortly after calving disrupted the normal process of calving and placental expulsion (Newby et al. 2017), resulting in increased incidence of stillbirths (if given before calving) and metritis (if given after calving). This particular approach to combatting calving-associated pain and inflammation is not advised until at least 24 hours after calving.

Second, we have seen variable milk production responses to NSAID treatment even when using identical strategies. Treatment with sodium salicylate for 3 days starting 24 hours after calving increased whole-lactation milk yield by more than 2,000 pounds in one study (Carpenter et al., 2016a), whereas in a follow-up study, we observed no milk response at all (Carpenter et al., 2016b). One potentially relevant difference between the cohorts in these two studies is that the responsive group had substantially greater post-calving inflammation, as the mean plasma haptoglobin concentration was more than twice as high in the responsive group compared to the unresponsive group on days 3-4 of lactation. Although we have been unable to demonstrate that individual cows with higher haptoglobin concentrations are more responsive to NSAID treatment, differences between these two studies seem to point in that direction.

Finally, it stands to reason that farms with very few infectious disease problems are less likely to have obvious benefits from immune stimulation. As a simple example, on-farm evaluation of responses to the dietary supplement Omnigen AF showed that decreases in somatic cell count after supplementation began were greatest in herds that started with relatively high somatic cells (Chapman et al., 2016).

Although there is little research basis for this suggestion, mechanisms connecting inflammation and immunity lead to the suggestion that cows in different herds may struggle with different mixtures of transition disorders because of imbalances between pro- and anti-inflammatory signals; excessive inflammation in some herds and inadequate immunity in others. Based on this logic, herds that have relatively high prevalence of infectious diseases in early lactation might be wise to focus on trying immune support tools in an attempt to enhance cows' abilities to combat pathogens. Conversely, herds with more metabolic disorders in early lactation should consider implementing anti-inflammatory management and nutritional strategies. Combinations of both types of supplements may or may not have additive benefits - these interactions simply have not been studied.

Conclusions

The growing number of tools available to aid cows successfully transitioning to lactation is exciting, but, as always, the devil is in the details. Several pharmaceutical and feed additive strategies have strong evidence for specific benefits, but individual farms differ in important ways that can lead to unique questions about secondary effects that are less clear. In particular, unresolved questions about tradeoffs between inflammatory status and immunity make it difficult to give one-size-fits-all recommendations when the transition problems encountered on one farm can differ so dramatically from another. Based on evidence available today, farms with more frequent infectious disease problems are encouraged to explore opportunities to promote immune function, whereas those with prevalent metabolic disorders should perhaps focus more on anti-inflammatory strategies. Research on combinations of such strategies are needed before recommendations can be provided with confidence.

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Serotonin: A New Approach for Hypocalcemia

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Serotonin regulates mammary gland physiology during lactation

Serotonin is synthesized in numerous tissues throughout the body and is incapable of crossing the blood-brain barrier. Serotonin is synthesized from the amino acid L-tryptophan in a two-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 bovine mammary gland epithelium expresses at least five 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 parathyroid hormone-related protein (PTHrP) production within the mammary gland in a rodent model (Hernandez et al., 2012; Laporta et al., 2013a; Laporta et al., 2014a,b). Furthermore, we showed that serotonin activates expression of various calcium (Ca) pumps and transporters in the mammary gland to stimulate transport of Ca from blood to milk during mouse lactation (Laporta et al., 2014a). Ca transport into the mammary gland is thought to occur through the Ca^{2+} influx channel (ORAI1) and subsequent pumping into the milk by the apical plasma membrane Ca^{2+} ATPase (PMCA2; Cross et al., 2014).

Current research in humans and rodents implicates PTHrP in the regulation of maternal Ca homeostasis during lactation. Our laboratory has demonstrated the necessity of serotonin for regulation of Ca transport in the mammary gland during lactation. We also showed that circulating serotonin concentrations post-partum are positively correlated with circulating Ca concentrations on the first day of lactation in dairy cows (Laporta et al., 2013b). Furthermore, we have demonstrated that serotonin is necessary for the production of mammary PTHrP during lactation. Mammary-derived PTHrP is critical for the mobilization of Ca from bone tissue to support lactation (Wysolmerski, 2010). 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 subclinical hypocalcemia (SCH) and clinical hypocalcemia (CH) in the U.S. dairy cow population.

Hypocalcemia and the Transition Period

The transition period (3 weeks pre-calving through 3 weeks post-calving) is an extremely critical time period in the life of the dairy cow. At this time, cows are highly susceptible to a variety of disorders that negatively impact the animal's health, and hence their overall production. Of particular concern during this time is the inability of the dairy cow 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 demand by the mammary gland 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 Holsteins (Oetzel, 1988; NRC, 2001). Hypocalcemia is associated with numerous other health disorders during this time period (Oetzel, 1988). Due to inadequate blood calcium concentrations at the onset of lactation, animals experience a range of clinical symptoms, depending on the degree of hypocalcemia (Adams et al., 1996). Clinical hypocalcemia (CH), or milk fever, is clinically defined as a total blood calcium level of less than 1.4 mmol/L, and subclinical hypocalcemia (SCH) defined as total blood calcium of 1.4-2.0 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 all dairy cows will develop clinical hypocalcemia in the United States (Goff, 2008). Recent data suggest that as many as 25% of primiparous and 47% of multiparous lactating dairy cows are affected by SCH and are at increased risk of culling (Reinhardt et al., 2011). Cows 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 a dairy cow be affected by an additional metabolic disorder or disease as a result of CH and/or SCH, costs increase substantially. SCH affects about 50% of second lactation and greater dairy cattle, and costs approximately $125/animal to treat. Overall, prevalence of CH and SCH are more common in Jersey cattle, likely due to their higher milk production per unit body weight (Oetzel, 1988). Typically, in order to compensate for decreased blood calcium, increased intestinal calcium absorption and/or calcium resorption from the bone must occur. Calcium resorption from the bone is the primary mode used during this time frame. Dairy cows, in particular, exhibit a delay in calcium resorption from bone.

Adequate circulating calcium concentrations throughout the transition period are necessary for productive lactation, but large quantities of calcium are lost from maternal calcium pools into milk and colostrum. Cows undergoing SCH are at a greater risk of suffering other health disorders including dystocia, retained placentas, displaced abomasums, uterine disease, mastitis, and subclinical ketosis during the peripartum period (Chapinal et al., 2011; Chapinal et al., 2012; Martinez et al., 2012). To illustrate the negative impact of SCH on other disorders, previous data has estimated that completely eliminating SCH from a dairy herd could reduce the incidence of metritis and puerperal metritis by 66.6 and 91.3%, respectively (Martinez et al., 2012). Furthermore, as stated previously, SCH predisposes dairy cows to other metabolic disorders and diseases during the transition period (**Figure 1;** DeGaris and Lean, 2008; Chapinal et al., 2011; Chapinal et al., 2012).

It is important to prevent SCH and CH because the early symptoms of milk fever often go undetected. Because the early symptoms of SCH and CH are short-lived, they are difficult to detect and treat therapeutically. The economic impact of hypocalcemia is enormous: considering the 9.2 million cows in the U.S. dairy industry with a cost of $125 and $300 per case of subclinical and clinical hypocalcemia, respectively, given treatments and lost milk yield, there is an estimated cost of $900,000,000 annually. Translating these numbers to the 1.27 million cows in Wisconsin, the annual average cost of hypocalcemia to a WI farmer is approximately $12,000 (Oetzel, 2013). While these estimates are purely economic, there are also animal welfare concerns, given that the cow may be unable to stand or walk until identified by the farmer. Potentially more troubling than the physical and economic ramifications of hypocalcemia is the fact that the subclinical form is nearly impossible to identify in a production setting, as cows do not display obvious clinical symptoms (Oetzel and Miller, 2012).

While there are prevention strategies currently utilized in the United States, they are often difficult to implement effectively. The primary target for prevention is through manipulation of the diet at the end of the dry period. The two major strategies are administration of low calcium diets (LCD) and adjustment of the dietary cation-anion difference (DCAD). Feeding of a LCD works by stimulating a transient hypocalcemia, inducing calcium resorption from the bone and increased absorption from the small intestine, in order to increase available calcium reserves (Horst et al., 1997). For the prevention of milk fever, a diet of 8 to 10 grams of calcium per day has been shown to have the greatest effect, but LCD with this little calcium are difficult to achieve mainly because the primary forage of alfalfa is quite high in calcium (Horst et al., 1997). Conversely, the strategy of DCAD manipulation is to increase availability of absorbable dietary anions and decrease the number of absorbable dietary cations through use of dietary anionic salts (Goff, 2008). While there is no doubt that this strategy aids in the prevention of milk fever (Charbonneau et al. 2006), there are two major concerns. The first is that the salts decrease palatability, reducing feed intake and predisposing the cow to other energy-related transition disorders. Importantly, new DCAD products are much more palatable than the original products developed. The second issue is that anionic salts are quite expensive, adding additional cost onto an already costly period in the cow's life. Additionally, the low DCAD diet is typically implemented during the 3 weeks immediately pre-partum, creating the need for two separate groups of cows in the dry pen. Further work has been done on vitamin D3 or oral calcium/metabolite administration, but these results are largely impractical and overly dependent on timing of administration (Martín-Tereso and Verstegen, 2011). Additional strategies are focused on administration of calcium boluses or gels post-calving as method to reduce CH and SCH. Recently, data has been presented demonstrating that using oral calcium boluses has differential effects on cows (Martinez et al., 2016a, b). Negative effects were seen in primparous cows, and rebound effects were noted when oral boluses were only administered on d0 and d1 post-partum (Martinez et al., 2016a). However, SCH was reduced and pregnancies per AI were improved in multiparous cows receiving 4 boluses, and further reduced when given 7 boluses of oral calcium (Martinez et al., 2016a,b). Another recent study providing one subcutaneous calcium injection post-calving resulted in only elevating calcium concentrations for 24 h post-treatment and had no significant effects on risk of disease or culling, milk production, or reproductive performance (Miltenburg et al., 2016). Based on currently available strategies to manage hypocalcemia, there is room to improve the health of these animals. Improvement of these prevention strategies depends on a solid understanding of the physiological mechanisms that govern calcium homeostasis in the dairy cow. Our lab has shown that manipulation of a key regulator of calcium dynamics, serotonin, may have significant impact as a novel therapeutic target in the prevention of hypocalcemia.

New ideas about calcium and serotonin

Our laboratory has 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 post-partum circulating serotonin, PTHrP, and Ca concentrations, and also increased total Ca 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 Ca mobilization.

Mammary serotonin production is a significant source of maternal circulating serotonin concentrations during lactation in mice

Using a mouse model in which we selectively deleted TPH1 in the mammary gland during lactation we revealed that the mammary gland is a substantial source of serotonin production during lactation. Serotonin is produced in many tissues in the body. Therefore, circulating serotonin concentrations are comprised of serotonin from numerous tissues. This allows serotonin to act in autocrine, paracrine and endocrine manners on the mammary gland during lactation. Dams lacking TPH1 in the mammary gland during lactation have an average circulating serotonin concentration on d10 of lactation of approximately 700 ng/ml, while the wild type counterparts average 1500 ng/ml (Weaver et al., In Review). Furthermore, when TPH1 is overexpressed in the mammary gland during lactation, maternal circulating serotonin concentrations increase to approximately 2000 ng/ml. These results support the hypothesis that serotonin production by the mammary gland is a significant contributor to circulating serotonin concentrations during lactation.

The onset of milk production drains Ca pools in dairy cows

Colostrum and milk synthesis rapidly depletes Ca from the maternal circulation and therefore Ca must be mobilized from maternal bone to maintain adequate circulating concentrations. Circulating Ca concentrations are tightly regulated and controlled by several hormones including: Vitamin D, calcitonin, parathyroid hormone (PTH) and PTHrP. Liberation of Ca from bone stores can only be triggered when circulating Ca concentrations dip below the animal’s minimal threshold for Ca, via a classic negative feedback loop. Dietary Ca is insufficient to maintain maternal Ca 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 as part of the normal physiological response to low calcium levels. Bone loss during lactation is an evolutionary strategy of mammals used to support the cow and specifically the mammary gland demand for Ca for milk synthesis (Wysolmerski et al., 1995; Wysolmerksi, 2010; Goff, 2014).

Our mouse studies revealed that serotonin is critical for the expression of key Ca sensors, pumps, and transporters in the mammary gland

Utilizing a mouse model deficient in TPH1 we investigated the necessity of non-neuronal serotonin in maintenance of maternal Ca homeostasis. TPH1-deficient mice have little to no circulating serotonin. We demonstrated that intraperitoneal injections of 5-HTP to these mice restored and even elevated circulating serotonin concentrations compared to wild-type dams. Our results also demonstrated that total Ca concentrations are decreased in TPH1 null mice and that Ca concentrations can be restored with intraperitoneal injection of 5-HTP (Laporta et al., 2014a,b). RNA-sequencing analysis of mammary glands collected on d 10 of lactation from wild-type, TPH1-

deficient mice and TPH1-deficient mice injected with 5-HTP revealed that serotonin is critical for the cellular response to Ca (Laporta et al., 2015). Upon further analysis of the specific Ca pumps and transporters present in the mammary gland we observed that mRNA abundance of several Ca pumps and transporters was reduced in the TPH1-deficient mammary gland and was restored by exogenous 5-HTP (Laporta et al., 2014a). These results indicate that peripheral serotonin is critical for maintaining circulating Ca concentrations and mammary gland Ca transport during lactation.

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 Ca into the systemic circulation (Wysolmerski et al., 1995; Wysolmerski, 2010). Normal calcium physiology is unable to be maintained in the classical fashion by parathyroid hormone (PTH). PTHrP is produced by the mammary gland only during lactation, allowing the mammary gland to act as an accessory parathyroid gland to support the homeorhetic process of lactation. The Ca sensing receptor (CaSR) present in the mammary epithelium plays a crucial role in controlling maternal Ca 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 Ca 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 Ca from bone during lactation to sustain maternal Ca homeostasis in rodent models (**Figure 2**). This occurs through induction of PTHrP 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 Ca concentrations and subsequent endocrine response that liberates bone tissue.

Mammary gland coordination with the skeletal system liberates Ca 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 Ca mobilization. PTH regulates this mechanism under <u>non-lactating</u> conditions. Research in humans and rodents has suggested the 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 Ca mobilization during lactation (Wysolmerski et al., 1995).

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 (d0 to d2 lactation), rebounding by approximately ten 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 dependent on stage of pregnancy and lactation indicating that serotonin may have different physiological functions related to the physiological stage of the cow. These results combined with our rodent data support our hypothesis that serotonin and PTHrP are critical players in the regulation of Ca homeostasis in Holstein dairy cows. We have demonstrated in a small population of multiparous Holstein cows that serotonin and PTHrP concentrations are positively correlated with each other, and negatively correlated with total calcium concentrations (Laporta et al., 2013b).

Intravenous (IV) infusion of 5-HTP in late lactation, non-pregnant, multiparous Holstein dairy cows increases circulating serotonin concentrations and alters Ca dynamics

In order to demonstrate the role of serotonin in Ca homeostasis in dairy cows, we performed a preliminary experiment in which we infused 5-HTP intravenously for one hour daily for four 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 Ca. All three doses of 5-HTP significantly 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 Ca concentrations following the same time course post infusion. While initially counter-intuitive, our data demonstrated that total Ca concentrations decreased in immediate response to 5-HTP treatments (Laporta et al., 2015). In order to determine where the circulating Ca was going after 5-HTP infusion, we measured urine and milk Ca concentrations prior to the start of infusion and two hours after the end of the infusion. Our results indicate that there was a decrease in urine Ca output with higher doses of 5-HTP treatment. This suggests that Ca is not being lost into the urine as a result of 5-HTP infusion. We then observed that the highest dose of 5-HTP increased total milk Ca concentrations. This supports the hypothesis that serotonin causes transient hypocalcemia by increased Ca transport into the mammary gland and subsequently into milk. Increased Ca transport into the mammary gland during lactation is critical for the stimulation of bone Ca mobilization by PTHrP because it decreases the circulating calcium concentrations sensed by the mammary gland, allowing for the production of PTHrP.

Use of 5-HTP before calving to prevent hypocalcemia: Does 5-HTP influence Ca during the cow transition period and does breed make a difference?

In order to determine if elevating serotonin concentrations in pre-fresh dairy cows would alter post-calving Ca concentrations, we treated multiparous Holstein cows with daily IV infusions of 1.0 mg/kg of 5-HTP beginning 7 d before the estimated calving date until calving. Our data demonstrates that IV infusions of 5-HTP pre-calving increased post-calving total Ca concentrations compared to saline treated controls (Weaver et al., 2016). Collaborating researchers in Switzerland also showed that 5-HTP increased calcium concentrations in their system post-calving (Hernandez-Castellano et al., accepted). Furthermore, we measured deoxypyridinoline (DPD), a marker of OC activity and therefore bone resorption, in the urine of our cows. These data demonstrate that cows receiving 5-HTP before calving have increased bone resorption at calving, suggesting that 5-HTP treatment pre-calving may improve post-calving Ca concentrations by increasing bone Ca resorption. Furthermore, we tested the same hypothesis in multiparous Jersey cows. Interestingly, Jersey cows responded to 5-HTP differently than the Holstein cows. Jersey cows had decreased calcium concentrations prior to parturition, 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 post-partum (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. With the growing number of Jersey cows in the dairy cow population, efforts should be focused on understanding the physiological mechanisms these cows use to maintain homeostasis and homeorhesis during lactation. Our data suggest that Jerseys are vastly different than Holsteins in calcium metabolism, and potentially metabolism of other nutrients. These data indicate that serotonin positively impacts calcium homeostasis in both Holstein and Jersey cows, but the mechanisms underlying the serotonin-calcium axis appear to be different and should be further investigated.

Interrelationship of a negative DCAD and serotonin

Given that 5-HTP treatment pre-calving was capable of increasing post-calving Ca concentrations, we wanted to determine if a common preventative treatment for SCH and CH, negative DCAD, controls Ca homeostasis via a serotonergic mechanism. To this end, we fed Holstein dairy cows a positive DCAD (+130 mEq/kg) diet for 21 days prior to calving or a negative DCAD (-130 mEq/kg) diet for 21 days prior to 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 (Martinez et al., unpublished results). This suggests the resulting improvement in post-calving Ca concentrations in the cows receiving a negative DCAD diet pre-calving could be due to serotonin's control of Ca homeostasis. We have preliminary results from a study testing the hypothesis that 5-HTP and negative DCAD diets have a synergistic effect on post-calving calcium concentrations. Our preliminary results indicate that the combination of 5-HTP treatment combined with a negative DCAD diet results in the largest increase in post-calving ionized calcium concentrations (Slater et al., unpublished results).

Conclusion

In conclusion, we have demonstrated that serotonin plays a critical role in regulation of maternal Ca transport, maternal Ca homeostasis, and mammary PTHrP production in the rodent. Additionally, our data demonstrate that mammary gland Ca transporter expression and induction of mammary-derived PTHrP during lactation are key regulators of maternal Ca homeostasis in rodent models. Furthermore, our rodent models indicate that the mammary gland is a significant source of serotonin during lactation. Our observational data in Holstein cows suggests that serotonin, PTHrP, and Ca are interrelated during the early post-partum period. Furthermore, our initial experiment exploring the effects of 5-HTP on maternal Ca homeostasis in late-lactation dairy cows supports the hypothesis that serotonin induces transient hypocalcemia by shuttling Ca into the mammary gland in order to stimulate bone Ca resorption. Treating pre-partum Holstein dairy cows with 5-HTP resulted in improvement of post-partum Ca concentrations. 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 pre-partum resulted in the increase of circulating serotonin concentrations. Our preliminary data examining the interaction of 5-HTP and negative DCAD suggests that two treatments together have a synergistic effect on improving post-calving calcium homeostasis.

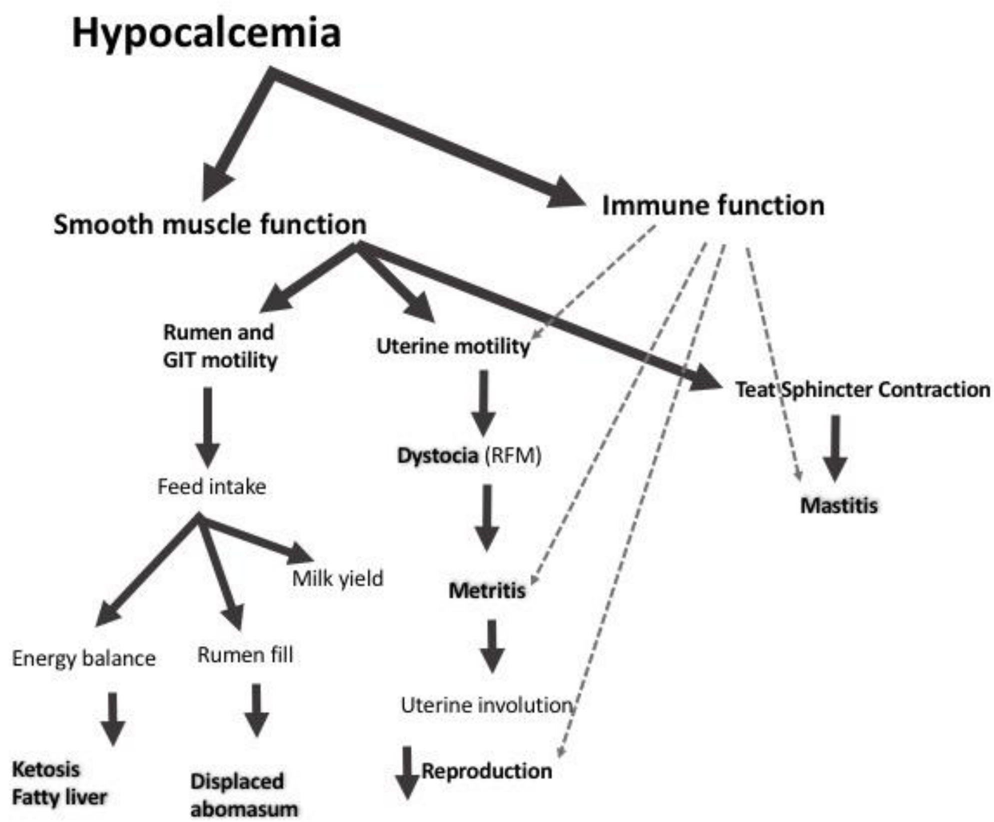

Figure 1. *Hypocalcemia is a 'gateway' disease that leads to increased risks of other periparturient diseases. (DeGaris and Lean, 2008).*

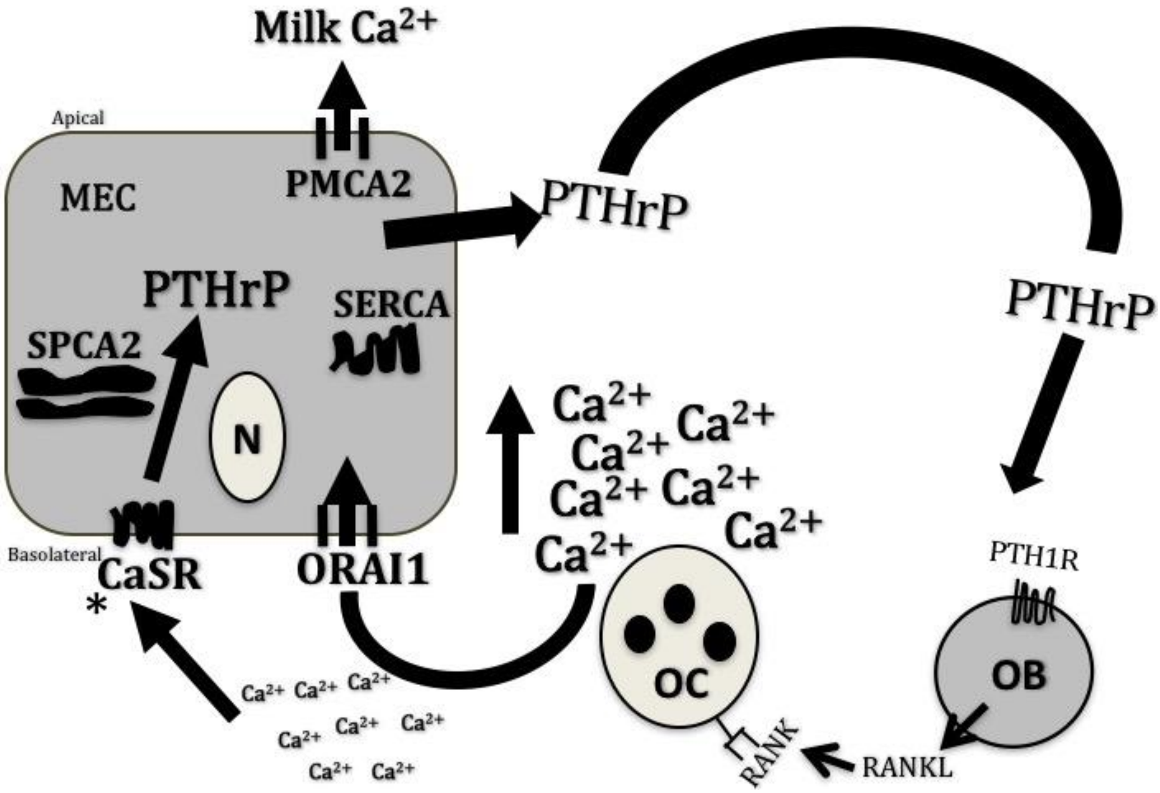

Figure 2. *Maternal Ca homeostasis is regulated by the mammary gland-bone axis. During lactation, the Ca sensing receptor (CaSR) on the basolateral side of the mammary epithelial cell (MEC) during lactation detects low blood Ca concentrations due to the increased transport of Ca into the MEC by Ca release-activated Ca channel protein 1 (ORAI1). Ca is either secreted into the milk through the apical plasma membrane Ca ATPase 2 (PMCA2) or sequestered in the Golgi apparatus by secretory pathways Ca ATPase 2 (SPCA2) or endoplasmic reticulum by the sarco(endo)plasmic reticulum Ca ATPase (SERCA). Detection of systemic decreased Ca 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 Ca liberation from bone.*

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Notes:

Nutrient Management: Your Best Defense is a Good Offense

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Introduction

As both the human population and the demand for animal protein grows, greater attention has been and will continue to be focused on allocation of resources: land, water and energy. This continued attention has sparked increased litigation involving dairy and other animal operators has occurred in the United States. Although environmental regulations exist at both the Federal, State and sometimes even the local level, every dairy operator in the country is not managing manure nutrients the same way. The objective herein is to provide a methodical approach to nutrient management that may aid in organizing the various aspects needed to have defensible farm data, should you need it. Think of sample collection, data management and use as your insurance policy. Most days you just feel good to have insurance and are grateful for not needing to use it. But, when something bad happens, it's there to provide a safe landing.

Dairy farmers are not strangers to nutrient management. Cow diets are formulated to deliver essential nutrients to animals depending on physiological status and production goals. The process requires procuring feed ingredients, knowing the nutrient composition and nutritional value, and mixing ingredients in the appropriate ratios to make a total mixed ration with just the right composition. Under-supplying nutrients is undesirable as it impairs animal productivity. Over-supplying nutrients is also undesirable as it may result in metabolic problems. Additionally, over-feeding of nutrients results in more nutrients being excreted and the subsequent need to manage them in the manure stream.

Conceptually, nutrient management of crops is similar to nutrient management of cattle. There's an assumed production target (yield) as well as anticipated nutritional need of the crops. A comprehensive understanding of soil characteristics, water applications, nutrient composition (manure and other potential sources of nutrients applied to crops) is important to fine tune both nutrient application rates and timing. Under-application of nutrients or losses of nutrients during crop production may be sufficient to reduce crop yield or quality resulting in reduced feed for animals or the need to reallocate the feed to a different class of animals. Over-application of nutrients may result in increased losses, potentially to groundwater or the atmosphere, if the nutrients are not utilized by the growing crop or maintained within the crop root zone.

Crop Nutrient Management Needs

The nuts and bolts of crop nutrient management include some estimate of crop nutrient needs as well as crop yield (tonnage) and nutrient composition. Knowledge of any field differences in soil characteristics and water management are also important. For those of farming in arid areas, irrigation water management is another key consideration. For those in a rain fed climate, understanding the impact of rain event frequency and intensity on nutrient availability and loss pathways is important.

The USDA NRCS (Natural Resources Conservation Service, United States Department of Agriculture) Nutrient Management 590 Standard provides foundational information. Its purpose is to establish a budget to supply nutrients for plant production, to properly utilize manure or organic by-products as plant nutrient sources, to minimize agricultural nonpoint source pollution of surface and ground water resources, to protect air quality be reducing N emissions (ammonia and NOx) and the formation of atmospheric particulates, and to maintain or improve the physical chemical and biological conditions of soil. If you're not actively conducting nutrient management on your dairy, you may want to contact your local NRCS field office or Cooperative Extension office to obtain information related to nutrient management. Many states with sizeable livestock production have individuals at the county level able to assist with nutrient management. Both NRCS and Cooperative Extension personnel are non-regulatory individuals and serve to provide technical and science based information from the US Department of Agriculture and your state's land grant university. Professional consultants are also available to provide assistance, for a fee.

Nutrient Budget

Typically nutrient management starts with a budget that serves as the basis to provide nutrients (application rate and timing) to the growing crop while minimizing impacts on water or soil resources. What's the anticipated yield of the crop? How many pounds of nitrogen (N), phosphorus (P) and potassium (K) will be harvested per acre in the anticipated yield? Are there any anticipated extenuating circumstances that might impact the yield (extended drought, potential flooding)? How variable is the anticipated nutrient composition of the crop? [Note: you can refer back to previous years' analysis of forage composition to identify if large or small variability in nutrient composition is likely.] Are nutrients stored or maintained in soil during the growing season? Nitrogen present in a plant available form as nitrate is highly mobile and can leach with water percolation through the crop root zone. Nitrogen present in a plant available form as ammonium can adsorb to soil particles. Nitrogen present as organic nitrogen is much less likely to leach, yet must be mineralized before it is plant available. This is why a slow release N needs to be applied before the nutrients are needed to allow for the N to be converted to a plant available form when plant use is anticipated. The different forms and characteristics of N make its management challenging. Based on the anticipated growth curve of the crop how much of each nutrient or just N is needed at specific times during the growing season? What is the logical form, quantity and timing of application of nutrient sources (manures or fertilizers)? Again, the objective is to pair application rates (timing, quantity, form and application method) with soil and plant needs.

Nutrient application rate. How much of each nutrient should be applied to a given crop. Nitrogen has plant available and not-yet plant available forms. The amount of each form applied may vary depending on how much material is in a manure form or how much commercial fertilizer is used. Recommendations suggest to apply nutrients as closely as possible to meet crop needs.

Nutrient application timing. When possible, application of nutrients in synchrony with plant nutrient uptake characteristics is useful. Application events need to be timed after consideration is given to cropping system limitations, weather and climatic conditions, field accessibility and any site specific risk factors.

Nutrient application methods. Nutrient application methods may reduce the risk of nutrient emissions (transport to surface water, leaching to groundwater, or volatilization to atmosphere). Application methods that allow for uniform distribution are preferred. Application methods need to be functional based on maturity or size of crop and compatible with irrigation or rain events.

Sampling and Analysis Plan

The application of manure or other materials should be based on results from nutrient analyses of the material to be applied (NRCS 590 Standard). The number of sources on a specific farm will vary by size of farm and the quantity of like material available for application. The frequency of sampling may vary depending on potential changes in nutrient composition.

The key components of a Sampling and Analysis Plan serve as a road map and useful organizer for sample collection needs. Whether officially named this or not, these steps serve to organize the record keeping processes. What is sampled (solid and/or liquid manure, plant tissue, irrigation or well water, soil). The frequency of sampling. Where is material sampled (source description: heifer solids, milking cow solids, etc.; barn well, irrigation well 28, etc.). What sampling method (protocol) is used. Which data are documented during sample collection and which analyses are performed by a laboratory. An example for solid manure is provided (Table 1).

Table 1. Example sampling and analysis plan for solid manure.

SOLID MANURE SAMPLING AND ANALYSIS PLAN				
Minimum Sampling Frequency	**Sampling Method**	**Source Description (pond, corral, separator, or settling basin solids, or other)**	**Minimum Analyses**	
			Field	**Laboratory**
Each application to each land application area	For laboratory analyses: One composite sample from stockpiled source per "Approved Sampling Procedures for Nutrient and Groundwater Monitoring at Existing Milk Cow Dairies" For field measurement: scaled weight by the truckload.	Stockpiled manure stored at G-Track	Total weight (tons) applied	Percent Moisture
Once within 12 months	For laboratory analyses: One composite sample from stockpiled source per "Approved Sampling Procedures for Nutrient and Groundwater Monitoring at Existing Milk Cow Dairies"	Stockpiled manure stored at G-Track	**None required**	General minerals, including: calcium, magnesium, sodium, bicarbonate, carbonate, sulfate, and chloride
Twice per year	For laboratory analyses: One composite sample from stockpiled source per "Approved Sampling Procedures for Nutrient and Groundwater Monitoring at Existing Milk Cow Dairies"	Stockpiled manure stored at G-Track	**None required**	Total nitrogen, total phosphorus, total potassium, and percent moisture

Sampling Frequency. Each sample collected is precious as it will provide you with valuable data. How often a specific source of a material is sampled will be determined by facility management, cropping cultural practices, climate conditions. How often samples are taken may be a function of a regulatory requirement or a recommendation by your crop consultant. Samples taken to provide input data for nutrient management calculations should represent what conditions exist on farm. Much variation may exist between a dairy operator in New York and one in California. In addition to growing multiple crops per year on the same field, the California dairy operator may have nutrient composition of liquid manure changing throughout the growing season resulting in sufficient need for updated data to use for midseason nutrient management modifications. The more variable an analyte or chemistry is in manure or plants, the more frequent samples should be taken.

Source Description. Which sources to sample by material are a function of which and how much material is land applied or manifested off-site. When sufficient amounts of material exist of any given source you may want to analyze the material for nutrient composition. Location or description within a material type is helpful if there are multiple sources. Source description directs the individual collecting the sample to the right material and alerts the individual responsible for record keeping to track the appropriate records. As an example, solid manure may be categorized as coming from lactating cows, a separator, replacement heifers, settling basins, or pond sludge (other sources may exist on your facility). These different classifications make sense if manure is handled separately and delivered to different places. Liquid manure sources that get sampled are those that are land applied. If you apply liquid from more than one pond or tank, you may want to define and sample each separately. Results of plant tissue analyses taken at harvest by field should provide data for more precise calculations of plant mass and nutrient removal from each field. Soil analyses are typically conducted by field and are done less frequently than a single crop cycle.

Sampling Protocol. The sampling protocol serves as a step by step instruction that when followed should ensure a quality representative sample is taken, well preserved, and delivered to the laboratory within the laboratory hold time. These may be very detailed or minimal in length. A detailed sampling protocol has information that identifies sampling and analytical requirements, sample preparation and location determination, and sample collection.

Sampling and analytical requirements includes doing homework before actually collecting the physical sample to obtain bottles or containers, labels, and specific instruction from the laboratory related to sample collection, preservation, holding times, record keeping and chain of custody forms. Know which analyses you want. This may be regulatory requirements or suggested analyses from your crop consultant.

Selection of an analytical lab is important. Some States or jurisdictions may have specific proficiency requirements of the laboratory used for specific analyses. If that's true in your area, be sure the laboratory you are using meets these requirements. Many programs maintain a list of participating or certified labs on a website. Do your homework if this is important to you. Containers and labels as well as lab forms should be obtained before samples are collected. This is a good time to check-in with the laboratory to determine how much time you have between sample collection and delivery to the laboratory (laboratory hold time) as well as any restrictions the lab may have on receiving samples. Depending on the volume of samples analyzed by the laboratory or the intricate nature of the analyses, a lab may receive certain samples at special times (i.e. groundwater accepted only Monday morning). You'll want to use the contact time with laboratory personnel to identify which constituents will be analyzed and if special rate packages are available for the type of material you will submit. Many labs have nutrient packages to streamline the billing process. Be sure the constituents you want to analyze will be conducted. Identifying your analytical requests before you arrive at the lab with a sample in hand will expedite the lab submission process.

The sample preparation and location determination is already partially done. The location determination should be in your Sampling and Analysis Plan. Preparation needed prior to sampling includes the ability to document the name of the individual taking the sample, date and time of sampling, and physical site location. Also important is to have all necessary sampling equipment available when it's time to sample. This may include disposal waterproof gloves during sampling, safety goggles if handling sample bottles containing preservatives, sample bottles, preservatives, ice, ice chest, labels for sample identification, chain of custody forms, notebook for record-keeping, etc. Identification of the grab sample collection method is helpful.

Sample Collection. This section of a protocol spells out in detail the steps needed to collect a grab sample of material for submission to a lab OR a number of grab samples from which a composite sample should be made. This section of a protocol includes parameters to be analyzed in the field (perhaps pH, temperature, electrical conductivity, ammonium nitrogen, etc.) and those to be analyzed by the laboratory. Proper preservation and storage must be followed. It's important to be sure the samples are handled appropriately. Most samples are placed into containers that close (bottles or bags) and preserved with chilling (placed on ice pack or in a refrigerator). Some samples may require additional preservation (acid or other chemical). If this is the case be sure that all personnel handling the sample are trained in use of the preservative and understand emergency actions needed should contamination of people occur.

Checking Your Progress

Information obtained from samples and data collected may be used to evaluate recovery of nutrients in individual fields. How many nutrients applied in each application of manure (or other nutrient source) is determined by multiplying the quantity of material by its nutrient content. Note: it is very important to carefully obtain representative samples of both plant tissue and solid or slurry manure as the moisture content of these materials may be highly variable.

A useful practice is to compare the current season analytical results with previous results. It's valuable to understand how management practices on the dairy impact nutrient composition of manure sources and the implication of these nutrient concentrations on application rates.

Targeted application to removal ratios of specific nutrients may be useful to achieve efficient use of nutrients and/or required through a regulatory process to protect the environment. Phosphorus application:removal near 1.1 are desired to minimize P loss to surface waters during soil erosion in high rainfall areas of the country. Targeted N application:removal rate of 1.4 (total N applied not plant available) is a regulatory objective in the Central Valley of California. Each geographic area may have specific regulatory targets given soil type, rain fall expectations, proximity to surface water, depth to groundwater, etc.

Conclusion

Natural resources are important, limited, and necessary for human survival. The increase focus on nutrient management in many air and watersheds of the United States is both a function of improving management on farms and defending against litigation. Nutrient management planning and implementation are key to the future success of dairy operations. Farm records documenting nutrient management applications are essential to defend nutrient management practices in the public's eye.

Select Citations

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Innovative Breeding Schemes: Best Combinations of Genomics, Semen Type, and Culling

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Introduction

Commercially affordable sexed semen (since 2006) and genomic testing (since 2009) have added to the options dairy farmers should consider when looking to increase profitability on the farm. These technologies, combined with good overall management, and older technologies such as embryo transfer or beef semen, lead to an expanded number of choices regarding genomic testing, breeding and culling. It is not quite obvious what the best combinations of these practices are. This paper attempts to describe the value of some of these combinations and shows some work on discovering new breeding schemes that lead to greater profitability.

Based on NAAB-reported semen sales, USDA reported that the use of (female) sexed-semen in heifers has increased from 9% in 2007 to 31% in 2015 (Hutchison and Bickhart, 2016). In cows, 0.2% of all breedings were with sexed semen in 2007, and this had increased to 1% in 2015. While sexed semen results in more heifer calves, it is also more expensive than conventional semen and reduces conception rates. USDA also reported that average conception rates for heifer sexed-semen breedings has recently increased due to improved technology (42% in 2007 compared to 49% in 2015). Comparable conception rates for heifer conventional breedings were 56% in 2007 and 59% in 2015. Conception rates for sexed-semen breedings to cows were 26% in 2007, and 30% in 2015 compared to 30, and 32% for conventional breedings during the same years. These conception rates are likely affected by the preferred use of sexed semen on more fertile animals.

Average reproductive performance has also increased considerably in the last 15 years due to improvements in management and technologies such as timed-AI and estrus detection gadgets. Characteristics of 7,032 Holstein herds (≥ 50 cows per herd) that participate in the DHIA Program showed an average pregnancy rate of 19% (records processed by DRMS by September 8, 2016) (De Vries, 2016). However, 11% of the herds had pregnancy rates of at least 28% and these herds accounted for 21% of the cows. These improvements in reproductive performance also allow for the creation of more dairy heifer calves.

The 7,032 DHIA herds had an average annual cow cull rate of 37%, which was independent of the pregnancy rate group (which varied from 6% to 37%). Annual cow cull rates have remained fairly constant in the last decade although the average cow breeding value for productive life has increased by 6 months since 2000, and has been increasing for 50 years (De Vries, 2017). Given that the national dairy herd is fairly constant at about 9 million cows, cow cull rates in the US are mostly decided by the number of dairy calves that are being raised to replace cows. When more heifer calves are created, the larger supply of heifers may force cows out of the herd that otherwise might have stayed. Other factors also play a role, such as cow health and performance, beef prices, the cost to raise or purchase heifers, and markets for dairy heifer calves and crossbred calves.

The availability of these technologies and good quality of management on many farms is leading to the ability to create more heifer calves than are needed to replace cows. Among the options to consider are now on which animals to use sexed semen, which dairy calves to raise as herd replacements, and which cows to cull. Other options in the decision mix are the use of beef semen to create crossbred calves, embryo production and transfer, and whether to use genomic testing.

The use of genomic testing has changed from use in primarily males in 2009 to now in females. The Council of Dairy Cattle Breeding (CDCB) national genetic evaluation of December 2016 shows that more than 1.67 million animals in the national database have been genomically tested since 2009. Of these, 1.28 million were genotyped in the US. In the 35 days from November to December 2006, the increase was 40,000 (30,800 Holstein females and 3,200 Holstein males, the remainder other breeds). Almost always young calves are tested. If 4.5 million dairy heifer calves are born every year, then this means that approximately 9% of these calves are genomically tested. Genomic test results are useful to better rank animals for genetic merit of individual traits or based on an index such as Net Merit (NM$), identify parentage misidentifications, and detect carriers of recessive alleles. Test results should improve culling and breeding decisions.

This paper first describes some basic genetic concepts that are needed to evaluate breeding schemes. Secondly, major factors are described that affect breeding schemes and these factors are tied together in a herd budget model to calculate a bottom line profitability. Third, several analyses show how the value of genomic testing depends on user-defined breeding schemes. Fourth, other analyses show how the optimal breeding scheme depends on genomic testing, the premium for crossbred calves, and the level of reproduction. The fifth part describes separate analysis not evaluated with the herd budget model such as the value of fixing misidentification and changing the cow cull rate. Part six contains some final thoughts and part seven has some take home messages.

Genetics and Genomic Testing 101

Genomic testing results provide better estimates of the genetic merit of animals and can be performed at a young age. Influenced by genomic test results, an often recommended policy is to sell the surplus heifer calves that are not needed to replace culled cows. These would typically be the genetically worst heifers, assuming health is fine. An additional use of genomic test results is to breed the top animals with sexed semen, the middle animals with conventional semen, and the bottom category with beef semen. When embryo transfer is employed, the top animals could be donors and the worst animals could be recipients.

Genomic test reports contain (categories) of predicted transmitting abilities and reliabilities for individual traits such as milk yield, daughter pregnancy rate, and production life, as well as their reliabilities (among other information). Table 1 is a part of a genomic test report for 9 calves tested at the University of Florida Dairy Unit. Results are expressed in Predicted Transmitting abilities (PTA) on the left with their reliabilities in percentages (%) on the right. NM$ and TPI are indices that combine multiple traits weighted by their relative importance.

The PTAs on the test report (called Parent Averages if no information from the animal itself is available) are the genetic merit that the animal is expected (predicted) to transmit to its offspring (the next generation). Expression of genetic merit in PTAs made sense when looking at proofs of sires, because the primary interest is in the genetic merit of the daughters. The daughter is expected to obtain half of her genetic merit from the sire while the other half comes from her dam. However, when genomic testing a calf we are primarily interested in the genetic merit of the tested animal itself. The expected genetic merit of the animal itself is the estimated breeding value (EBV), which is PTA x 2 = EBV. This matters when interpreting the difference in the genomic test results between the calves. In table 1, the best calf has a PTA of NM$ of $530 whereas the worst calf has a PTA of NM$ of $253. This is a difference of $227 PTA. However, the expected genetic difference is 2 x $530 – 2 x $253 = $554. The NM$ index is a lifetime measure, say 3 lactations. The best calf is therefore expected to be $554 more profitable than the worst calf, or $185 per lactation. These are larger differences than they appear when the PTAs are compared. The multiplication of the PTA by 2 does not change the ranking of the calves, of course.

Table 1*. Partial genomic test results for 9 heifer calves at the University of Florida Dairy Unit.*

On-farm ID (Herd Management #)	Birth Date	Sex	Breed	NM$	TPI	Milk	DPR	PL	NM$	TPA	Milk	DPR	PL
9598	2015/12/09	F	HO	253	1785	777	0.8	4	71%	NA	74%	66%	68%
9615	2015/12/23	F	HO	480	2159	747	2.8	6.4	71%	NA	75%	67%	69%
9605	2015/12/17	F	HO	358	2031	72	2.3	4.5	75%	NA	77%	71%	72%
9592	2015/12/02	F	HO	530	2249	593	3.7	7.3	70%	NA	74%	65%	67%
9593	2015/12/03	F	HO	484	2169	347	2.8	5.2	71%	NA	74%	66%	68%
9610	2015/12/22	F	HO	410	2041	619	2.9	5.4	69%	NA	73%	62%	65%
9590	2015/12/01	F	HO	365	2045	700	0.7	3.9	73%	NA	76%	67%	70%
9594	2015/12/05	F	HO	273	1907	410	2	4.3	73%	NA	76%	67%	70%

NM$ = Net Merit, TPI = Total Performance Index, milk = milk yield (in lbs/lactation), DPR = daughter pregnancy rate (in %), PL = productive life (in months). Results are expressed in Predicted Transmitting abilities (PTA) with reliabilities in percentages (%) on the right.

The reliabilities show the uncertainty, both positive and negative, of the PTA to predict the true transmitting ability of the trait (the true genetic merit as determined by the DNA of the animal). The higher the reliability, the more information has been used, and the more certain we are that the true transmitting ability is near the PTA (or equivalently that the true breeding value is near the EBV). Without genomic testing, the reliabilities of the parent averages are around 20% when the sire is identified, and just over 30% when both sire and dam are identified. The PTAs will be more similar when reliabilities are low. Genomic testing therefore widens the distribution of the PTAs. Reliabilities for NM$ are on average a little greater than 70% in table 1. These higher reliabilities provide more confidence in the rankings of animals, for example to make culling or breeding decisions. Ideally, animals are ranked by their true breeding values (or true transmitting abilities) but they are unknown.

The quality of the genomic testing technology to predict actual future performance is constantly improving as a result of better statistical methods and a bigger dataset of genomically tested animals that also have performance data. Weigel et al. (2015) presented some of the evidence that genomic testing works and helps predict future phenotypic performance.

When not all animals are needed to create the next generation, a useful formula to estimate the genetic progress from one generation the next is the "breeder's" equation. One of the simplest forms of this formula is: genetic progress/year = genetic variation x selection differential x √(reliability) / generation interval. This formula is at least 80 years old and was mentioned by dairy genetics pioneer Jay Lush in 1937.

Genetic variation is the natural genetic difference that exists among the animals in the population. This would be the distribution of the true breeding values. USDA calculated the standard deviation (a measure of this variation) of the true breeding value of NM$ in the US herd at $388. One can estimate the genetic variation in a herd based on the PTAs, but this estimated variation is generally less than the true genetic variation that exits, because the reliabilities of the PTAs are less than 100%.

Selection differential is a mathematical function of the fraction of animals that are used (the selecting intensity). The value varies from 0 to more than 3 and increases when a smaller fraction is selected. For example, if 90% of the animals are used, the selection differential is 0.20. When 80% are selected, it is 0.35. At 10% it is 1.76. At 1% it is 2.67 and so on.

The square root of the reliability is the accuracy. It represents how well all animals can be ranked for true breeding value. When the reliability is low, genetic progress is minimal even when the selection intensity is high because we have little information about each animal's true genetic merit. We'd more often select animals that in really have lower true breeding values. Genomic testing can be seen as increasing the reliability of the ranking and thus the genetic progress in the animals that are kept is increased (if the goals is to select the best ones). The generation interval is the average age of the parents when the offspring is born.

The first part of table 2 shows how the average NM$ of the selected animals increases from $0 (the herd average) based on the selection intensity and the reliability in the breeder's equation. For example, if 90% of the animals are selected and the reliability of the ranking the animals on their true breeding values is 30%, then the average true breeding value for NM$ of the selected animals is $37 greater than the population they were selected from. On the other hand, the bottom 10% in this case has an average true breeding value of -$336 because the average of all animals is $0. The average increase in NM$ is the greatest when the reliability is high and a few best animals are selected such as with embryo donors after genomic testing.

The second part of table 2 is the net monetary gain after all animals (selected and not selected) are tested with a test that costs $50 and delivers a reliability different from 0%. For example, if the reliability is 70% and the best 90% of the animals are selected, then the gain in profit of those 90% is only $1. The gain in average true breeding value is offset by the testing cost to obtain the 70% reliability. This assumes that without the test, the reliability is 0%. In practice, the reliability is greater than 0% because the performance of the sire and dam are probably known.

Table 2. *The breeder's equation applied to selection based on NM$ and a $50 cost of testing per animal. All animals are tested. The standard deviation is $350.*

Average true breeding value, per selected animal

Reliablity ↓	←Animals selected→ 10%	30%	50%	70%	90%
10%	$194	$128	$88	$55	$22
30%	$336	$222	$153	$95	$37
50%	$434	$287	$197	$123	$48
70%	$514	$339	$234	$145	$57
90%	$583	$385	$265	$165	$65

Net gain after $50 testing cost, per average selected animal

Reliablity ↓	←Animals selected→ 10%	30%	50%	70%	90%
10%	-$306	-$39	-$12	-$16	-$34
30%	-$164	$55	$53	$24	-$19
50%	-$66	$120	$97	$52	-$8
70%	$14	$172	$134	$74	$1
90%	$83	$218	$165	$94	$9

Typical applications of the breeder's equation use reliabilities as seen in table 1 to show how genetic progress in the herd increases if animals are selected based on genomic test results vs. traditional PTAs. But some recent genetics theory says that the reliabilities used in the breeder's equation are often too high, especially with low parent average reliabilities (Calus et al., 2015). The theory is difficult, but the implication is that the reliabilities without genomic testing in the breeder's equation should be a lot lower, and with genomic testing should be somewhat lower. The result is that the value of genomic testing is actually greater than when calculated by the breeder's equation with the reliabilities in table 1 and traditional reliabilities of 10 to 30%.

The ideas in table 2 can be used to value selling the genetically worst surplus calves (reducing the number of animals selected from 100% to fewer, and indirectly when breeding the better animals with sexed semen (or as embryo donors) to propagate the better genetics. The data in table 2 is not sufficient, however, to design and evaluate breeding schemes on farms because too many factors are left out.

Using the breeder's equation idea as part of the analysis, a Dutch study by Calus et al. (2015) and a Danish study by Hjorto et al. (2015) showed conflicting results of the economic value of genomic testing. In the Danish study, net gain was negative in most cases and the Dutch study showed a positive net gain. The Dutch study looked at all or nothing use of sexed semen, different cull rates and hence a varying fraction of surplus heifers that were sold, but they did not include all relevant costs such as the cost to raise heifers, cow cull prices, or reductions in conception rate when sexed semen was used. The Danish study, on the other hand, used beef semen in the herd so there was no surplus of dairy heifer calves to sell. The value of genomic testing came from better identification of animals to breed with sexed, conventional, or beef semen. Optimization of breeding schemes was not pursued in both studies. Comprehensive analysis that looked at combinations of genomics, semen type and culling in the US and aboard appear not to be available.

How to Evaluate Breeding Schemes

At the University of Florida, a herd budget model was put together to evaluate breeding schemes and even find the optimal scheme given all kinds of herd specific data and prices. The bottom line is profit per milking cow per year. The budget moves animals from birth to culling over time and observes revenues and expenses such as feed costs, breeding costs, labor and other variable cost, and genomic testing cost (if applicable). Revenues come from milk sales, cow and heifer culling, sold calves, and kept dairy calves. Animal performance depends on reproductive efficiency, lactation and feed intake curves, body weights, and involuntary risk of culling, among many other inputs. This herd budget model was earlier used to evaluate stall stocking density (De Vries et al., 2016) and the economics of using natural service sires. New was the addition of genetics of the NM$ trait as a comprehensive index of the value of genetic merit.

Kept dairy calves were valued based on their genetic merit. The breeder's equation was part of the analysis. This genetic merit depends on the genetic merit of the dams and sires of the calves and on the sale of surplus dairy heifer calves. The value created through the sale of surplus calves depends on the reliabilities, which increase with age and can be increased through genomic testing. A greater surplus of dairy calves can be created with sexed semen, but at a higher cost than conventional semen breeding and at lower conception rates. Sexed, conventional and beef semen can be applied to different groups of cattle, for example sexed semen on the genetically better heifers and beef semen in some of the genetically worse older cows. Younger dams are genetically better than older dams. The genetic variation decreases a little with age as a result of involuntary culling, which is associated with poorer genetics.

Reasonable prices and other assumptions (not shown) were chosen for the analyses that follow. The standard deviation of the true breeding value of NM$ in calves was set at $350 and the genetic trend in the herd was $70 EBV per year. The cost of genomic testing was set at $50 per tested calf which included extra labor cost. All born alive dairy calves were tested if genomic testing was applied. Culled cows were sold at approximately half the cost of raising heifers. Dairy bull calves and surplus dairy heifer calves were sold at a young age at a profit of $150 after their expenses. This price for surplus dairy calves was assumed to be independent of the genetic merit of these calves. As table 2 shows, the greater the reliability and the smaller the fraction of the surplus dairy heifer calves that are sold, the lower their genetic merit will be. In other words, the market is assumed to be naïve about the genetic merit of the sold dairy heifer calves. The initial premium for a crossbred calf was $75 over the price of a dairy bull calf. The cow cull rate was fixed and did not vary with the breeding scheme.

User-Defined Breeding Schemes

In **scenario 1**, only conventional semen was used which let to 12% surplus of calves given a fixed cull rate of 36% and a pregnancy rate of 21%. Four reliabilities for selecting the surplus calves were set. They were set at set at 0%, or 6%, or 20% (all at $0 cost, traditional evaluation), or 57% (at $50 cost, genomic test). These reliabilities may seem low but they are likely more correct to use in the breeder's equation (Calus et al., 2015). The higher the reliability, the better the 88% genetically truly best heifer calves are selected to remain in the herd.

Increases in revenues compared to the profit per milking cow at 0% reliability (0%) were $14 (at 6% reliability), $26 (at 20%) and $42 (at 57%) per milking cow per year. However, genomic testing all heifer calves born alive in the herd cost $27 per milking cow per year. The increases in profit per milking cow per year were therefore $14 (at 6%), $26 (at 20%) and $42-$27=$15 (at 57%). Expressed per born alive dairy calf, the increases in profit were $26 (at 6%), $47 (at 20%) and again $26 (at 57%). In this scenario, genomic testing was not profitability when the farm had some reliability for free through the traditional genetic evaluation. Because only conventional semen was used, the reliability information was not used when breeding heifers and cows. Thus, the genomic test information was only used to identify the 12% dairy heifer calves to be sold.

In **scenario 2**, the top 50% of heifers were bred with sexed semen twice. All other breedings in heifers and cows were with conventional semen. As a result, 18% surplus dairy heifer calves were created. The genomic test information was now used to identify the 82% of dairy heifer calves that were kept, and also to identify the 50% genetically best heifers to breed with sexed semen. The increases in profit (over the 0% reliability setting) were $22 (at 6%), $41 (at 20%) and $37 (at 57%) per milking cow per year. In scenario 2, the higher reliability was more valuable because it was used twice. As a result, genomic testing was more likely to be profitable. The increase in profit per milking cow in scenario 2, compared to using only conventional semen (scenario 1), was $18 when reliability was set at 0% and $40 when reliability was 57%. The use of sexed semen on the better heifers was profitable regardless of the reliability of the genetic information.

In **scenario 3**, all heifers and the top 50% of first parity cows were bred with sexed semen twice. This extended use of sexed semen led to a 25% surplus of dairy heifer calves. The increases in profit (over the 0% reliability setting) were $25 (at 6%), $49 (at 20%) and $58 (at 57%) per milking cow per year (reliabilities for cows were set slightly greater). The value of genomic testing therefore increased compared to scenarios 2 and 1. Scenario 3 was also more profitable than scenario 2 and 1 at any level of reliability.

In **scenario 4**, the top 50% of heifers were bred with sexed semen twice and the bottom 20% of older cows were bred with beef semen. This scenario let to only 11% surplus dairy heifer calves because crossbred calves were created. Thus there was less genetic progress because the selection intensity among the dairy calves was lower but crossbred calves were sold at a premium of +$75. The increases in profit (over the 0% reliability setting) were $14 (at 6%), $31 (at 20%) and $28 (at 57%) per milking cow per year. Profit was slightly lower than in scenario 3 but greater than in scenarios 2 and 1 at any level of reliability.

These four scenarios show that profit of the breeding scheme depends on the interaction between reliability of genetic testing and semen type. The results also depend on many other assumptions that were set and not varied such as the genetic variation of the selection index.

A genetic standard variation of $350 for NM$ was used in scenarios 1 to 4. A selection index can have a greater genetic variation, for example when new, economically important traits are included. For example, if the genetic standard deviation is increased to $450, then the increases in profit (over the 0% reliability) were $29 (at 6%), $53 (at 20%) and $56 (at 57%) per milking cow per year in scenario 2 (50% sexed semen in heifers). The value of the greater reliability of genetic testing is greater when there is more genetic variation. Genomic testing is now the most profitable of the 4 reliabilities that were evaluated. On the other hand, a greater reliability of genetic testing is less valuable when there is less genetic variation in the herd, for example as a result of more inbreeding.

Another consideration is the use of the genetic merit of the service sires. Instead of using genomic testing to capture value from better selection of surplus calves and from better breeding decisions, service sires with greater genetic merit could be used. Again using scenario 2, the PTA of the service sires was varied for the 0%, 6% and 20% reliabilities to obtain the same profit per milking cow per year as with using genomic testing (57% reliability). These changes in PTA were assumed to be free. Changes in the PTAs to obtain the same profit were +$50 (0% reliability), +$20 (6%), and -$6 (20%). In this last case, a sire with a slightly lower PTA could be used than when genomic testing was used. These changes are not large and confirm the importance of first selecting good service sires.

Optimal Breeding Schemes

The breeding schemes in the scenarios 1 to 4 were user-defined based on strategies that seem reasonable, but they are not likely to be optimal. Of interest is the identification of breeding schemes that result in the greatest profitability, given the prices and other inputs. The best breeding scheme generates the greatest profitability. This means finding the optimal combinations of semen type (sexed, conventional, beef) per service number and per parity. The herd budget model can search for these best breeding schemes. A constraint is that at least enough dairy heifer calves must be created to replace culled cows. Cow cull rate was kept at 35%.

Figure 1 shows results from an analysis where the premium for crossbred calves was set at +$75, +$150 and +$225 over the sale price of purebred dairy calves. The top part has a user-defined breeding scheme where the top 60% of heifers were bred with sexed semen (se). The bottom 50% of second parity and older cows were bred with beef semen (be). All other breedings in heifers and cows were with conventional semen (co). This scheme resulted in the creation of just enough dairy heifer calves to replace culled cows but there was no surplus.

Profit per milking cow per year increased with a greater premium for crossbred calves as expected. Genomic testing resulted in a loss of $5 per milking cow per year for all three premiums. Genomic testing results were used to identify the top 60% heifers to breed with sexed semen, and the bottom 50% of older cows to breed with beef semen, but not for calf selection.

The bottom part shows results for better breeding schemes. The schemes depend on the premium of crossbred calves and use more sexed semen. Conventional semen is not used at all. The schemes also depend a little on the use of genomic testing or not. Profit per milking cow is increased by $13 to $81 compared to the user-defined scheme in the top part of the figure. The better breeding schemes are clearly more profitable than a reasonable user-defined breeding scheme. Genomic testing now adds additional value compared to relying on traditional genetic reliabilities, but the value appears to decrease with the size of the premium.

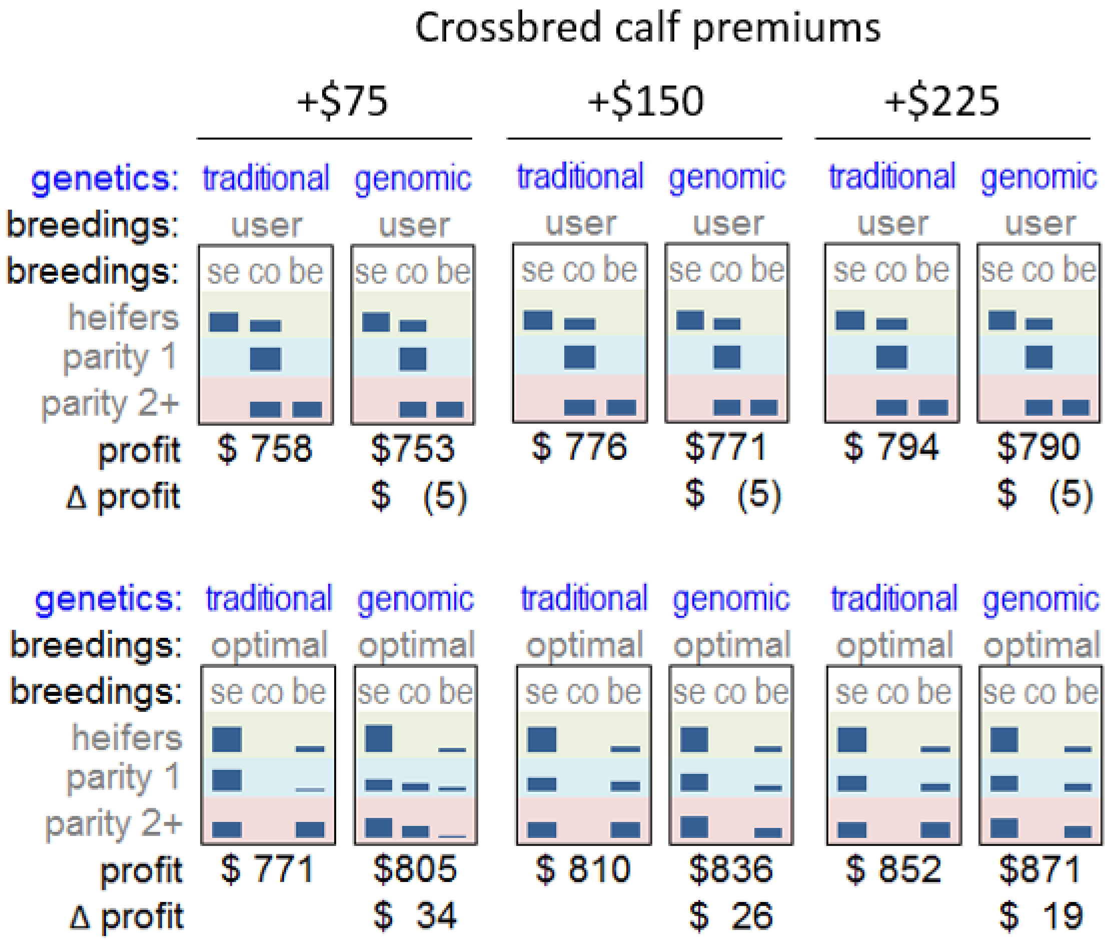

Figure 1. *User-defined and optimal breeding schemes and profitability depending on the premiums paid for crossbred calves and the use of genomic testing or traditional genetic reliabilities. The top part has a user-defined breeding scheme where the top 60% of heifers were bred with sexed semen (se). The bottom 50% of second parity and older cows were bred with beef semen (be). All other breedings in heifers and cows were with conventional semen (co). In the bottom part no conventional semen is used although this was an option. Profit is profit per milking cow per year.*

Figure 2 shows the effect of greater pregnancy rates (≈14%, ≈20%, ≈28%) on the profitability and optimal breeding schemes. The set-up is the same as in figure 1. The user-defined breeding scheme used 50% sexed semen in the top heifers and conventional semen elsewhere. The pregnancy rates changed some when more or less sexed semen was used.

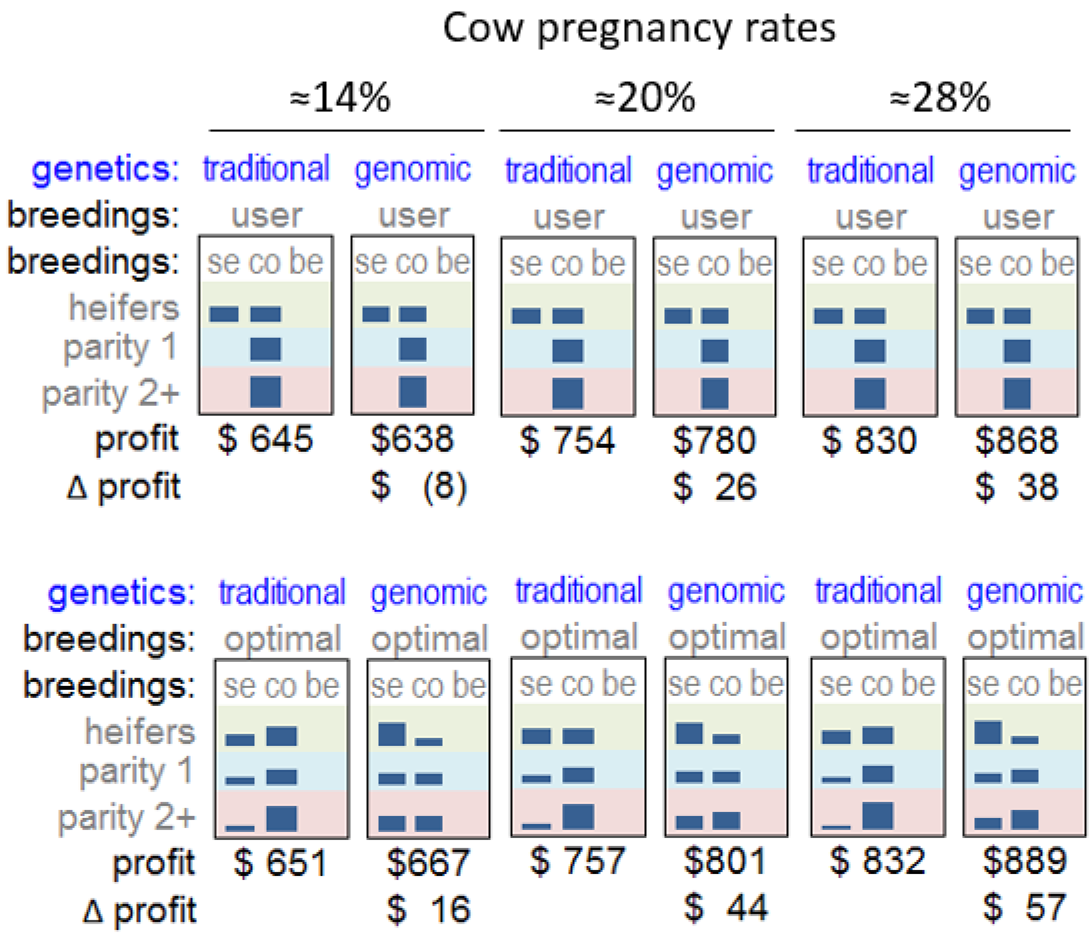

Figure 2. *User-defined and optimal breeding schemes and profitability depending on pregnancy rates and the use of genomic testing or traditional genetic reliabilities. The top part has a user-defined breeding scheme where the top 50% of heifers were bred with sexed semen (se). All other breedings in heifers and cows were with conventional semen (co). Beef semen (be) was not allowed to be used. Profit is profit per milking cow per year.*

The user-defined schemes show increases in profitability with greater pregnancy rates, as might be expected. Genomic testing was not profitable when pregnancy rate was ≈14% but generates $38 more profit per milking cow per year when pregnancy rate is ≈28%. At the low pregnancy rate, no surplus calves are available so genomic testing results are only used to select the top 50% of heifers. At the high pregnancy rate, genomic testing is used to select the surplus calves (26% surplus when pregnancy rate is ≈28%) and again to identify the top heifers to breed with sexed semen. There is clearly a strong interaction between the value of genomic testing and the level of reproduction in the herd.

The bottom part of figure 2 shows again increases in profitability over the user-defined scheme in the same situation. Genomic testing results in the use of more sexed semen. Genomic testing is now profitable even at the low pregnancy rate in combination with the use of more sexed semen, which results in a small surplus of dairy calves. At the highest pregnancy rate, genomic testing results in a $57 increase in profit per milking cow per year compared to no genomic testing.

The optimal breeding schemes were limited to the use of only sexed and conventional semen in figure 2. Beef semen was not allowed to be used to help the comparison with the user-defined scheme. This means that even better breeding schemes are possible when all three breeding types are available at these varying levels of pregnancy rates.

Figure 3 is a first attempt to show when the $57 increase in profitability with genomic testing and a change in breeding scheme is realized over time. Genomic testing costs are in year 0. Return from genomic testing is realized from a better selection of the dairy heifer calves that are kept in the herd (own extra value), and the offspring from these dairy heifer calves (kept dairy calf value (current)) and even their future offspring (kept dairy calf value (future)). There are also small differences in the number of bull calves (other calves) that are sold when breeding schemes are sold. The small differences in operational profit are the results of the use of more sexed semen, such as the higher cost and lower conception rates. The profit line becomes positive between years 3 and 4 after genomic testing. The genomic test has at that point paid for itself.

Genomic testing costs are in year 0. Return from genomic testing is realized from a better selection of the dairy heifer calves that are kept in the herd (own extra value), and the offspring from these dairy heifer calves (kept dairy calf value (current)) and even their future offspring (kept dairy calf value (future)). Small effects are differences in the number of bull calves (other calves) that are sold. Differences in operational profit are the results of the use of more sexed semen, such as the higher cost and results from lower conception rates. The profit line becomes positive between years 3 and 4 after genomic testing.

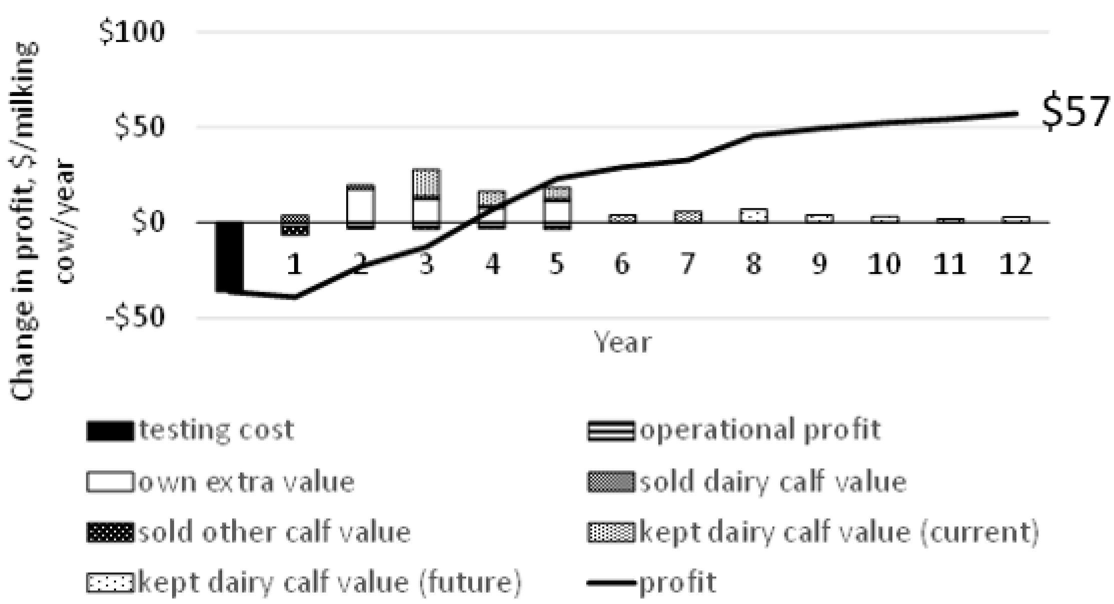

Figure 3. *Decomposition of the $57 increase in profit per milking cow per year from the use of genomic testing and the optimal breeding scheme compared to the optimal breeding scheme used with traditional reliabilities. Pregnancy rate is ≈28%.*

Avoiding Inbreeding

Another value of genomic testing, not included in the breeding schemes above, is the ability to correct parent misidentification errors. The DNA analysis of the genomic test flags animals that are reported to have one or both different parents. The average national misidentification rate is thought to be around 15% but large variations exist between farms. Misidentified females could more likely be mated to closely related sires which increases inbreeding. Cassell (1999) estimated the economic loss per 1% greater inbreeding in a cow at approximately $25 in her lifetime. This value was recently also obtained by USDA. This value is likely underestimated because inbreeding might lead to earlier losses such as a lower calving rate following a mating of related animals. The calculation in table 3 assumes that 80% of the misidentified cases are resolved with genomic testing. On the left is the level of misidentification before and after the genomic test. All animals are tested because it is not known which animals are misidentified. Genomic test costs are not included. In the center block is the economic loss per tested animal that is avoided depending on the amount of inbreeding that is avoided. For example, if 15% of the dairy calves are misidentified, and these 12% now correctly identified calves are mated to sires that are less related, resulting in offspring that is 1% less inbred, the economic loss avoided is $3 per tested calf. These values are generally too low to warrant genomic testing only for correction of misidentification errors.

***Table 3**. Avoided lifetime economic loss per calf from correcting misidentification errors in the herd. Results are per tested animal and all animals are tested.*

$25 : reduction in lifetime profit per 1% inbreeding
80% : misidentification resolved by genomic test
1 : number of female calves born during lifetime

misidentification		inbreeding avoided				
before genomic test	after genomic test	4%	3%	2%	1%	0%
5%	1%	$4	$3	$2	$1	$0
10%	2%	$8	$6	$4	$2	$0
15%	3%	$12	$9	$6	$3	$0
20%	4%	$16	$12	$8	$4	$0
25%	5%	$20	$15	$10	$5	$0
30%	6%	$24	$18	$12	$6	$0
50%	10%	$40	$30	$20	$10	$0
100%	20%	$80	$60	$40	$20	$0

Culling and Genetic Improvement

The analyses above assumed a fixed annual cull rate to avoid the complicated effects of more or less voluntary culling. There is an economic trade-off between genetic improvement and cull rate in dairy cattle (reviewed in De Vries (2015, 2017) and partly restated here). Primarily as a result of genomic testing and shortening of the generation interval, the genetic improvement in sires used for AI is increasing faster compared to a decade ago. The genetic merit of replacement heifers is also increasing faster and the genetic lag with older cows in the herd increases. Asset replacement theory says that this should trigger greater cow culling to capture this greater genetic improvement in heifers. On the other hand, lower culling rates are often viewed favorably because the costs and environmental impact to maintain herd size are generally lower.

The annual increase in average EBV of NM$ of Holstein sires is accelerating from $70/year when the sire entered AI around 2002 to $171/year for sires that entered AI around 2012. The expectation is therefore that heifers born in 2015 are at least $50 more profitable per lactation than heifers born in 2014.

Few studies have investigated the direct effects of genetic improvement on optimal cull rates. A 35-yr old study found that the economically optimal cull rates were in the range of 25% to 27%, compared to the lowest possible involuntary cull rate of 20%. There was only a small effect of using the best surviving dams to generate the replacement heifer calves. Genetic improvement from sires had little effect on the economically optimal cull rate. Another study that optimized culling decisions for individual cows also showed that the effect of changes in genetic improvement on optimal annual cull rates was relatively small. Reduced involuntary cull rates improved profitability, but also increased optimal voluntary culling. Finally, an economic optimal culling model with prices from 2015 confirmed that optimal annual cull rates were fairly insensitive to genetic improvement in heifers (De Vries, 2015). These studies concluded that the economic optimal cull rates continue to depend more on cow depreciation than on accelerated genetic improvement in heifers.

A point of consideration is the true cost of raising additional heifers, assuming the breeding scheme and good management are able to generate more heifers. Heifer purchase prices in 2015 in the 8 western regions in the US ranged from $1,719 to $2,251 (Frazer LLP, 2016). The cost of raising a heifer is often said to be more than $2,000 in the eastern US. However, when raising the farm's own heifers, the raising cost for additional (marginal) heifers should not include fixed costs when there is room in the facilities and labor supply to raise these heifers with no extra expenses than feed, health care, and breeding. In some cases, raising more heifers may not be very expensive and might warrant a higher cow cull rate, especially when beef prices are strong. This would reduce the number of surplus dairy heifer calves.

A preliminary analysis with the herd budget model looked at the economics of raising all heifers and a variable cow cull rate vs. selling surplus heifer calves and a fixed cow cull rate (De Vries, 2016). Genetics was included. The analysis also included increases in pregnancy rate from 15% to 35% and some sexed semen. More heifer calves were born when pregnancy rates were increased. The results showed that selling surplus dairy heifer calves while maintaining a fixed cull rate was a more profitable strategy than forcing all heifers into the herd by increasing cow cull rate. The advantage of the fixed cull rate strategy was greater when pregnancy rates increased. The higher the pregnancy rate, the higher the cow cull rate in the variable cull rate strategy. This also resulted in more first parity cows and therefore fewer older but higher producing cows. On the other hand, the genetic level was higher in the variable cull rate strategy.

These results are preliminary because results will depend greatly on heifer raising and selling prices, and cow cull prices. Also, average cows within the parity were culled in the analysis where in practice the worst cows will be culled which raises the average performance of the remaining cows that stay in the herd. These comprehensive analyses are difficult to do well.

Discussion

A proper exploration of the value of innovative breeding schemes has proven to be challenging. In part this is because it is difficult to put all important factors correctly in a model so they can be analyzed together and a bottom line profitability can be calculated. Further, the best combinations are not always absolutely best because the optimization software that was used struggles with non-linear models. More capable (and expensive) optimizers should be used. But practical decision making aids are being developed. What is also not yet completed is a structured sensitivity analysis to find which factors affect the best breeding schemes the most. We are only recently learning how to do this well.

More importantly, the best combination of genomics, semen type and culling depends on many factors that are farm dependent such as the level of reproduction efficiency and health of the herd. Prices also play a major role, such as the sale and purchase prices of heifers, cow cull prices, and premiums for crossbred calves. These prices are volatile and may have changed greatly from the time when breeding decisions were made to the time when calves are born 9 months later. What was best then is likely no longer best. Difficult to quantify is the importance of having enough own raised heifers for biosecurity, risk aversion, and expansion reasons. Other options that should be considered are the use of embryo transfer and breeding policy in terms of voluntary waiting period and do-not-breed. This is currently work in progress.

Take Home Messages

- Genomic testing of females on the farm can be profitable, depending on the fraction surplus heifers that can be created and smart breeding decisions regarding the use of sexed and beef semen.
- Better reproduction makes innovative breeding schemes more profitable.
- Best breeding schemes are dependent on prices that are volatile, unfortunately.
- Recent increases in annual genetic progress in sires compared to a decade ago should increase cow culling by a few percentage points at most.
- The opportunity cost of not innovating breeding schemes is greater than a decade ago.
- Seek professional help to discover and implement an innovative breeding scheme that combines components of genomics, various semen types, and voluntary culling while protecting the farm's risk.

Acknowledgment

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Introduction

There are challenges surrounding training the next generation in the dairy industry.
Is this about the next generation of owners and managers, or the next generation of dairy employees and supervisors? Or are we talking about the next generation of service and allied industry professionals? The answer, for the purpose of this article and panel presentation is "all of the above". Given current industry trends, the challenges associated with effectively preparing the next generation of dairy workers for an industry in transition are issues of great concern. Several industry experts recently have characterized the labor situation as the Achilles' heel of the dairy industry. An Achilles' heel is defined as a weakness in spite of overall strength, which can actually or potentially lead to downfall. The dairy industry has made great strides when it comes to sustainability efforts as was evident during the November 2015 completed 30th ADSA Discover Conference on Food Agriculture entitled Creating an Enduring U.S. Dairy Production sector. However, when it comes to preparing the next generation, especially during these challenging times of dwindling margins, extreme market volatility, consumer concerns about where and how food is produced, increasing competition from alternative protein sources, and many other threats, the future success of the U.S. dairy industry relies on how well we prepare the next generation to deal with those challenges. The question is Who is preparing the next generation, and how successful are we in preparing this next generation?

Current Industry Trends

In the U.S., the number of operations continues to decrease, and the volume of milk produced per operation continues to increase, due to increased production per cow, and the increased numbers of animals per operation. This trend is not unique to the U.S., but manifests itself all across the globe. More milk is being produced by fewer, but larger operations. This consolidation in the industry is primarily driven by economies of scale.[1] The number of dairy cows in the U.S has been holding fairly steady between 9.0-9.3 million head over the last decade, which prompts the following question. If there were about 90,000 dairy operations at the turn of the century with an average size of about 100 milking cows, and today, only 17 years later, we have approximately 45,000 farms with an average size of about 200 cows; then, how long will it take for the dairy industry in the U.S to evolve to 9,000 farms with 1,000 cows, or 900 farms with 10,000 cows, or alternatively completely flip from the year 2000 to 100 operations with each 90,000 cows? It's a hypothetical question and there will always be room for smaller farms in special markets where producers can secure higher margins because of their niche or specialty products, whatever the driver.[1] However, the real question is, where in the U.S. and on what kind of dairy farms will the large volume of commercial milk for the domestic and the export market be produced? To date the answer to that question has been on farms that (a) have grown in scale or size to offset the smaller industry margins, or (b) those farms that have grown in their level of diversification to be able to offset bad times in one area with good times in another.[1] There is no indication that this trend is not going to continue into the foreseeable future and may be accelerated or decelerated by external impacts such as world markets, weather and climate or public policy decisions.

Implications of These Trends on Labor Needs

Larger operations hire and employ an increasing number of workers. Our research has shown that on New Mexico dairies in 2008, an average dairy size of 2,100 cows had about 1 employee per 90 cows.[2] In 2011 (after the 2009 economic downturn), that number had increased to 1 employee per 100 cows.[3] After feed costs the next largest expense on large operations is labor costs Some industry experts are now predicting this ratio is likely to increase to 1 employee per 200+ cows.

Hiring a large number of employees changes the structure and the operational model of the dairy farm. On smaller dairy farms, the person milking the cows is typically also the impromptu maternity technician, hospital technician, milking barn technician, etc. As operations increase in size, we see an increasing degree of specialization and distinction between job functions to the point that positions become highly specialized and training becomes highly technical and job and task specific. These changes require employees who are better prepared, with a higher level of technical skills, particularly hands-on skills. The question again is: who is going to provide that level of specific training, and how are the trainers in turn prepared to provide that training? Many dairies utilize a "buddy training" approach where an experienced employee works alongside the new hire until the new hire demonstrates task proficiency.

The missing link in this system is that oftentimes both employees end up knowing "what" to do, without knowing "why" it is what they are doing. Unfortunately, the lack of worker comprehension of the "why" of the tasks contribute to critical errors, creating some of the major issues in the industry, especially in the public eye (animal handling, antibiotics, etc.). The dairy industry does not have an effective program or a system which instructs while simultaneously developing a worker's ability to do the job effectively and proficiently, regardless of the position on the dairy. There is a need for a system that addresses both comprehension and hands-on and practical training, while simultaneously assessing competency in the process.

Dairy employees are increasingly hired-labor as opposed to family-labor. Family-labor was raised while learning the tricks of the trade, and there was ample time for discussion of the "why". For hired-labor there are many missing links when delivering the same level of training and oversight. NAHMS Dairy 2014 indicates that 99.1% of large operations (>500 cows) utilize hired workers to milk the majority of the cows.[4] The number of operations that train milkers on proper milking procedures increase as herd size increases. Nearly 60% of operations train their milkers. On-the-job training was used on more than 90 percent of these operations.

Our experience in providing on-dairy employee training over the last few years has been that recent hires have no previous experience in working on dairies or with large animals. As a result, employees are not hired based on skills but based on the willingness to perform the job. Therefore the responsibility of all the training mainly falls on the shoulder of the owner/manager or his designee. It sparks the question how well is leadership prepared to adequately provide this training and oversight? Especially on today's dairies with the daily demands of operating an increasingly more complicated business.

Middle Management and Leadership Development

Dairies, with increasing herd sizes and a larger number of hired employees require a different management structure. A layer of middle management or supervisors is now required to oversee the work being done in the different departments (e.g., parlor, maternity, fresh cow, hospital barn & hospital pen, day old calves, breeding heifers, close-up, dry cow, feeding, farming operations, maintenance-mechanic, etc.). Dairy owners in turn are becoming more dependent on front-line supervisors to effectively manage a larger workforce. As a result, owners are increasingly seeking supervisors who demonstrate effective management and leadership skills. However, good workers are often promoted to leadership positions because of demonstrated skill proficiency in their current role (managing cows), not because of leadership or management abilities needed in a supervisory position (managing people). This 'Peter Principle' approach often leads to ineffective supervisory performance, particularly as it relates to leadership in terms of job preparation and training, job evaluation and coaching, and resolving employee issues.

During the 2015 Western Dairy Management Conference, a panel of producers discussed this subject and identified different ways of addressing this emerging issue for their specific dairy operations. Two producers on the panel, both in their own unique ways, had developed different, but functional leadership training models based on core competencies and core values inspired by the situational leadership model. However, very little guidance, few examples, and limited training models within the industry exist to assist them in this process.

One producer hired an accomplished HR manager from the human health industry, without any dairy knowledge, but with an accomplished track record to help develop a functional HR program for his operations. Specialized HR and management consultants can sometimes be of help assisting dairy producers accomplishing these goals. Some dairy extension specialists are venturing into this arena as well.

The goal of one of our latest projects is to reduce injuries and fatalities among a vulnerable workforce on dairy farms by operationalizing an integrating a safety leadership and management model in dairy farm enterprises. The central hypothesis of the proposed project is that a targeted safety leadership and management training will yield improved safety leadership and management practices among dairy supervisors which in turn will improve the safety climate and behavior among workers. The rationale that underlies the project is that improved supervisory safety leadership and management will translate into a reduction of injuries and fatalities among workers.

This 5-year collaborative project will kick off in the spring of 2017, and the team will be working with dairies across the West. The Primary Investigator (PI) for this project Dr. David Douphrate at the University of Texas Health Science Center at Houston, School of Public Health will be working with extension dairy specialists at New Mexico State University (Dr. Robert Hagevoort), Colorado State University (Drs. Noa Roman Muniz and Stephen Reynolds), and Kansas State University (Dr. Luis Mendonca). The project is funded through the National Institute for Occupational Safety and Health (NIOSH) through the High Plains and Intermountain Center for Agricultural Health and Safety (HICAHS), headquartered at Colorado State University.

Training Not Just a Must for Employees and Management

The lack of a comprehensive understanding of today's dairy industry and the practical aspects of large modern dairy operations is not just reserved for prospective employees. Dairymen continue to express their frustrations that people, not just in society, but within in the industry do not know what owners and managers are experiencing. Subpar comprehension and the lack of recognition of what it takes to run a large dairy farm from any perspective including the regulatory framework, the financial constraints, and the technical requirements of feeding, breeding and milking of a herd of 3,000 cows is extensive.

In 2007, a group of university faculty, industry representatives and dairy producers in the Southwest, concerned about the direction where many universities were going with their agricultural, animal science and dairy science programs, came together in an effort to do something about this issue. to The key issue was preparing the next generation of dairymen, managers and allied industry professionals despite diminishing university dairy programs. This concern was very real because of recent closures of on-campus dairies at Texas A&M University, New Mexico State University and the University of Arizona, despite booming dairy sectors. With the cows gone, the opportunity to learn ceased, which lead to fewer students and ultimately to fewer dairy faculty.

A search of U.S. dairy science programs nets the following results for either 4-year or 2-year associate dairy programs. Hoard's Dairyman mentions 40 colleges with a 4-year dairy program and 30 colleges with a 2-year associate or certificate program.[5-6] Of the 40 4-year colleges 10 offer a dairy major, 14 colleges offer a dairy option and 16 colleges don't offer a dairy science degree program. Interestingly of the 40 colleges listed, 39 do have a dairy herd, 25 of those herds are located on campus, and 11 colleges have off campus herds. Of the 30 2-year colleges 19 have a dairy herd.

Although there are several universities that have been able to find funding to update, modernize or even (re)build brand new dairy research/teaching facilities, many of the facilities around the country are older facilities, outdated, and certainly not representative of today's modern dairy operations. In addition, either because of diminished student numbers, tough times in the dairy industry or due to a lack of institutional support, many colleges and departments are having difficulty in keeping the barn doors open.

In 2008 the U.S. Dairy Education and Training Consortium (USDETC), formerly known as the Southern Great Plains Dairy Consortium, was established. A multi-university organization has the goal to meet the educational and training needs of the rapidly changing U.S. dairy industry. The USDETC is a unique partnership between academia, allied industry and dairy producers. Since the cows are no longer where the students and the faculty are located, the premise of this program was to bring students and faculty where the cows are located. The USDETC is organized to provide practical, hands-on large herd dairy education and training.

The program is meant to be a capstone learning experience for advanced college students in Animal Science, Dairy Science and Ag-Business in preparation for entry into the dairy industry or advanced degree programs. The program strives to unite the best students with the best faculty in a geographical location conducive to hands-on practical teaching through on-farm practica combined with field trips, laboratories and allied industry interactive experiences. Instructional faculty are nationally recognized experts from universities and agribusiness. The material presented ensures that the latest in technology and information is available to the students.

The program has been organized in Clovis, New Mexico, primarily because of its proximity to many large-herd dairy operations within a 30-mile radius. During the 6-week program, students visit about 20 dairies with different housing, milking, and management systems. These visits, field trips, labs and other on-dairy activities, can only be accomplished because dairy families open their doors and welcome the students. Dairy producers realize from experience the value of experiential learning in the realistic setting of an operational dairy farm. These dairy families are the real success story of the program: without their help the Dairy Consortium would be just another class in college. Throughout its 10-year existence, the USDETC has received exceptional support from producers, producer organizations and allied industry. Many faculty members recognize the value of a capstone class like this by recommending their students to attend.

Since its inception, the USDETC has graduated 40 students per year from 44 different universities throughout the U.S. A little over half of the students come from universities in the Southwest, but increasingly the students are coming from across the U.S. For the last 5 years, program coordinators have capped the program at about 50 students, while the number of applications has now nearly doubled the number of available slots. Program leadership is evaluating ways to expand the program both in number of students as well as the learning experience to possibly include farms in the Midwest.

In a 2013 survey among former Dairy Consortium students, a third indicated they were working on a dairy, while another third of students had found employment in a dairy related industry. Interestingly, 60% of the students rated the program very to extremely important to their status at that time as a student or as an employee, 80% of the students rated the material covered during the program as very to extremely helpful with their coursework and professional career, and 92% of the students rated the Dairy Consortium program A to A+.

Invited to join this panel is Jason White, a Dairy Consortium graduate who recently completed his Master's at Oklahoma State University. Jason will be sharing his experience with the program as a student and as a graduate assistant involved with the coordination and day-to-day operations of the program.

Professional Advancement Program

The next step for the Dairy Consortium was to offer this kind of hands-on training and practical education to allied industry professionals. This professional development program provides current dairy professionals with dairy educational experiences beyond their respective fields of expertise. Much like the college student program, the professional advancement program is taught both in both the classroom and on dairies by nationally recognized experts from universities and agribusinesses. In this program, the client can pick topics from a menu as many topics may not be of interest or applicable to the client. However, these employees may lack professional advancement in areas such as facilities and design, animal handling and welfare, parlor management and milk quality, financial analysis, reproductive management, dairy herd dynamics, dairy labor issues, dairy safety training, calf and heifer development, heat stress abatement, etc.

For the first time the Dairy Consortium offered a two-week program in 2016 and the feedback has been overwhelmingly positive. During this panel presentation, we have invited Dr. Jeff Brose with Cargill's Dairy Enterprise Group and coordinator for the Dairy Consortium professional advancement program to share his experiences with the newly developed program.

Responses from dairy producers to the program have been very positive. An advantage of the program is to be able to work with allied industry professionals that comprehend the depth and breadth of the business and understand what a producer is experiencing at any point at time. As with the college student program, the success of the professional advancement program lies in the willingness of producers to open their doors and share of their experiences. We see a multitude of opportunities for this program going forward not only in the Southwest, but able to be duplicated across the nation. The Dairy Consortium is looking forward to being able to formulate similar programs to other allied industry companies.

Workforce Development

The most daunting challenge in preparing and training the next generation is workforce development. There are virtually no national programs preparing potential dairy workers prior to seeking employment. There are no industry-wide standardized training or certification programs that workers can take to indicate to employers that they have acquired specific proficiency or competency levels. Many of the breeding companies offer certificate programs for artificial insemination technicians, however these are in essence only a “Certificate of Attendance or Completion”, because there is no national program for certification in artificial insemination. Dr. Jan Shearer offers the Master Hoof Care Technician Program through Iowa State University. Successful completion of this program, qualifies the candidate as a Master Hoof Trimmer. The University of the Frasier Valley in British Columbia offers a 1-semester Milker Technician Certificate program.

Beyond basic employee level training and certification, Michigan State University offers a Dairy Management Certificate Program developed to meet the specialized needs of the herd manager and commercial dairy farmer. This technical training program consists of two 15-week semesters and one 9-week semester on campus for a total of 48 credits. Programs of study are tailored to the individual's educational goals. Areas of study include: dairy herd management, nutrition, artificial insemination, crops, and farm management. A certificate is granted at the completion of the program requirements.

Nationally, National Milk Producers Federation (NMPF) in collaboration with the cooperatives, is advancing the FARM Animal Care program assuring responsible management for U.S. dairy producers. A second piece, FARM Environmental Stewardship program is currently under development. Within these programs there is potentially room to house workforce development training and certification programs. The new FARM Version 3.0 will provide educational materials (video training modules) on stockmanship. However, neither one of these programs directly provides actual training programs or on-farm training at this time.

Regionally, there are many producer organizations that have taken on this charge and are providing a myriad of excellent educational programs. Professional Dairy Producers of Wisconsin (PDPW), Professional Dairy Managers of Pennsylvania (PDMP) are just a few which provide excellent educational programs for their membership. Across the country many grass roots state producer organizations partner with industry or university dairy extension programs in an effort to do the same.

However, at this point, essentially all dairy skill training and development is done on-the-job as employees learn the practical “what” skills. The critical “why” portion of the equation is the great unknown. Many allied industry companies have filled this gap and have created workforce development programs in their respective fields of expertise either as a for-a-fee or free-of-charge service program. Many dairy industry professional service providers such as veterinarians, nutritionists, environmental consultants and others have made it an essential part of their service to provide workforce training.

Training Tools Target Audience

A major dilemma for most regarding dairy training is what training resources to utilize. There is only a limited arsenal of training tools developed for a predominantly Hispanic dairy workforce. There is a wide variety of written materials available developed for training purposes, many of them in Spanish and many with a healthy dose of pictures. These materials are very useful; however, many of the skillsets needed on a dairy are difficult to teach with pictures: they require hands-on instruction and return demonstration. Animal handling and stockmanship are probably the best example of that, followed by skills such as breeding, milking, treating sick cows, calf management, etc. Just providing employees (beginners or advanced) with instruction manuals probably doesn't achieve the level of comprehension and retention we would like, which ultimately leads to process drift and poor performance.

Likely the least effective way of training employees is by simply handing out standard operating procedures (SOP's) or best management practices (BMP's). The dairy industry has been very good in developing these and they are essential reference materials at the management level, but are useless as training or teaching material. They are neither practical nor visual, and they are complex for employees because they often require decision-making along the command chain.

We have provided safety trainings over the last 2 years to 1,048 dairy employees on 28 dairies in 5 states across the U.S. Data obtained during these dairy safety trainings indicate that 77% of the employees are from Central or South American nationality, while 82% indicated their primary language is Spanish. Collected data suggest 30% of trainees had completed a middle school equivalency, 18% had completed elementary level education while 5% indicated they had received no schooling. This suggests that in order to reach all employees, training tools need to be based on secondary education, and be available in both English and Spanish. A complicating factor is that almost 19% of the dairy workforce originates from Guatemala, where some of the employees indicated to only speaking one of the many indigenous languages, limited Spanish, or no Spanish at all.

Interestingly, 32% of the trainees indicated they had completed high school equivalency while 16% had completed a professional degree. However, with over half of the employees having completed a middle school equivalency or less, the training materials will need to be focused on that level of reading comprehension. In short we are dealing with a predominantly adult audience which we initially need to address at probably no higher than a 5^{th} or 6^{th} education grade level. In order to engage and motivate the majority of the employees in a training program we need to use tools that are innovative and captivate both visual (think in pictures) and kinesthetic (tactile or hands-on) learners. Simple pictures or PowerPoint-based presentations are likely not sufficient nor effective learning tools.

Employees who milk, feed, breed, treat and take care of cows, need to have tools that instruct and train them on those important specific skills. And most importantly, how to perform tasks in a safe manner. Today's newly hired dairy employees are less experienced in farming operations prior to their dairy employment, and basic understanding of working with large herding animals is nonexistent. Dairy owners and managers who grew up around cows may find it difficult how to explain these skills because they learned them instinctively. They know instinctively a cow has a flight zone that changes depending on how calm she is, but may find it hard to explain that to employees. Producers may not know what these specific concepts are called, but they know how they work.

One simply cannot train employees stockmanship using a flow chart. The most effective method to train adult learners is using hands-on learning activities, with a group of cows in the corrals showing how handling concepts work. Currently we do not have a comprehensive program in our industry that teaches employees these skills, tests for comprehension and competency and subsequently rewards them accordingly. In our opinion, every employee working directly with cows should routinely be trained and re-trained on animal handling and stockmanship.

Milker schools or trainings are probably the kind of trainings most frequently conducted on dairy farms. Milking cows is typically the starting position for most employees on a dairy. The task is physically challenging and repetitive, in particular on large farms where milking is a continuous process and the cows are milked in shifts. To milk cows properly and do it efficiently, a great deal of understanding of a wide range of disciplines such as animal health and physiology, animal handling and stockmanship, and milking machine operation and maintenance are required. Often beginning milkers are instructed how to milk the cows without much detail of why it is they are asked to perform the routine a certain way. A large amount of research has established proper milking routines. If milkers are not instructed the reasons why the routines are what they are and why it is critical to follow these routines, it is easy for workers to find reasons for short cuts and process drift ultimately leading to employee turnover.

Milker schools are typically delivered in a team setting, which may include hands-on show and tell, discussing the why's about the routine and milk let down, animal handling, hygiene, and how to detect cows that may need additional treatment. Training, motivating, and coaching a good group of milkers is a challenging task. We need barn managers that understand the technical aspects of milking cows, but even more important, we need barn managers that can work well with people and who can effectively coach and motivate an effective team of milkers. Simply promoting your best milker is not a guarantee he or she will become an effective barn manager.

Too often milkers are viewed as a unit or team: the day crew or the night crew. However, they are individual milkers who are either more or less experienced. Some do a great job, and some don't. The industry must develop individual performance metrics for our milkers, such that we can evaluate how an individual is performing his or her job – as part of a team. This approach will reward individuals for their specific performances and contributions and coach them accordingly. Judging milkers based on somatic cell counts (SCC) is a poor metric for individual performance. If dairies do not evaluate the individual milker's performance, the farm will eventually lose the best milkers because of a lack of appreciation for the good job they are doing. Critical is the training and development of all barn positions, including that of the "pusher". This person should be the most experienced person in the barn, equipped with the right skills and the patience to always bring cows into the parlor gently, no matter the circumstances.

Beyond what you can do on the farm to train, develop and coach individual employees, we also need a federal farm worker policy that compliments these efforts. A system which is conducive to worker training, development and retention and which would give producers additional incentive to improve job training protocols as part of long-term workforce development. However, the lack of this comprehensive federal workforce policy in agriculture, cannot be an excuse not to develop the right tools and programs at the farm level to adequately train and prepare our employees.

Development of Training Tools

In the dairy industry, there is a need for the development of not just more training tools, but for more effective training tools. Effective training tools are materials that maximize learning comprehension and retention in adult learners, both visual and hands-on, in their respective language and at their level of comprehension. In addition, we need appropriate performance metrics which will allow us to measure progress and evaluate job performance for the individual employee.

When developing our initial dairy safety training program in 2011, we originally created two safety training DVD's entitled "Considering Human and Animal Safety".[7] The DVD's contain 12 chapters dealing with both general and more specific dairy safety topics. These chapters are short individual vignettes visualizing and describing specific dairy tasks. After every chapter, there is a "remember" section reiterating the critical messages for the chapter. The DVDs were a hit and over 6,000 copies have been distributed worldwide. The strength of a video is that it visually presents the issues and the narration complements the storyline. The weakness of the DVD is that even though watching it in its entirety takes only 20-30 minutes, the trainee can be distracted and loose attention. This is a legitimate concern with training tools which are not interactive and where the trainee is only required to watch without participation. Dairy owners have no way to evaluate and measure if trainees actually paid attention and learned the training topics.

In 2014, with funding from OSHA Susan Harwood Targeted Topic Training Grant, Dr. David Douphrate at UT Health Science Center Houston proposed utilizing the video vignettes on iPads to individualize the dairy safety training. This program allowed us to create a continuous training, in both English and Spanish, with interactive activities between vignettes, to more effectively accommodate adult learning for this population. In addition, we added pre- and post- tests to evaluate the training. The trainees were given an iPad and a set of earbuds so that they could individually participate in the training at their own pace. The software allowed us to insert questions throughout the vignettes so that trainees must actively participate and answer questions advance the program. We later discovered this eliminated “group dynamics” where in certain circumstances group leaders may be engaged while followers are not. The individual trainings would take about 1.5 hours, and we could accommodate 20 trainees in a single training session. Trainings were conducted in offices, break rooms or even outside, weather permitting. An additional benefit of using earbuds is that once a person is engaged with the training, trainers can still instruct other trainees on the program without interrupting the others. Training evaluations according to Kirkpatrick’s model of evaluation (e.g., Level I, Level II, and Level III) were delivered. Each worker received a Certificate of Safety Training upon completion of the training and dairy owners received a training report with names of participating workers, the training content, as well as the mean scores of pre- and post-tests. The gender ratio of workers was 15% females to 85% males, with an average age of 34.3 years, and an average of 7.5 years of experience on dairy farms. The most promising part about this project was the average pre-test score was a 73% while the average post-test score was a 94%, suggesting the workers retained the knowledge gained during the safety training.

We have received very favorable feedback from both employees and owners/managers. Both groups liked the visual learning component complemented with interactive questions and a test. One advantage is that in a reasonable timeframe a fairly large number of employees can be trained. We would generally have a group of milkers attend prior to their shift while the current milkers would attend as soon as they came of the shift. Feeders, calf feeders and outside technicians would receive training as they completed their tasks. This training approach created minimal interruption in the daily schedule for owners and managers.

A key question still remains related to degree of training effectiveness related to worker safety behavior. One way to measure this conduct is to return to the dairy and measure worker behavior through observation. This however is near impossible both timewise or budget wise. Additionally, a one-time training is likely not going to make much impact in the long run.

Worker training should be viewed as an ongoing quality improvement endeavor. Training is part of a strategy which starts at the top and makes it way down to individual workers. Training is the means of demonstrating and visualizing the “what” and more importantly the “why”. Training needs to be evaluated and adjusted to the level of experience. However, what this project taught us is that the use of modern technology can accommodate and facilitate on-farm training for adult learners with minimal interruption of the work environment.

Mobile Learning Platform and Content Development

The use of video and audio in an interactive environment as described above can be utilized on the farm for many different training purposes at all levels of experience. This methodology can be used for instruction and it can be used to evaluate comprehension or competency. Additionally, it can be made part of a continuous training program on-farm or as a prerequisite and certification prior to employment. This approach can be made part of a program to evaluate worker performance and as a tool for continued education. The development of content is crucial. We are currently in the process of developing the video content or a video library for this mobile learning platform. One track is the development of training materials for healthy animals such as: animal handling and stockmanship, feeds & feeding, silage production, equipment handling and maintenance, reproductive health and AI, and milk quality and the milking routine, and others to come. Another track would be that for special needs animals: hospital management and the hospital barn which would include non-ambulatory cow management and euthanasia, animal handling for the maternity area and animal handling for day old calves and heifer raising.

This process is in essence translating paper SOPs to video-SOPs (VSOP), hereby creating a library of video content for the purpose of training and evaluation. Training material would be developed to the highest standards and training modules can be more efficiently distributed to employees via a mobile platform using cellphones or tablets. Employees can be reminded that certain protocols have changed and that they need to (re)take the additional training and (re)certification. Only employees that are involved in these practices and/or cross-trained for these positions would receive these notices. This would allow us to customize a training program for every department with the help of modern technology. We would also be able to monitor who is trained and certified for certain positions or activities. This could help us with scheduling and planning. Moreover, this can also be the basis for a true employee job performance evaluation and promotion program. Employees with the desire to advance or acquire additional skills can do so at their own pace or as part of a concerted company effort. Employees would now have a standard level of competency when applying for a job: dairy owners would know what training a worker has received and their specific skillset. Now we can start hiring based on competency in addition to the willingness to perform the task.

Taking Mobile Learning Live

The ultimate goal is to utilize these training modules as a part of hands-on training. We can make content available via mobile platforms such as cellphones or tablets, or screens in parlors, maternity or treatment areas. We can demonstrate on a mobile device the “what” while explaining the “why” directly to employees as they are being instructed by management, consultants or other trainers. We can demonstrate to workers directly on a screen how to pull a calf during a difficult delivery. We could even bring in the veterinarian remotely if needed. At the end of the day nothing speaks as well as seeing it performed while doing it, being instructed in the “what” and “why” simultaneously with the option of evaluating performance live through return demonstration.

We are currently in the final phase of editing the stockmanship video NMPF is planning to utilize for the newly released FARM Version 3.0. This video and other video content are the basis for the development of our next mobile platform training project funded through another OSHA Susan Harwood Training Grant. Safe animal handling and stockmanship training modules include simple cartoonlike representations of difficult to visualize concepts such as the "flight zone", "point of balance" and "pressure and release."

We will provide a (small) group of 5-10 animal handlers stockmanship training via iPad after which we will provide live demonstration. This is the only effective mechanism in which concepts such as the "flight zone" or "point of balance" come alive. After the live demonstration, handlers will be provided the opportunity to practice proper animal handling concepts and will be asked to perform a return demonstration to assess skill fluency As with the safety training, a pre- and post-test will give us a way to evaluate the training tool, and receive information about the level of comprehension.

The Dairy Consortium: A Vehicle to Train the Trainers

Much effort is required to take these projects from their current research and development phase to real world application on dairies. Even after all the video content is developed, a comprehensive industry effort is necessary to put the program into practice across the national industry. This is where the Dairy Consortium will play a key role. The Dairy Consortium is already in the business of preparing the next generation of dairy industry professionals. How more appropriate than to use this established and effective program to train the next generation of trainers.

Industry Buy-In and Support

A number of drivers have facilitated industry support for this initiative. In an age of diminishing profit margins, owners and managers are looking for opportunities for efficiency and performance improvements. A second driver is the lack of available dairy labor. The flow of potential laborers willing to work on a dairy and perform the physically challenging tasks has diminished greatly over the last few years. Reasons for that reality go beyond the scope of this article and it suffices to state that a lack of comprehensive immigration reform is a significant contributor to the problem. This does imply that current dairy employees have to become more effective, efficient and productive with diminishing time and resources.

Another piece of the equation relates to industry regulations. Working in agriculture in general and dairies in particular is associated with inherent hazards including large animals, large equipment, chemicals and other dangerous working environments. As dairies become larger and hire more employees beyond family labor, they now fall under OSHA regulatory oversight. OSHA has already implemented Local Emphasis Programs (LEP's) for dairy in Wisconsin and New York, with plans for an additional LEP for Idaho agriculture operations. This means that dairies will be inspected and they have to provide evidence that they conform with OSHA rules and regulations. Regulatory compliance is already being implemented on dairies and it is our experience that most dairy operations are a long ways towards becoming OSHA compliant. However, there are certain areas (administrative being one) most producers are unaware and unfamiliar with the exact requirements.

A Practical Example: Idaho

Part of the safety training Dr. Douphrate and his team in collaboration with NMSU Dairy Extension has provided is reviewing and preparing for what exactly OSHA rules and regulations mean on a dairy. For example: we are working with producers to identify practical and cost-effective solutions to protect workers for the hazards associated with manure lagoons.

Providing training to over 500+ workers in multiple states is a daunting undertaking. To facilitate this endeavor, the Idaho Dairymen's Association is proactively in search for a dedicated personnel to deliver safety trainings on Idaho dairy farms. For the purpose of this panel we have invited Mr. Bob Naerebout, Executive Director for Idaho Dairymen's Association (IDA) to share an industry perspective on this project.

Conclusion

U.S. dairies are becoming larger and are employing larger numbers of hired-labor as opposed to family-labor. The industry does not have a comprehensive training program for its managers, supervisors and workers., Our universities have diminished capabilities to prepare the next generation of owners, managers or allied industry professionals. The U.S. dairy industry as a whole has only found limited means to adequately prepare the next generation of employees and middle managers. Leadership development at the middle manager level is almost non-existent.

Dairy families across this country are doing all they can, with the tools they have, to train and prepare employees for increasingly specialized positions through on-the-job training. Larger dairy operations have developed their own individualized toolboxes for this purpose. Many of the tools are currently provided by allied industry either as a service or for a fee. Training materials are developed largely by allied industry and dairy extension. A large part of effective training and preparation programs currently available is provided through excellent efforts provided by grassroots producer organizations. As an industry, we are waking up to the realization that workforce development and HR issues are the Achilles heel of the dairy industry.

The industry collectively must develop tools needed to prepare the next generation. Universities alone have limited capabilities as workforce development is not their mission, nor do they have the resources. A larger role for community colleges is likely required as they are the most logical vehicle for both academic and certificate programs. National dairy organizations supported by cooperatives and in conjunction with grass roots producer organizations will have to determine what exactly those requirements for training and certification programs need to be.

In the Southwest, the USDETC was established to address the issues described earlier. Initially, the efforts were regional; however, over time, the efforts have increasingly become national. The objective was to address the educational needs of the next generation of owners, managers and allied industry professionals. As time progressed and the needs became clearly defined, the USDETC became involved in workforce development through dairy safety training, animal handling and stockmanship training. The next venture is professional advancement or continued education programs for allied industry. Widespread industry support is providing the impetus for this growth. The USDETC's non-profit status allows for industry contributions as well as grant writing efforts to sustain the educational goals. Training tools being developed make use of the latest mobile technologies, are innovative and target the specific needs of the current and future dairy workforce. At the end of the day the question needs to be asked: how sustainable is an industry that cannot adequately address the challenges of preparing the next generation?

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Top Ten Considerations for Dry Cow Cooling

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While producers are quite familiar with the positive effects of cooling cows during lactation, fewer understand the impact of cooling dry cows. Yet there is increasing evidence that failure to cool cows when they are dry leads to negative effects on productivity and health in the next lactation. Perhaps more critical is the emerging data that indicates a significant impact of in utero heat stress on the developing heifer, which results in long term effects on that calf's productivity and health. This paper considers those topics, along with the economic and implementation considerations.

1) How does dry period cooling affect milk yield?

Cows that experience heat stress during the dry period make 8 to 10 pounds less milk each day in the next lactation compared with herdmates that are cooled. There is no impact on milk composition, though component yields are increased with cooling. The effect is present on the first day of lactation and persists for at least 40 weeks, though all evidence suggests it persists through the entire lactation. Mammary epithelial cell growth is depressed in heat stressed dry cows relative to cooled animals, and that is consistent with greater capacity to produce milk in the next lactation.

2) What are the metabolic effects?

Similar to lactating cows, heat stressed dry cows consume less feed compared with cooled cows. Despite the lower nutrient intake, there is no evidence that heat stressed dry cows experience any impact metabolically during heat stress. Indeed, there is no difference in basal or stimulated insulin, glucose or free fatty acids between cooled and heat stressed dry cows. After calving there are some transient effects of dry period cooling, but they are all consistent with the observed increases in milk yield in those cows, and it is important to note that all cows are cooled during lactation so those metabolic effects could not be due to continued heat stress.

3) Is cow health affected?

During the dry period, heat stress reduces antibody response to vaccination, and lymphocyte (i.e. white blood cell) proliferation is also lower. Thus, heat stress has direct negative impacts on the cows ability to respond to pathogens during the dry period. Interestingly, there are carry-over effects of dry period heat stress on immune function, with those cows having lower innate immune responses in early lactation relative to their cooled herdmates, even though they are at a lower level of milk production. The improved immune status in cooled dry cows resulted in better responses to *S. uberis* challenge in early lactation.

4) What about reproductive performance?

The strongest indication that dry cow cooling does not negatively impact subsequent reproduction comes from a study that compared cows that were dry in the coolest months of the year (i.e. December to February) to those dry in the hottest months of the year (i.e. June to August). Cows dry in the coolest months produced more milk and were less likely to contract disease compared with those dry in the Summer. Cows dry in the cool months had fewer services to pregnancy, fewer days to pregnancy and thus fewer days open versus those dry in the hot months; all indications that despite higher milk yield, and being bred during the hottest months of the year, a dry period during the coolest months improves reproductive performance.

5) Is calf health and growth altered?

Calves born to heat stressed dams are lighter at birth, remain lighter at weaning and even through 12 months of age, relative to calves from cooled dams. Calves that are heat stressed in utero are also shorter through a year of age. Passive transfer is also compromised in calves from heat stressed dams, with lower apparent efficiency of immunoglobulin (IgG) absorption translating to lower circulating concentrations of IgG through the first month of life. This is not due to a reduction in colostrum quality from the dam, but rather a limitation of IgG uptake. We have tracked calf health through the first lactation and found that more in utero heat stressed calves leave the herd due to sickness or illness before puberty, and thus fewer complete the first lactation.

6) Is heifer reproductive and first lactation performance affected?

Heifers born to heat stressed dams achieve puberty at the same age as those from cooled dams, but they require more services to achieve pregnancy. Most importantly, heifers born to heat stressed dams produce about 10 lbs/d less milk in their first lactation compared to the heifers from cooled dams; this effect is apparent from the beginning of lactation and extends to at least 250 DIM, and likely through the entire lactation. This response is not associated with differences in growth during the first lactation, as both groups of animals calved at the same bodyweight (BW) and had identical BW through the first lactation.

7) What are the economic impacts of heat stress for dry cows?

In a recent analysis we considered the economic losses associated with a lack of dry cow cooling across the US. Potential days during the year that a cow would experience heat stress were estimated for each state and the total number of cows in each state was used to estimate the total potential milk loss. The total potential loss from a lack of dry cow cooling is at least $810 million annually. However, that estimate only considers milk losses, and does not include any impact on cow health or on the calf. Thus, the total negative impact is likely much greater. But prevention of the milk loss alone is enough to yield significant positive return on any cooling system improvements.

8) How do I assess heat stress?

Because temperature and humidity both influence the ability of a cow to lose heat to the environment, it is best to use the temperature-humidity index (THI) to assess the relative heat load on an animal. Rectal temperature (RT) is the gold standard to determine heat stress, and RT increases at a THI of 68, so abatement should begin before that THI is reached. In addition to RT, respiration rate (RR) will indicate the relative heat stress a cow is experiencing, and can be used effectively in a barn to determine if animals are heat stressed. For example, measuring RR by observation of flank movements of a group of sentinel cows within a pen should provide an indication of heat load; an average RR of 60 or greater suggests that heat stress is occurring and abatement strategies need to be employed to actively reduce the heat load on cows.

9) How are dry cows best cooled?

Methods of cooling are no different from those used on lactating cows. In a hot, humid environment such as we have in Florida, soakers, fans and shade are effective abatement strategies for heat stress, whereas misters may be effective in more arid locations. However, shade alone will not provide adequate cooling for cows during high heat and humidity. Sand bedded stalls may also provide additional relief via conductive heat transfer to the sand. Overcrowding will exacerbate heat stress so be sure that dry cows pens are not above 100% stocking rate.

10) Where can I get more information?

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Notes:

Water Conservation for Next Gen Dairies

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Introduction

Water availability is an issue in many dairy regions in the US and internationally. Conserving water for the next generation of dairies in important to meet the global nutritional needs projected for 2050. There are many factors which determine water usage of a dairy such as heat abatement practices, milk parlor protocols and milk production (drinking water). Priority by the management and helping employees understand the long term importance of water to the future of the dairy industry is necessary to transition dairies to the next generation. This paper reviews current studies related to dairy water usage and outlines 10 potential conservation practices as starting point for water conservation.

Overall Water Usage on Dairies

Bjorneberg and King (2014) studied ground water withdraws on six Idaho dairies ranging in size from 660 to 6,400 milk cows. They based their water usage on “equivalent cow” to account for relative differences due to dry cows, heifers, milk cows and calves on each dairy. Average water withdrawals ranged from 29.1 to 66.1 gallons per day (gpd) per equivalent cow with an overall average of 50.2 gpd/ equivalent cow. Waste water that was available for irrigating crops was measured on three dairies and ranged from 5.5 to 39.6 gpd/equivalent cow. In this study, none of the dairies used sprinklers or misters to cool cows but summer water withdraw rates increased 26.4 gpd/ equivalent cow. Daily milk production averaged 70.4 pounds per milk cow. The average water to milk ratio was 6.8 +/- 1.8.

Robinson et al. (2016) monitored water usage on 17 Ontario dairy farms over a 20 month period using continuous flow water meters. Meters were installed to measure cow consumption and milk-house and parlor usage. They found water usage was on dairies equaled 35.0 +/- 13.0, 37.0 +/- 13.4, 37.8 +/- 8.7 and 26.8 +/- 0.2 gpd/cow for dairies with parallel, robotic, rotary and tie stall types of milking systems, respectively. These averages and ranges were based on sample sizes of 2 to 4 dairies per type of milking system. Overall, the water to milk ratio averaged 5.3 +/- 1.3 lbs water/lb of milk. This study found water usage per cow per day similar to those reported by Brugger and Dorsey (2008). The dairies in Robinson et al. (2016) study averaged 122 total cows with 13.5 % dry cows in the herds. Average water usage was reported as 35.6, 44.6, 26.8 gpd/milk cow for parlor, robot and tie stall type of dairies, respectively. For milk house parlor, water usage was 5.4 gpd/lactating cow. Overall the water usage was 20 to 25 % higher in summer months versus winter months.

Bray et al. (2014) published water budgets for Florida dairy farms. The average water consumptions was 25 gpd/cow with variation depending on “milk yield, dry matter intake, temperature and other environmental conditions.” They showed predicted water intakes ranged from 22.2 to 31.9 gpd/cow depending on temperature, dry matter intake and milk production using Murphy et al. (1983) model.

Potts (2012) evaluated meter well water records for twenty-four dairy farms consisting of 10 dry lot dairies, 12 freestall dairies, and 2 dairies using both freestalls and drylots were obtained from 2000 to 2009. The dry lot dairies average size was 4,387 cows and freestall dairies averaged 3,632 cows. The combined average water usage was 57 gpd pumped/cow. The dry lot dairies averaged 52.6 gpd/cow and freestall dairies average 61.4 gpd/cow.

Zuagg (1989) summarized the daily water usage on five dairies in Arizona (Table 1). Early lactating cows drank between 29 and 35 gpd/cow while late lactating cows drank 25 to 28 gpd/cow. Water consumption was less than 20 gpd/cow during the dry cow period on all of the farms. Water usage on a dairy varied from 72 to 186 gallons per lactating cow per day and averaged 127 gpd/cow. In reviewing the data in Table 1, wash pens accounted for 37.5% of the total water usage per cow on average. Comparing water usage on Dairies B, C, and D, where some form of heat abatement was implemented and heifers beyond 6 months were not raised on the dairies, the average water usage was 89.3 gpd/cow when considering the water used in wash pen and 58.6 gpd/cow when the water used in the wash pen was omitted. For the 5 dairies, the wash pen water usage ranged from 19 to 93 gpd/cow and averaged 50 gpd/cow. However, on dairies B, C, and D, the water usage in the wash pen averaged 30.6 gpd/cow. Water usage in the milking center excluding the wash pen ranged from 2.3 to 18.3 gpd/cow and averaged 11.2 gpd/cow.

Table 1. Summary of daily water usage on five dairies (adapted from Zaugg, 1989).

	Dairy Identification and Milking Frequency				
	A(3X)	B(3X)	C(2X)	D(2X)	E(3X)
Calf include from 0 to 6 month	No	Yes	Yes	Yes	Yes
Heifers include from 6 to 22 months	No	No	No	No	Yes
Dry & Close-ups cow (D–dry * C- close ups)	D	D & C	No	No	D & C
Cooling (M – Milk Center & P – Pen)	M only	M & P	M & P	M & P	M & P
Total Water Usage per Lactating Cow (gpd)	186	101	95	72	182
Wash Pen Usage per Lactating Cow (gpd)	93	49	19	24	65
Drinking Water per Lactating Cow (gpd)*	71.2	32.2	59.3	40.1	81.1
Milk Center Usage per Lactating Cow (gpd)**	18.3	2.3	7.7	3.3	14.5

* Includes water for dry cows, close-ups, calves and heifers
** Includes water reported usage for vacuum pump

Water Usage at the Milk Center

The most comprehensive study involving water usage in the milking center was conducted in Victoria, Australia, where water usage on 780 dairies was analyzed (Williams, 2009). Water usage varied among herds of similar size which is similar to previous studies. The 75th percentile water usage was defined by the industry as the “upper limit of what is ‘reasonable’ dairy water use for Victorian dairy farmers”. Herringbone parlors water usage per cow tends to increase with herd size and water usage in rotary parlors tended to level out after 500 cows at 16 gpd/cow. This extensive data set suggests an upper limit of ‘reasonable’ dairy water use equals 16 gpd/cow in the milking center.

Meyer et al. (2006) evaluated parlor water use on 16 dairies to calculate the amount of water flowing into dairy lagoons and holding ponds from August 1998-August 1999. They found parlor and udder hygiene water comprised an average of 56% of the total water entering the farms’ lagoons. The range was 45 to 194 gpd/cow with an average of 78.5 gpd/cow. Like the other studies, they reported that parlor water use was consistent throughout the year on each farm (Meyer et al., 2006). A second study in California (Castillo and Burrow, 2008) installed 64 water meters on 3 dairies in Merced County. Average water usage was 44, 51, and 49 gpd/cow.

House et al. (2014) monitored water usage in milking center from 29 different types of dairies in the Ontario Providence of Canada during the summers of 2011, 2012 and 2013. There was variability amongst the dairies but the milk center water usage averaged 5.97 gpd/cow (11 dairies), 8.95 gpd/cow (6 dairies), 3.67 gpd/cow (only 1 dairy) and 5.10 gpd/cow (4 dairies) for parlor, robotic, rotary and tie stall milking centers, respectively.

Water Conservation

Potable water usage on a dairy occurs primarily at the parlor facility (milking center) or the housing area. Water usage in the milk center includes sanitation, cow area including milking deck and holding pen, and plate cooler. The primary use of potable water in the housing area is either for drinking or heat abatement. The authors are not aware of any studies specifically designed with an objective to determine the overall water savings potential on a dairy. The milking center and housing area provide opportunities to begin to develop water conservation strategies.

Conservation Practice 1: Repair Water Trough Leaks and Adjust Floats Valves

Water leaks are common on most dairies in the parlors and housing areas. Leakage may occur due to inadequate pipe and joint connections, improperly adjusted floats on water troughs or toilets, and damage to main pipe lines. An observation of an improperly adjusted water float on a single water trough (Brouk 2013) estimated water losses of nearly 1.5 million gallons of water per year. The overflow pipe was discharging 2.81 gpm of water into the cow alley. In another pen the float was allowing 1.31 gpm to discharge into the alley resulting in annual water losses of 690,000 gallons assuming no adjustments. In other barns on the same dairy, water leaks from water troughs resulted in more than 1,000,000 gallons of water lost annually. It was calculated that daily at least 3 gpd per cow were lost due improperly adjusted floats on water troughs and leaks. Similar water losses were observed on a 2^{nd} dairy.

Brouk et al. (2001b) studied water consumption on three dairies during the summer months. Water consumption averaged 40 gpd/cow in the north barn and 64 gpd/cow in the south barn (Figure 1). Figure 1 shows the water consumption for individual water troughs in the north and south barns. The far water trough in the south barn indicated water consumption of nearly 31 gpd/cow. This water consumption was found to be significance due to monitoring in each water trough but was due to what was considered “a minor leak”. While a minor leak, the cost were significant since the purchased water resulted in about $0.25 extra production cost per cow housed in the south barn per day.

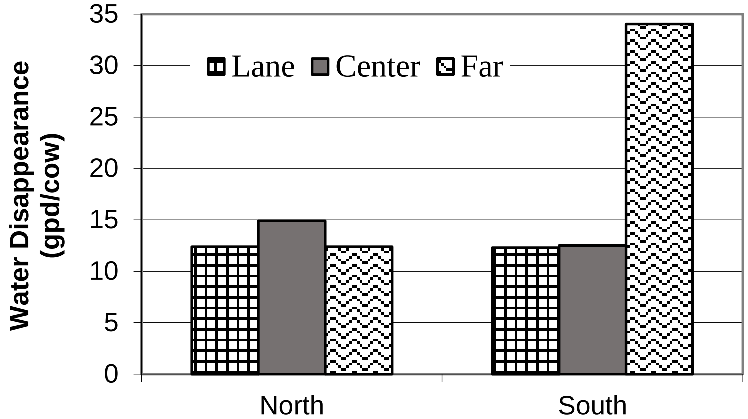

Figure 1. Water disappearance of individual water troughs in freestall barns on a northeast Kansas dairy (Brouk et al., 2001b).

Improperly adjusted toilets can result in water losses of 0.5 to 2 gpm. A 1 gpm overflow in a single toilet we result in extra 0.5 gpd/cow being required. EPA (2016) estimates the average household leaks are equivalent to 270 loads of laundry. Similar leaks in a milk center would equate to 0.5 to 1 load per day for washing towels.

Conservation Practice 2: Recycle Plate Cooler Water for Potable Uses

Most recycle the plate cooler water for other usages on the dairy. The warm water is most often used to supplement drinking water requirements or parlor deck flushing in parallel or herringbone parlor. To reduce water consumption on a dairy, the plate cooler water should be recycled for activities requiring potable water, such as drinking and parlor deck flushing, rather than using as an additional water source. Many state milk sanitation codes allow for non-potable water to be used for flushing the holding pen and some allow non-potable water to be used for flushing the parlor deck. Using potable water for flushing the holding pen should be minimized unless required by milk codes. Since the water exiting the plate cooler is clean even though warmer than ground water, usage for filling water troughs or washing the cow deck are better options. Generally the plate cooler water usage is 2 to 4 lbs of water per lb of milk. Assuming 80 lbs of milk and a ratio of 3 to 1, 28.8 gpd/cow of water should be available for refilling water troughs. During the winter months when water consumption is lower (Bray et al., 2014), the balance of the plate cooler water could be used for washing the cow deck.

Brugger and Dorsey (2008) monitored water usage on a 1,000 cow dairy in Ohio via installing 13 water meter at various water use locations. Monitoring water use enabled the dairy to implement water conservation strategies including adjusting the water flow rate through the plate cooler. The flow rate initially was 42 gpm through the plate cooler and this was reduced to 21 gpm without compromising the milk quality of plate cooler performance. Brugger and Dorsey (2008) reported this reduction saved 24 gpd/cow of water savings with lower the water flow rate through the plate cooler. The herd was reported to have an 80 lb milk herd average so the milk to water ratio was reduced from approximately 5.2 to 2.6 assuming the parlor was used 20 hours per day (not reported in the paper).

The water requirements of plate coolers is 1 to 2 lbs of water per lb of milk (Reinemann and Springman, 1992; Spencer 1992). Water usage may be more than 2:1 if no attempts are made to control water and irrigation water is diverted through the plate cooler prior to cropland application. At ratios of 4 to 1 or 6 to 1 the plate cooler water should be able to meet most of the other water demands on a dairy depending on time of year and current consumptive uses.

Conservation Practice 3: Adjust Feed Line Soakers and Holding Pen Sprinkler Nozzles

Feed line soaker systems for heat abatement may account for 10 to 30 % of the annual water consumption depending on the duration of hot weather. Water usage for heat abatement ranges from 17 to 100 gpd/cow. Brugger and Dorecy (2008) reported only 1 gpd/cow was used for cooling so there was minimum heat abatement on the NW Ohio dairy. One of the early recommendations was 2.6 lbs of water every 15 minutes. Armstrong et al. (2004) studied the impact of feedline soaker systems in a tunnel ventilated building in Thailand. The study compared evaporative cooling of the air vs strategies using evaporative cooling of the air and feed line soaking cows with 2.2 lbs or 4.4 lbs of water every 5 or 10 minutes. They reported body surface temperatures and respiration rates were lower for all treatments compared to the control. Treatment respiration rates ranged from 40 to 55 while control respiration rates were above 75. Lowest respiration rates were obtained using the 5 minute soaking cycle.

Means et al. (1992) studied consumptive water use for cooling dairy cows using nozzles with flow rates of 1.4, 1.9 and 3.1 gpm and 1.5 minutes and off 13.5 minutes. The sprinkler nozzles were turned on any time dry bulb temperatures exceed 78 °F. There was no difference in milk production, corrected milk yield, dry matter intake or milk protein between three trails using of 57, 84.4 and 120.4 gpd/cow for cooling cows. Means et al. (1992) recommended changing the nozzle size to reduce the water usage.

Strickland et al. (1989) studied the impact of cooling on cow performance. Milk production increased from 39.8 lbs. to 44.4 lbs. or 11.5 %. Cooled cows had an increase in both feed consumption and milk protein. In this study, cows were cooled in the holding pen with a sprinkler on cycle of 30 seconds every 5 minutes when temperatures exceeded 78 °F. They compared 3 treatments: sprinklers that delivered 0.34 or 13 gpm (both 3 min on and 9 min off, 24 h/d) and an unsprayed control.

Chen et al. (2016) found cows spent 5.8 ± 0.9 h/24 h (mean ± SD) at the feed bunk overall regardless of sprinkler delivery rate using a soaking strategy of 3 minute on and 9 minute off cycle. The cows soaked at the feed line stayed at the feed bunk on average 23 to 27% longer and made 13 to 16% less frequent trips compared non soaked cows. They found cows which were soaked at the feed line, had on average body temperatures increase 01.1 to 1.26 °F per 18 °F temperature rise in the hot dry climates in California. Non-soaked cow's body temperature increased 2.88 °F per 18 °F ambient temperature rise. They found no difference in milk production between soaking cows with application rates of 0.34 gpm versus 1.30 gpm but a water savings of 73 %.

Water conservation with feed line soakers is possible since research does not indicate an advantage to using more water assuming the same on cycle time. The original recommendation of 0.05 inches (Florida) appears to be still valid.   Assuming the cows back is equivalent to 10 sq ft, this presents an application amount of 2.6 lbs. or 0.31 gallons per soaking cycling. The current recommendation of 1 gpm nozzles spaced 8 ft on center and on for 1 minute results in 0.25 gallons or 2.1 lbs. per application cycle. Water conservation requires individual dairies to adjust the nozzle “on” cycle to limit water application rates to 0.25-0.35 gallons per cycle per cow. Some suggest turning off soaker nozzles when water is observed reach the widest (belly region) of a cows body using visual inspection.

Harner et al. (2015) estimated annual water requirements per dairy cow for heat stress abatement for different locations in the US (Figure 2). Annual water requirements were between 1,500 and 2,000 gallons per cow. However, in the extremely hot regions and areas where dry lot dairies are located the water utilized for cooling cows exceeds 4,000 gallons per year. Current heat stress abatement is based on air temperature control strategies; however, as shown in Figure 3 an estimated 30 to 50 % water savings could occur if technology was available to operate the controllers on THI rather than air temperature.

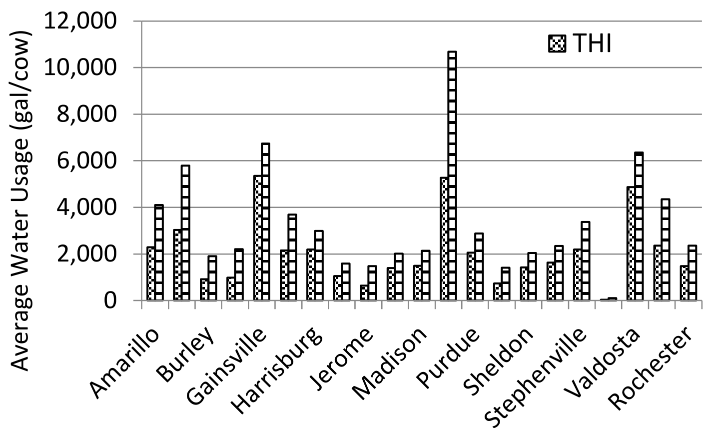

Figure 2. Estimate of the annual water requirements per cow for cooling using a feedline soaker system with 1 gallon per minute nozzle and spaced 8 feet on-center.

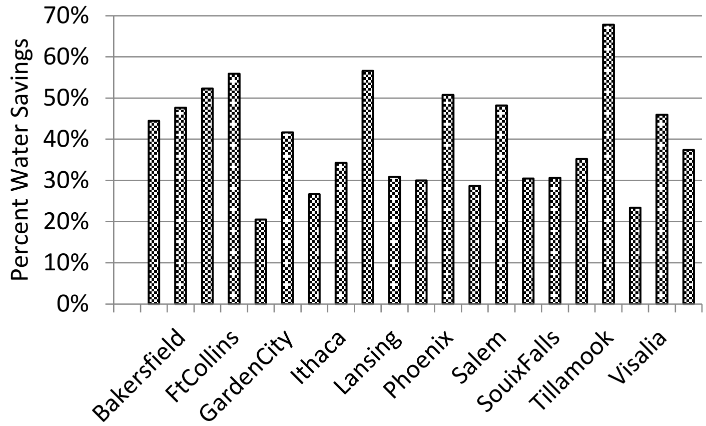

Figure 3. Estimated annual water savings if feedline soaker system was controlled based on THI rather than temperature

Conservation Practice 4: Adjusting Milking Center Floor Flush System and Use of Cow Deck Washers

Meyer et al. (2006) reported that dairies with wash pens averaged 78.5 gpd/cow while dairies without wash pens averaged 53.4 gpd/cow. This data is similar to the findings of Zaugg (1989). Sweeten and Wolfe (1993) found on Texas dairies milk centers with flush systems used 47 gpd/cow and scrape systems using 20 gpd/cow. The average water usage was 39.6 +/- 20.3 gpd/cow. Zuagg (1989) summarized the daily water usage on five dairies in Arizona (Table 1). The wash pens accounted for 37.5% of the total water usage per cow on average. For the five dairies, the wash pen water usage ranged from 19 to 93 gpd/cow and averaged 50 gpd/cow. However, on dairies B, C, and D, the water usage in the wash pen averaged 30.6 gpd/cow (Table 1). The range of water usage in the wash pens varies greatly based on available research reports. A reasonable goal for dairies would be to have the average water consumption in the wash pen of less than 40 gpd/cow.

Fresh, potable water is required by most milk codes when flushing the parlor deck of parallel or herringbone parlors. Water can be recycled from the plate cooler to perform this task. Weeks (1992) reported that 7.5 gpd/cow was required for flushing the milk parlor and holding pen. However, the milk parlor was only used several hours per day. Some data suggest an adequate flush can be obtained using 1.3 gallons per sq. foot per flush (Moore, 1989).

The parlor decks area is approximately 4,000 sq. ft. in a D50 parlor (3,000 cow dairy) or 40 sq ft per milk unit. Daily water usage is 12 gpd/cow if the deck flushing routine uses 1 gal of potable water per sq ft for flushing 3 times per 8 hour milk shift. Some dairies are using Programmable Logic Controller (PLC) controllers to limit the valve open cycle and frequency of flushing the parlor deck to reduce potable water usage. If a dairy is trying match plate cooler water to parlor deck flushing, then only 19 gpd/cow of water should be used or a total of 14 flushes per day. Using the 1.3 gal/sq ft (Moore, 1989) then with the above example the deck floor could be flushed 11 times per day to balance the flush water required with plate cooler water utilized.

A target based on a plate cooler ratio of 2 to 1 should be to use less than 2/3 of plate cooler water for flushing the deck and the remaining 1/3 for available for filling water troughs. If a dairy flushes between every group of cows, then potable water usage is 32 gpd/cow and additional water will be necessary. Dairies using more than 1 to 1.5 gal per sq ft for deck flushing should evaluate their protocols and determine if water usage can be reduced. In rotary parlors, the plate cooler water should be utilized to fill water troughs since potable water is not necessary for washing a parlor deck. Some dairies flush the parlor deck more frequently than necessary to eliminate water tank overflows due to excessive plate cooler water. Water conservation strategies should incorporate protocols to reduce flush frequency and transfer water to other applications.

Conservation Practice 5: Evaluate Water Trough Protocols

Brouk et al. (2001b) monitored summer water disappearance in the housing area on three dairies. Combined water trough disappearance on one dairy averaged 35 gpd/cow. Based on Murphy et al. (1983) drinking water equation and Bray et al. (2014) water recommendations, water consumption was higher than anticipated. This dairy had a protocol to tip and clean all water tanks once a day. Based on the tank volume, it was estimated that refilling required 4.7 gpd/cow or was equal to approximately 14 % of the anticipated water consumption of 30 to 32 gpd/cow. Modern tanks which are shallower and have less water capacity use about 1 gallon per cow to refill a drained tank. Adjusting the frequency of cleaning water troughs to every 2 or 3 days may be a way to reduce water consumption without reducing herd health impacts. The other option is for the cow pusher to use a skimmer to remove the “crud” from the tanks rather than tipping or pulling a drain plug to clean the tanks.

Many dairies are located in colder regions where ice in water trough is a problem. One common solution is to adjust the floats to allow for a continuous flow of water. This management strategy results in approximately 1 gph/cow of extra water used with the continuous overflow management strategy. If water is being purchased, frost free or insulated water troughs may be economical.

Conservation Practice 6: Use and Control of Water Hoses in the Parlor

The authors are not aware of any studies looking at the water use by hoses located throughout the milk center. The general consensus of the milk center data collected is water used probably ranges from 6 to 12 gpd/cow. Strategically located hoses are critical in the milk center to maintain necessary sanitation to meet milk quality standards. Assuming a least one hose of the many hoses in a milk center is on 25 % of the time, then estimated water usage is 1 to 2.5 gpd/cow. Monitoring hose usage and total time per day to wash down individual claws may reveal an opportunity to conserve water in the milk center. Installing and maintaining easy to hose nozzles so no water flow is occurring when hoses are not in use will help conserve water.

Conservation Practice 7: Look for Abnormalities in the Cow Wash Cycles

Brugger and Dorsey (2008) relatively early in the Ohio pilot project discovered metering to be an effective management tool for water conservation. He noted:

> “*Observation of parlor water data revealed a 6-gallon per minute spike over “normal” usage. This 6-gpm flow remained even during down time of parlor water usage. Investigation eventually led to a faulty valve in the high pressure parlor wash down line. This*

"leak" was responsible for 8,640 gallons of waste water in a single day. Undiscovered, it could have resulted in much greater loss."

Monitoring parlor water usage also led to observations of shorter and longer wash down cycles. This led management to conduct corrective employee training. After the training, the parlor wash water use was very consistent and at a reasonable level." Metering of the water usage during cleaning of the bulk tank metering discovered the recommended wash down cycles was shorter than desired. The drivers were not turning the activation knob to the full 60-minute position.

The Dairy Practice Council (DPC) (Weeks et al. 2004) recommends water requirement for bulk tanks with an automatic washing, cleaning in place (CIP), of 5 gallons of water per 100 gallon. So for a 5,000 gallon tank, the CIP water required would be 250 gallons.   The DPC guide suggests 1, 4 and 3 gpd/cow for udder washing (towels), stall preparation and back flush milker units, respectively. The DPC "Guidelines for milkrooms and bulk tank installation" provide additional water usage recommendations for cleaning pipe line systems on pipe diameter and length.

Conservation Practice 8: Consider Eliminating Extra Yard Work (infrastructure leaks)

Most dairies have a small "wet spot" creating extra yard work due the green grass or weeds growing. These "wet spots" are due to infrastructure losses such as an above ground pipe joint that has a small "drip" leak or an underground leaking pipe. No one knows the volume of water lost on dairies due infrastructure leaks.   A 2011 report by the California Public Utilities Commission estimated 10 % of all urban water deliveries are lost due to leaks and antiquated infrastructure. Review of web news articles of municipal public water supplies shows estimated infrastructure water losses from 3 to 20 percent. Martin (2016) noted California water losses could equal 840,000 acre-feet of water. This is approximately 75 gpd per US dairy cow.

Conservation Practice 9: Take Advantage of Free Water

Dairy cow's water intake is a combination of ration water and free water. Brugger and Dorsey (2008) estimated in the Ohio study cows obtained 6 gpd/cow of water from the fed ration. A 5 % decline in harvested silage moisture (from 60 % to 55 %) results in a loss of 67 gallons of water per ton of silage available as part of the ration water. This equates on a 3,000 cow dairy feeding 50 lbs of silage to 1.7 gpd/cow of free water that is lost by harvesting dry silage. Potts (2012) showed the free water to equal about 2.82 lbs of water per pound of milk based on his meta- analysis of research studies measuring water consumption of dairy cows.

Conservation Practice 10: Plug the Evaporative Cooling System Leaks

Harner et al. (2007) looked at water consumption of evaporative cooling pads on five different dairies. The average water usage was 0.33 gallons per hour (gph)/sq ft of evaporative pad and ranged from 0.1 to 0.75 gph/sq ft depending on temperature and relative humidity. Evaporative pad system leakage has been observed on US as well as international dairies. On each dairy, the distribution pipe and the return pipe were observed to have significant water leaks. It is recognized most leaks are due to inadequate implementation of the manufacture's recommended installation procedures of the evaporative cooling system. Proper installation to avoid leaks requires time during installation to seal all the joints and seams. While it is difficult to quantify the losses, to a casual guest on a dairy the water wastage is observable. A best guess is probably 3 to 5 % of the designed water consumption recommendation for an evaporative pad systems is lost from pad leaks occurring outside and inside the pad system.

Summary

There are many factors which determine water usage of a dairy, such as heat abatement practices, milk parlor protocols and milk production (drinking water). Many conservation practices may be implemented based on changes in management strategies such as on time of soaker systems, fixing leaks or cleaning of water troughs. Other conservation strategies will required installation of water meters to monitor actual usage in certain areas and then developing a plan to reduce water consumption. Priority by the management and helping employees understand the long term importance of water to the future of the dairy industry is necessary to transition dairies to the next gen.

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Notes:

Precision Dairy Monitoring of Fresh Cows

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Introduction

Dairy cow health is multifactorial and complex. High producing dairy cows have been described as "metabolic athletes," but 30 to 50% of cows are affected by a metabolic or infectious disease around calving (LeBlanc, 2010). Cows are highly susceptible to metabolic and infectious disease during the transition period, or the period from 3 weeks before to 3 weeks after calving (Huzzey et al., 2007, Mulligan and Doherty, 2008). The transition period is marked by a series of adaptations to the demands of lactation. These adaptations are described as homeorhetic, or long term physiological adaptations to changes in state (i.e. the transition from dry to lactating) (DeGaris and Lean, 2009). Transition dairy cows are immunosuppressed and often have to deal with sudden dietary changes that cause metabolic problems. This fragile group of cows is also likely to experience environmental stressors, like routine group changes that are associated with dairy farm management of dry and lactating cows. These effects combined with the stress of parturition lead to a period of great risk for production diseases right after parturition. Dairy cow diseases signify a cow's inability to cope with the metabolic demands of high production. Unfortunately, these diseases cause economic losses to the dairy industry and are an animal welfare concern (Mulligan and Doherty, 2008).

Ketosis, fatty liver, hypocalcemia, retained placenta, metritis, and displaced abomasums are linked etiologically. Unfortunately, this interrelationship regularly results in "cascade effects" that increase the incidence of infectious and production diseases, reduce fertility, reduce milk production, and increase lameness incidence. The complex interaction of transition cow diseases, their relationship with nutrition, and their effects on social behavior and attitude make prevention and control of these diseases difficult (Mulligan and Doherty, 2008). Metabolic events starting two weeks before calving have effects on reproductive performance months later (LeBlanc, 2010). Therefore, early identification of disease may be especially useful during this time (Huzzey et al., 2007, LeBlanc, 2010).

The probability of death is highest in the first month of lactation for both primiparous and multiparous cows. Cows are under great metabolic stress during this time and may be more vulnerable to disease. Risk factors for death in this period include retained placenta, milk fever, displaced abomasum, and mastitis for multiparous cows. Risk factors for death in the first month of lactation in primiparous cows include mastitis, retained placenta, and displaced abomasum. Milk fever, ketosis, and displaced abomasum increased the risk of culling while, interestingly, retained placenta decreased the risk (Hertl et al., 2011).

Disease detection using Precision Dairy Monitoring technologies

As average herd size increases, time producers can devote to each animal decreases (Schulze et al., 2007, Ipema et al., 2008, Bewley, 2010, Brandt et al., 2010) as the administrative, technical, organizational, and logistic workload for the producer increases (Berckmans, 2004). Livestock production today requires the desire to look beyond economic goals (Frost et al., 2003, Berckmans, 2004). Consumer pressure and concern for animal well-being and health, efficient and sustainable farming, food safety and quality, and control of zoonotic diseases, pathogens, and medical treatments has altered decision-making processes on farms (Berckmans, 2004, Schukken et al., 2008, Bewley, 2010). Dairy operations also have narrower profit margins than in the past because the government is less involved in regulating agricultural commodity prices. Because of these major industry shifts, on-farm decision making is changing and dairy cow monitoring tools will likely increase in importance (Berckmans, 2004, Schulze et al., 2007, Ipema et al., 2008, Bewley, 2010) to help make decisions that previously were based solely on producer experience and judgement. Unfortunately, on-farm decisions are riddled with complexities, many of which the effects have to be estimated or guessed at by the producers (Frost et al., 2003). One way to counteract these problems is through the use of automated monitoring systems (Chagunda et al., 2006b).

Throughout history, agricultural techniques have advanced to support larger populations, with the growth of the non-farming population alongside an increase in living standards, agriculture's role and function has been transformed (Marchesi, 2012). Precision agriculture refers to the use of technologies to increase efficiency and reduce environmental damage in crop farming. Precision livestock farming applies the precision agriculture principles to animals, focusing on individual animal production and environmental impact (Laca, 2009). One goal of precision livestock farming to develop in-line systems that monitor animals objectively, continuously, and automatically, without adding stress on the animals (Berckmans, 2004). Precision Dairy Monitoring (PDM) is the use of technologies to measure physiological, behavioral, and production indicators on individual animals to improve management and farm performance (Bewley, 2010, 2012). This type of management system relies on the observation that the animal herself is the important part of the biological production process at hand (Berckmans, 2004).

Objective physiological measures of animal responses to environmental stressors can be used to evaluate the degree of stress and consequent adaptations to that stress (Hahn et al., 1990). Animals are complex and respond differently at different moments of time compared to their herdmates. Outside of precision livestock farming, animals are commonly considered an "average of a population" thus creating a steady-state system. Within precision livestock farming, however, each animal can be treated as its own CIT system (Complex, Individual, and Time-variant) (Berckmans, 2004). Real-time data from PDM technologies could be incorporated into decision support systems to facilitate decision making when multiple data sources are necessary (Bewley, 2010).

The goals of PDM are maximizing individual animal potential, early disease detection, and maximizing preventive care instead of medical treatments. Perceived benefits of PDM technologies include increased efficiency, reduced costs, improved milk quality, minimized environmental impacts, and improved animal health and well-being. Additionally, information from PDM technologies could potentially be incorporated into genetic evaluations for traits targeted at improving subsequent generations' health, well-being, and longevity (Bewley, 2010).
Marchesi (2012) explained that implementing an animal monitoring system is both a moral and commercial interest to producers because it helps them satisfy the animal's needs.

To date, PDM evaluations have focused mainly on automated estrus detection, aimed to supplement or replace visual estrus detection (Dolecheck et al., 2015). Precision Dairy Monitoring technologies also have the potential to detect disease early, maximizing individual animal potential. Disease detection in the past has relied on producers observing clinical signs, but once clinical signs are displayed, it is often too late to act effectively. Clinical signs are often preceded by physiological changes that are undetectable with human senses, but may be possible with PDM and could allow producers to intervene sooner. Technologies may alert producers to cows at risk for a disease instead of the existing disease detection method of identifying cows that are already sick (Itle et al., 2015).

Many disease cases go unnoticed because veterinary examination is the gold standard of disease detection, are conducted relatively infrequently on most dairy farms (Urton et al., 2005). Instead, dairy producers often rely on their experience and judgement to identify sick animals, but human perception of a cow's condition is limited. Additionally, some diseases do not present obvious signs (Weary et al., 2009). Even worse, sometimes, by the time an animal does display outward signs of illness or stress, it is too late to intervene. Physiological changes typically occur before clinical symptoms, though. If a producer were able to detect these physiological changes, interventions could occur sooner. Even when individual monitoring is employed on farms, behavioral indicators used to detect illness are often based simply on the experience and intuition of the producer and tend to be unreliable (Weary et al., 2009).

Producers can examine real time data and reports to identify abnormal deviations from a baseline (Bewley, 2010). However, the data itself is meaningless unless it is transformed into a good decision management program. Thus, the producer remains a critical factor in good animal management and technologies will only support, not replace, the producer (DeGaris and Lean, 2009, Bewley, 2010, Marchesi, 2012). The ability to combine computer systems with the strengths and abilities of the producer is where the potential benefits of PDM systems lie (Marchesi, 2012). However, to achieve success using precision livestock farming processes, three conditions apply. First, animal variables should be monitored continuously and the data should be analyzed consistently. The definition of "continuously" depends on the animal variable of interest, like weight, activity, drinking and feeding behavior, feed intake, body temperature, etc. Second, a reliable prediction or expectation on how the animal will respond to the change must be available constantly. Lastly, this prediction should be coupled with the technology measurements in an algorithm to monitor or manage the animals automatically, and to monitor animal health or welfare or make desired system changes (Berckmans, 2004).

Often, each individual process involved in livestock production is controlled separately. Integrated management systems can control multiple, and ideally all, the interrelated processes involved in production. Each of the various processes within a dairy is usually controlled by one or more open-loop control systems, which has limited consideration for the effects that it has on other parts of the process. Management systems where various processes are integrated so that the production system is managed as a whole closed-loop system is a solution to the problems current systems being used on-farm create (Frost et al., 2003).

Sensors fall into two categories, attached and non-attached. Attached sensors would be the sensor on or inside the cow's body. Non-attached sensors would be off a cow's body measuring as a cow walks past or through the devices, or a sample taken to run an analysis. The developed sensor systems are divided into four different levels, (I) capability of measuring behavior about the cow (e.g. activity); (II) interpreting and summarizing the change of sensor data (e.g. increase in activity) in order to provide information of cow status (e.g. estrus); (III) combining information (e.g. economic information) and produce advice (e.g. whether to inseminate a cow or not); (IV) making decision autonomously of producers or sensors (e.g. the inseminator is called) (Rutten et al., 2013). Daily milk yield recording, milk component monitoring, pedometers, automatic temperature recording devices, milk electrical conductivity monitors, and automatic estrus detection monitors, and daily body weight systems are currently available for producers to implement on-farm. PDM systems may also be able to measure: jaw movements, ruminal pH, reticular contractions, heart rate, animal positioning and activity, vaginal mucus and electrical resistance, feeding behavior, lying behavior, odor, glucose, acoustics, progesterone, individual milk components, color, infrared udder surface temperatures, and respiration rates. Because the rapid development and availability of new PDM continues to grow, they are becoming more feasible for producers to implement in their own herds.

Although the technology required to achieve fully automated dairy systems is available, multidisciplinary and innovative research is required to achieve its application. The bottleneck for application is the availability of reliable sensor systems because the required algorithms to go along with them can be developed (Berckmans, 2004). Unfortunately, the dairy industry is relatively small, which limits corporate willingness to invest in developing technologies exclusively for dairy farms. Thus, technology development is instead driven by the availability of a technology in other industries and then transferred to the dairy industry, regardless of the actual needs.

Precision Dairy Monitoring technologies provide great opportunities to improve dairy herd management systems and may improve individual animal management (Bewley, 2010, Singh et al., 2014). However, the data itself is not useful unless it is interpreted and used effectively in decision making (Bewley, 2012, Singh et al., 2014). Most data management systems currently available are not used to their full potential. Other PDM limitations include: slow adoption rates, erroneous animal reads, equipment failure, the amount of data may overwhelm systems during data transfer, a lack of validated research results, and cows are normally housed in a restricted spatial area (Singh et al., 2014).

Variables measured by Precision Dairy Monitoring technologies

Temperature. Body temperature is influenced by health, environment, ambient temperature, eating behavior, drinking behavior, estrus, and the pregnancy status of an animal (Bewley et al., 2008). Fever, or a body temperature over a predefined threshold, is an indicator of disease (Leon, 2002, Burfeind et al., 2010). Fever is a complex physiological response to infection and inflammation. Once the body recognizes a pathogen invasion, macrophages and other immune cells release cytokines which signal the hypothalamus to increase the thermal set point. Although the mechanism of cytokine action remains unclear through studies in mice, this reaction causes body temperature to increase to match the increased thermal set point (Leon, 2002).

Producers often implement rectal temperature recording into their disease detection system (Schutz and Bewley, 2009, Burfeind et al., 2010, Vickers et al., 2010). The accuracy of commercially available electronic rectal thermometers is within 0.1°C (Vickers et al., 2010). However, several limitations to rectal temperature recording do exist. The first is that the presence of the recorder may affect temperature by making the animal nervous (Simmons et al., 1965, Bewley and Schutz, 2010). Other limitations include air in the rectum, failure to insert the probe deeply, and the creation of ulcers in the rectum from forceful insertion. Ambient temperature also has an effect and accuracy is related to the competency of the recorder (Aalseth, 2005).

Fever is described as a rise in body temperature above the “normal” range. Fever is a common, but complex, physiological response to infection, inflammation, and trauma aimed at the host’s survival (Leon, 2002). Generally, average daily body temperatures for cattle fall within a range of 38 to 39.4°C (Lefcourt et al., 1999, Aalseth, 2005, Benzaquen et al., 2007). Temperatures can vary between individual cows in the same conditions and can vary within cows throughout a day (Simmons et al., 1965, Lefcourt et al., 1999).

Manual collection of rectal temperatures is the most common method of obtaining body temperatures in practice because of the ease of measurement and low purchase costs of rectal thermometers (Aalseth, 2005). Furthermore, because restraining animals to collect temperature data by manual means may cause stress that alters temperature, a reliable method of collecting temperatures without human intervention is likely to provide a more accurate measure of temperature in dairy cattle (Hahn et al., 1990). Pararectal temperature rose when the four study cows stood and decreased when they laid down. The opposite occurred in subcutaneous temperature where a thermometer was placed under the skin behind the shoulder (Simmons et al., 1965).

Firk et al. (2002) suggested that the value of a temperature monitor is highly dependent on its location. Body temperature has been monitored in dairy cattle in several anatomical locations including the rectum, tympanic and skin portion of the ear, vagina, reticulorumen, intraperitoneal cavity, udder skin, and milk. Internal temperature measurement sites may be more useful indicators of body temperature because they are not as readily affected by ambient conditions (Hahn et al., 1990). However, water consumption temporarily, but dramatically, decreases reticulorumen temperatures (Simmons et al., 1965, Brod et al., 1982, Bewley et al., 2008). In fistulated sheep, microbial activity decreased when injected intra-ruminally with 2 liters of 0°C water, which did not occur for the 10, 20, and 30°C water treatments. For the 0, 10, 20 and 30°C water treatments, temperatures did not return within ± 0.5°C to baseline rumen temperature for 108, 96, 96 and 72 minutes (Brod et al., 1982).

Simmons et al. (1965) cited that the mean pararectal, subcutaneous, and reticular temperatures over four days were 38.4 ± 0.3°C, 35.6 ± .8°C, and 38.8 ± 1.2°C., respectively. Pararectal and subcutaneous temperatures consistently dropped between 6 pm and 7:30 pm, likely related to water ingestion. One cow on the study showed greater variation in her pararectal and subcutaneous temperatures than the other cows. Observationally, she drank more often throughout the day and had a more nervous temperament than the other three, which the authors stated as a reason for her temperature variation.

In a Canadian study evaluating rectal temperature measurements to determine intra- and interinvestigator variability and to determine the effects of penetration depth into the rectum and defecation on measured body temperature, repeated rectal temperatures by a single researcher were consistent (39.5 ± 0.1°C). Correlation between two researchers was high ($r = 0.98$; $P < 0.001$). However, temperatures were 0.4°C ± 0.2°C greater when the probe was inserted deeper into the rectum ($P < 0.001$). Temperature around defecation varied, with some cows having a difference of ≥ 3.0°C after defecation while others had a difference of ≥ 3.0°C before defecation and some had no difference before or after defecation (Burfeind et al., 2010). Reticular temperatures decrease when cows drink water and take 1.5 (Simmons et al., 1965) to 3.5 hours (Bewley et al., 2008) to return to the pre-drinking temperature. Simmons et al. (1965) observed reticular temperatures as low as 32°C after water consumption.

Automatic temperature recording may allow producers to detect disease, estrus, heat stress, and the onset of calving earlier than currently possible (Bewley et al., 2008). Body temperature has commonly been used to detect fever, heat stress, and the onset of calving for many years. However, core body temperature is desired, but is fundamentally difficult to obtain and rectal temperature only approximates core body temperature. Taking rectal temperatures may cause stress that alters the temperatures so a reliable method with no human intervention may be a more accurate measure. Attempts to measure body temperature of cattle have been made at various anatomical locations including rectum, ear (tympanic), vagina, reticulum-rumen, and milk (Bewley and Schutz, 2010).

Adams et al. (2013) explained that cows with clinical mastitis had 6.7 times higher odds of having a reticulorumen temperature 0.8°C above their baseline within 4 days of diagnosis compared to control cows (76.9% specificity and 67.0% sensitivity). However, reticulorumen temperature was not different for cows diagnosed with metritis compared to control cows. Cows with retained placentas averaged 0.1°C greater temperature than matched control cows ($P < 0.001$) (Vickers et al., 2010).

Cows with puerperal metritis underwent a significant rectal temperature increase 24 hours before clinical signs (reaching 39.2 ± 0.05°C on the day of clinical diagnosis) (Benzaquen et al., 2007).

In a Canadian study, rectal and vaginal temperatures were highly correlated ($r = 0.81$; $P < 0.01$) in the 1,393 temperatures recorded for 29 fresh cows. However, rectal and vaginal temperatures were only moderately correlated ($r = 0.46$; $P < 0.01$) for the 556 temperatures recorded from the 13 peak lactation cows in this study. The correlation difference may have been because the fresh cows exhibited a larger temperature range (37.7 to 40.5°C) compared with peak-lactation cows (37.9 to 39.6°C) (Vickers et al., 2010). Healthy cows and cows with retained placentas both showed diurnal rhythms in their vaginal and rectal temperatures, with increases in the afternoon and decreases during the morning (Vickers et al., 2010). Diurnal variations in temperatures may be attributed to individual cow or breed characteristics and ambient weather conditions (Bewley et al., 2008). Some limitations to vaginal temperature monitoring are logger movement (particularly around calving when the vaginal cavity was enlarged), influx of ambient air, expulsion from the vagina (Vickers et al., 2010).

Reticular temperatures were lowest between noon and 4:00 PM (39.4°C) and between 8:00 AM and noon (39.5°C). In contrast, reticular temperatures were greatest between 8:00 PM and midnight (40.2°C) and between midnight and 4:00 AM (40.3°C) (Ipema et al., 2008). In an E. coli intramammary mastitis challenge, ruminal temperature peaked between 40.5°C and 41.0°C and remained above 40.0°C for two hours (AlZahal et al., 2011). Reticular temperature of cows diagnosed with mastitis deviated more than 3 standard deviations from baseline temperature in 45.7% of cows in another study (Bewley and Schutz, 2010).

Lying time and activity. Accelerometers measure three different movements: side-to-side, up and down, and front to back, and are thus provide more information than pedometers. A decrease in activity could be a sign of illness (Marchesi, 2012).

In dairy cattle, lying down is a high-priority behavior, which ensures that the necessary time to rest and ruminate is achieved. Danish researchers restricted time to feed access and explained that this restriction decreased time spent on all activities, but the proportion of time spent feeding and time spent on social contact remained constant. Yet the proportion of time spent lying increased. Therefore, the authors concluded that the priority for the behaviors studied were lying, followed by eating and social contact (Munksgaard et al., 2005). Lying time has been referenced between 10.5 and 11 hours per cow per day (Ito et al., 2009, Bewley et al., 2010c, Cyples et al., 2012, Medrano-Galarza et al., 2012).

Researchers contend that many behavioral signs shown by sick animals indicate the start of an action to fight off disease (Hart, 1988, Dantzer, 2004). Behavior is a crucial indicator that is affected by energy expenditure. Changes in lying behavior may be related to a state of chronic stress (Ladewig and Smidt, 1989). Reduced mobility and increased rest may be strategy of energy conservation in order to allow more energy to be spent on fighting the infection and to allow the full development of a fever, which may help the animal recover (Aubert, 1999).

Cook et al. (2007) video recorded lying behavior of 14 dairy cows over all seasons and discovered that mean lying time decreased from 10.9 to 7.9 hours/day from the coolest to the hottest session recorded because of heat stress ($P < 0.01$). Additionally, cows with greater locomotion scores (using a 1 to 4 scale where 1 represents non-lame and 4 represents severely lame) lied down more (2.9, 4.0, and 4.41 hours/day for locomotion scores 1, 2, and 3, respectively; $P < 0.01$ between 1 and 2; $P = 0.02$ between 1 and 3), indicating that pain may increase lying time.

Canadian researchers challenged 19 cows with an E. coli lipopolysaccharide and cited that baseline lying time (averaged from the two days before mastitis induction; 707.0 minutes/day) was higher than the day of induction (633.3 minutes/day; $P = 0.005$). Lying time increased on the two days after infusion (743.1 and 726.3 minutes/day for days one and two after infusion, respectively), but not significantly (Cyples et al., 2012). In a behavioral study of cows with naturally-occurring clinical mastitis, cows with clinical mastitis laid down more than control cows on the day after mastitis detection (707.5 versus 742.5 minutes/day, $P = 0.04$). However, no difference was observed in lying times of animals with mastitis that had been treated with antibiotics and control animals (Medrano-Galarza et al., 2012).

While physical discomfort may decrease dairy cow lying time, lying on hard surfaces may also exacerbate pain caused by mastitis, causing lying time to decrease during mastitis (Cyples et al., 2012). Chapinal et al. (2013) explained that lying down at the time when the most severe signs of local inflammation occur causes pain, forcing cows to stand for longer periods during mastitis. Total daily standing time was 20% longer for cows later diagnosed with clinical ketosis during the week before calving (14.3 ± 0.6 vs. 12.0 ± 0.7 h/d) and 35% longer on the day of calving (17.2 ± 0.9 vs. 12.7 ± 0.9 h/d) compared to those without ketosis, but no differences were observed postpartum. Cows later diagnosed with clinical ketosis also stood up fewer times (14.6 ± 1.9 vs. 20.9 ± 1.8 bouts/d) and stood for longer periods (71.3 min/bout vs. 35.8 min/bout) than cows without clinical ketosis on the day of calving (Itle et al., 2014). Cows with ketosis behave in a subordinate fashion (Itle et al., 2014), causing them to be less motivated to engage in behaviors that are energetically expensive like changing position from lying to standing (Susenbeth et al., 2004) or competing for feed (Goldhawk et al., 2009). Ketosis is a progressive disease associated with gradual changes in non-esterified fatty acids and blood glucose, starting in the prepartum period and progressing toward the more severe fatty liver disease (Bobe et al., 2004). Other researchers cited that postpartum activity was reduced among cows that were diagnosed with subclinical ketosis (502.20 ± 16.5 vs. 536.6 ± 6.2) (Liboreiro et al., 2015). Cows diagnosed with metritis had reduced postpartum activity (512.5 ± 11.5 vs. 539.2 ± 6.0 arbitrary unit) (Liboreiro et al., 2015).

Feeding time. Dry matter intake, rumination time and feeding time are important parameters for detecting illness. In order to increase milk production, energy requirements must be met. Researchers indicated that disturbances of fermentation and rumen activity can lead to subclinical and clinical diseases (Nocek, 1997, Maekawa et al., 2002). Consistently monitoring feeding behavior is a tool for tracking the health status of the whole herd or individual cows (Hansen et al., 2003). Edwards and Tozer (2004) explained that cows with ketosis had lower activity ($P < 0.01$) than healthy cows up to 5 DIM, but then actually became more active after 12 DIM. The difference in activity may have been due to sick cows having lower appetites, spending less time at the feed bunk, and spending more time lying down. During the week before, week after, and two weeks after calving, the dry matter intake (DMI) of cows with subclinical ketosis was 18, 26, and 20% lower that the DMI of cows without subclinical ketosis after calving ($P < 0.01$). Cows with subclinical ketosis also visited the feeder 18, 27, 28, and 16% fewer times during two weeks before, one week before, one week after, and two weeks after calving and spent less time at the feeder the same weeks (Goldhawk et al., 2009).

Cows with severe metritis consumed less feed than healthy cows beginning 2 weeks before calving and continued to consume less dry matter through three weeks post-partum. Cows with mild metritis ate less dry matter compared with healthy animals during the week before calving and throughout the 3-wk postpartum period. The odds of severe metritis increased by 2.87 for every 1 kg decrease in DMI during the week before calving. The odds of severe metritis increased by 1.72 for every 10-min decrease in feeding time during the week before calving. During the two weeks before calving, healthy cows displaced others from the feed bins 16.8 ± 1.74 times/d compared with severely metritic cows who only displaced others on average 12.2 ± 1.58 times/d ($P = 0.06$) (Huzzey et al., 2007). Urton et al. (2005) also explained that cows with acute metritis spent 24 minutes less at the feed bunk compared to those without acute metritis between 12 days pre-calving to 19 days post-calving ($P < 0.01$). In this study, the odds of a cow having metritis increased by 1.97 for every 10-minute decrease in average daily feeding time. Hansen et al. (2003) cited a linearly negative relationship between feed intake and plasma calcium level in cows with induced hypocalcaemia.

Rumination time. Rumination is defined as the regurgitation of fibrous ingesta from the rumen to the mouth, remastication, followed by swallowing and returning of the material to the rumen. Dairy cows normally ruminate for eight to nine hours a day when measured by visual observation. Researchers in a Vermont study fitted steers with a facemask that restricted all jaw movement for ten hours a day during the study period. When the facemask was removed, the steers were offered hay, but the animals instead chose to ruminate (Welch, 1982). A more recent study using rumination collars by Kaufman et al. (2016) cited rumination times of 7 and 8 hours for primiparous and multiparous cows, respectively.

Rumination is affected by diet, including feed digestibility, neutral detergent fiber intake, forage quality (Welch and Smith, 1970), and particle size (Welch, 1982). Rumination time decreases with acute stress (Herskin et al., 2004) and disease (Welch, 1982, Hansen et al., 2003). Researchers have estimated rumination based on direct visual observations, but systems now exist to automate this process (Schirmann et al., 2009). Automated rumination-monitoring system was validated by comparing values from a rumination logging device with those from a human observer for 51 two-hour observation periods on 27 Holstein cows. Rumination times from the electronic system were highly correlated with those from human observation ($R = 0.93$), indicating that the automated system accurately monitored rumination in dairy cows (Schirmann et al., 2009).

Kansas researchers studied nine Angus-Hereford cows and observed that high cortisol levels (above 22 ng/mL, the mean of the group) were highly correlated with less time spent ruminating ($r = -0.85$, P < 0.01). Cortisol is released when an animal is stressed, therefore an association between stress and decreased rumination may exist (Bristow and Holmes, 2007). However, decreases in rumination may not always occur around stress. A study examining behavioral changes related to increased stocking density reported that at 100% stocking density, 95.1% of rumination occurred within a stall, but as stocking density increased to 142%, only 87.3% of rumination occurred within a stall. However, overall rumination time did not decrease between any of the stocking densities (P > 0.05) (Krawczel et al., 2012).

Cows diagnosed with metritis had reduced postpartum daily rumination time (416 vs. 441 minutes/day) (Liboreiro et al., 2015). Induced hypocalcaemia resulted in reduced rumination time, possibly related to the anti-peristaltic esophageal movements during rumination (Hansen et al., 2003) or decreased ruminal contractions (Jorgensen et al., 1998) because Ca is required for muscle contractions (Hansen et al., 2003).

Kaufman et al. (2016) explained that cows with greater rumination time the week before calving was associated with decreased odds of ketosis. The odds of a cow getting ketosis and another health problem increased when rumination time decreased from 1 week before calving to one week after. Rumination time decreased in primiparous and multiparous cows from two weeks prepartum and began to increase from weeks 1 to 2 postpartum. The increase postpartum may represent changes in dry matter intake. Clément et al. (2014) explained that rumination was a small, but significant, contributor in dry matter prediction. However, rumination time within weeks and cows are variable, making it difficult to use rumination time to predict dry matter intake. Primiparous cows ruminated less than multiparous cows 3 and 4 weeks postpartum (Kaufman et al., 2016). Maekawa et al. (2002) visually observed rumination times and explained that primiparous cows ruminated 52 minutes per day less than multiparous in mid-lactation.

Milk yield and components. Milk yield began to decrease 6 d before clinical ketosis diagnosis and remained lower (P < 0.01) than that of healthy cows (cows without ketosis, displaced abomasums, or digestive disorders) until at least d 10 after diagnosis (Edwards and Tozer, 2004). Cornell researchers cited that milk loss started 4 weeks before and continued for at least 2 weeks after a clinical ketosis diagnosis. The daily milk loss was greatest within the first 2 weeks after diagnosis: 3, 4, 3, and 5 kg/d for parities 1, 2, 3, and ≥ 4, respectively. The overall production loss during lactation was between 126 and 535 kg per cow. Cows without clinical ketosis in parity 1 yielded 1 kg less milk/day and cows in parity 4 or greater yielded 2 kg less milk/day than cows with clinical ketosis in the same parity (Rajala-Schultz et al., 1999a). In another study, cows with clinical ketosis produced 141.1 kg more 305-d yield than cows without clinical ketosis, but production was 44.3 kg less over 17 d following diagnosis (Detilleux et al., 1994). However, Rowlands and Lucey (1986) cited a 7% decrease in peak milk yield but overall no difference in 305-d yield. In contrast, Dohoo and Martin (1984) explained that a case of clinical ketosis increased milk production by 2.5%. The authors contributed this beneficial effect to the initial treatment of cows with clinical ketosis with malt or propylene glycol. However, it is likely that the cows with ketosis were higher yielding and were able to continue milking more even after ketosis, which was also the case in (RajalaSchultz et al., 1999a).

Average daily milk production during the first 21 d after calving did not differ between cows with subclinical ketosis compared to those without (Goldhawk et al., 2009). Higher producing cows are at greater risk of ketosis, which comes with a temporary milk yield decrease, so if they do not develop ketosis their milk yield would be even greater (Detilleux et al., 1994, RajalaSchultz et al., 1999a). Milk yield began to decrease 6 d before clinical ketosis diagnosis and remained lower ($P < 0.01$) than that of healthy cows (cows without ketosis, displaced abomasums, or digestive disorders) until at least d 10 after diagnosis (Edwards and Tozer, 2004). Cornell researchers cited that milk loss started 4 weeks before and continued for at least 2 weeks after a clinical ketosis diagnosis. The daily milk loss was greatest within the first 2 weeks after diagnosis: 3, 4, 3, and 5 kg/d for parities 1, 2, 3, and ≥ 4, respectively. The overall production loss during lactation was between 126 and 535 kg per cow. Cows without clinical ketosis in parity 1 yielded 1 kg less milk/day and cows in parity 4 or greater yielded 2 kg less milk/day than cows with clinical ketosis in the same parity (Rajala-Schultz et al., 1999a). Detilleux et al. (1994) explained that cows with clinical ketosis produced 141.1 kg more 305-d yield than cows without clinical ketosis, but production was 44.3 kg less over 17 d following diagnosis. However, Rowlands and Lucey (1986) cited a 7% decrease in peak milk yield but overall no difference in 305-d yield. In contrast, (Dohoo and Martin, 1984) explained that a case of clinical ketosis increased milk production by 2.5%. The authors contributed this beneficial effect to the initial treatment of cows with clinical ketosis with malt or propylene glycol. However, it is likely that the cows with ketosis were higher yielding and were able to continue milking more even after ketosis, which was also the case in (Rajala-Schultz et al., 1999a).

Canadian researchers discovered that milk production was less in cows identified with severe or mild metritis during the first three weeks after calving. The decreased yield is likely a consequence of the decreased dry matter and water intake observed after calving in the cows with severe and mild metritis (Huzzey et al., 2007). Mahnani et al. (2015) explained that a case of metritis reduced 305-d milk yield by 129.8 ± 41.5 kg per cow per lactation. In contrast, Wittrock et al. (2011) cited no difference in milk yield between cows with metritis and those without.

Sensitivity/specificity. Reneau (1986) outlined the ideal clinical test as being able to establish the presence or absence of disease in every case screened without any false positives or false negatives. He also suggested that the ideal test would provide a correct diagnosis, data to aid in prognosis, an indication of subclinical disease, data that may indicate possible disease reoccurrence, and would also be able to monitor treatment effects. Correctly identified events are considered true positives (TP), non-alerted events are false negatives (FN), non-alerted non-events are true negatives (TN), and alerted non-events are false positives (FP) (Firk et al., 2002). Specificity is the probability that a negative sample is from a disease-negative cow. Sensitivity is the probability that a positive alert is a true indicator of a disease (Hamann and Zecconi, 1998, Sherlock et al., 2008, Hogeveen et al., 2010b). Because sensitivity and specificity are interdependent, thresholds should be set to optimize both (Hogeveen et al., 2010b). Specificity is equal to TN / (TN + FP) x 100. Sensitivity is determined by the following equation: TP / (TP + FN) x 100 (Sherlock et al., 2008, Hogeveen et al., 2010b). Accuracy, which can account for the prevalence of a disease whereas sensitivity and specificity cannot, can be determined by: [(TP + TN) / (TP + TN + FP + FN) X 100]. Accuracy depends on how strongly and closely the measured parameters are associated with the event, how accurately the technology measures the parameters, and how well the manufacturer algorithm processes the data to create useful alerts (Dolecheck et al., 2015).

Positive predictive value is the proportion of true positives against the apparent positives (Hamann and Zecconi, 1998). A true positive occurs when the event occurs with an alert from the automated detection system (Hogeveen et al., 2010b). Negative predictive value is the proportion of true negatives against the apparent negatives (Hamann and Zecconi, 1998). A true negative occurs when the event does not occur and an alert is not produced (Hogeveen et al., 2010b). False positives, or type I errors, can cause financial losses because healthy animals may be treated. Conversely, false negatives, or type II errors, may leave sick animals untreated causing animal welfare problems and decreased milk yield and health throughout the lactation (Burfeind et al., 2010). Therefore, although a 90% sensitivity may seem acceptable in a research setting, it would likely be inadequate when applied in a herd setting (Sherlock et al., 2008). Steeneveld et al. (2010) explained that a general complaint of producers using robotic milking systems was the "relatively large" amount of false alerts. Even the most sensitive and specific test still needs to be available and affordable (Reneau, 1986). To be a valuable commercial management tool, cow performance should be related to the potential improvement in management of subclinical disease (Nielen et al., 1995).

Sensitivity and specificity of a disease detection tool depend on the disease definition (Nielen et al., 1995) and time window (Mollenhorst et al., 2012) in which alerts can be given. Wider time windows will produce a higher sensitivity and specificity (Hogeveen et al., 2010b, Kamphuis et al., 2010), but they will also lose their practicality in a commercial setting (Kamphuis et al., 2010).

The results of a survey of 139 Dutch producers that owned an automated milking system revealed that farmers preferred a clinical mastitis detection system that produced few false alerts and provided alerts for severe cases with enough time to take effective treatment action. Producers preferred that time windows were set at a maximum of 24 hours before clinical symptoms appear. However, variation in responses to the survey varied greatly, suggesting that detection systems should be adaptable to match the conditions of each farm (Mollenhorst et al., 2012). Kamphuis et al. (2010) used an alert time window < 24 hours, but the authors were not confident that it was the correct window to use for other studies. The use of a decision tree and this narrow time window resulted in 40% sensitivity and 99% specificity. Rasmussen (2002) suggested that a clinical mastitis system should provide 80% sensitivity and 99% specificity and that time windows should be within 24 to 48 hours of a clinical mastitis event.

Sensitivity and specificity will be lower if a new test disagrees with the comparison to the gold standard. Disagreement between the gold standard and a new test is often interpreted as the test lacking capability. However, the test could be better at detecting negatives, causing true negatives to display as false negatives (Nielen et al., 1992). This problem is made even more complex by the circumstance that neither the new test nor the gold standard detection methods may be ideal (Vickers et al., 2010). A universally accepted gold standard does not exist, though. Another limitation of an automated disease detection method is that clinical infections are infrequent, causing statistical analyses to be "weak" (Mein and Rasmussen, 2008).

Conclusions

Dairy cow diseases, particularly during the transition period, are expensive and compromise cow well-being and milk production. Current disease detection methods rely on visual observation. However, early disease detection may allow producer intervention (e.g. antibiotic treatment), thus decreasing the negative economic and well-being implications of the disease. Precision dairy technologies, or technologies that reside in and on cows to monitor individual cow physiology, production, and behavior, may be able to predict and detect disease and alert producers to cows with changes in the indicators monitored.

Notes:

A Life Cycle, Lesion Oriented Approach to Lameness Control

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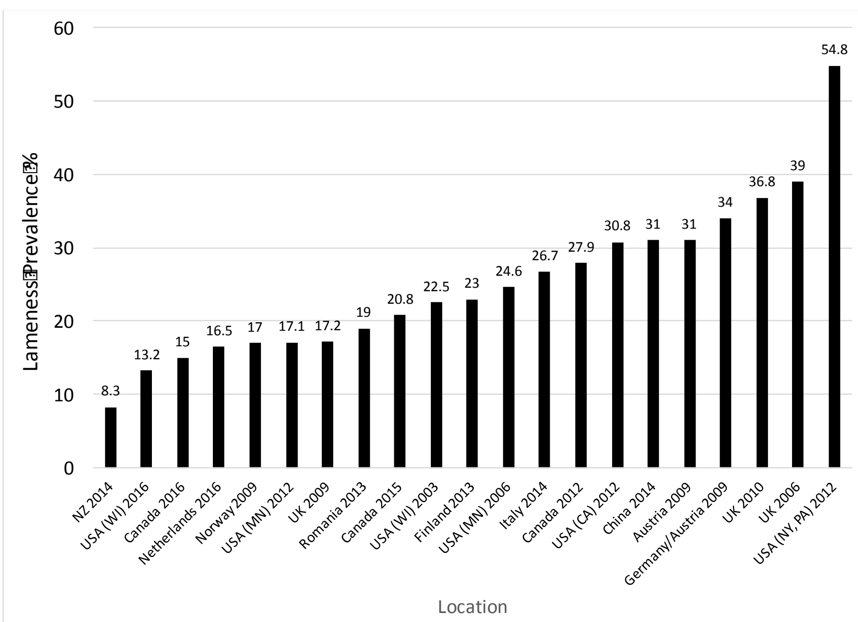
Introduction

We have a global lameness crisis in our dairy industry. The worldwide prevalence of lameness in dairy herds (defined as a cow walking with noticeable weight transfer and a 'limp') is approximately 24% across studies based in Austria, Canada, China, Finland, Germany, Italy, Netherlands, New Zealand, Norway, UK and the US (e.g., Amory et al., 2006; Barker et al., 2010; Chapinal et al., 2014; Cook, 2003; Cook et al., 2016; Dippel et al., 2009; Fabian et al., 2014; Kielland et al., 2009; Popescu et al., 2014; Sarjokari et al., 2013; von Keyserlingk et al., 2012), with a trend toward lower prevalence in grazing or mixed housing and grazing systems (e.g. 16.5% in Amory et al., 2006; 8.3% in Fabian et al., 2014; and 15% in Haskell et al., 2006), and a higher prevalence in confinement housed freestall herds (e.g. 31% in Chapinal et al., 2014; 54.8% in North East US dairy herds in von Keyserlingk et al., 2013).

Figure 1. *Worldwide prevalence of lameness in dairy herds by location from the peer reviewed literature since 2003*



Despite research and a significant improvement in our understanding of the causes of lameness over the last three decades, we appear to be fighting a losing battle, and the problem has been associated with increasing intensification of the dairy industry, higher milk production and confinement housing, with the obvious conclusion that lameness is an inevitable consequence of these decisions.

Consumers carry an expectation that cows should graze and appear to place considerable value on cattle having access to the outdoors, where they have fresh air and freedom to roam (Cardoso et al., 2016). They emphasize the need for humane care of the animals (Cardoso et al., 2016), so the sustainability of the industry is threatened when the general public learns that production systems do not meet their expectations – and lameness is an obvious problem that has been and should continue to be a high priority for us to resolve.

What Causes Lameness in Dairy Cattle?

The aetiopathogenesis of a variety of hoof lesions has been researched and reviewed extensively (eg. Bicalho and Oikonomou, 2013; Cook and Nordlund, 2009; Cook, 2015; Evans et al., 2015), centering on genetic, nutritional, hormonal, mechanical, infectious and environmental factors.

Across numerous surveys in different production systems, three lesions emerge consistently as the most significant contributors to lameness – digital dermatitis (DD), white line disease (WLD) and sole ulcer (SU) (eg. Barker et al., 2009; Defrain et al., 2013). Our ability to impact lameness globally will depend on developing effective control strategies targeted at these three lesions. I will concede that some differences do exist between production systems and some countries. For example, DD has yet to become a dominant hoof lesion in New Zealand and Australia, likely due to the absence of environmental risk factors. However, the disease has spread in association with confinement housed dairy systems around the world, and now even in these locations DD is appearing at a low prevalence (Chesterton, 2015). In grazing systems, WLD appears to dominate, with sole bruising and axial wall fissures often reported. It is however important to note that a healthy sole is unlikely to 'bruise' unless the sole thickness is compromised, suggesting this as an underlying cause. We know thin soles emerge as a significant problem in larger confinement dairy systems in association with toe ulceration (Shearer et al., 2006), where cows are asked to walk long distances to and from the parlor for milking. It is therefore likely that hoof wear is the underlying issue in both, due to exposure to the track (grazing herds) or concrete alley (confinement herds).

I will contend that we now know more than ever what causes lameness, and while we still have more to learn, we know enough currently to solve the global lameness problem in our dairy industry.

A Life Cycle Approach

No matter what the causation of lameness, once the cow develops a lesion, they are at much greater risk for developing the same lesion again in the next lactation (Oikonomou et al., 2013), likely due to permanent anatomical changes to the structure and function of the claw – including the fat pad, the suspensory apparatus and the pedal bone itself (Table 1).

Table 1. *Lactation adjusted incidence of lameness lesion (white line disease = WLD, sole ulcer = SU and digital dermatitis = DD) by lesion status (0 = no lesion, 1 = lesion) in the previous parity (1-3). (from Oikonomou et al., 2013)*

Lesion	Parity	Lesion Status	Lactation Adjusted Incidence			P-value
			2	3	≥4	
WLD	1	0	6	11	15	<0.01
		1	20	21	24	
	2	0		9	13	<0.01
		1		20	18	
	3	0			10	<0.001
		1			21	
SU	1	0	12	20	26	<0.001
		1	44	32	23	
	2	0		15	24	<0.001
		1		40	30	
	3	0			18	<0.001
		1			41	
DD	1	0	7	7	8	<0.001
		1	32	15	10	
	2	0		5	7	<0.001
		1		19	12	
	3	0			5	<0.001
		1			14	

We are also aware that while claw horn disease is relatively uncommon in heifers, DD infection may impact 20-30% of heifers after breeding age in many rearing facilities, likely as a result of the same poor leg hygiene risk factors that have exacerbated the problem in mature cows. Laven and Logue (2007) and Holzhauer et al. (2012) have demonstrated the importance of the pre-partum period in affecting DD occurrence during the following lactation, and Gomez et al. (2015) were able to demonstrate increased risk for DD in primiparous cows when they suffer one or more episodes of DD during the rearing period, compared to heifers that are unaffected during the rearing period.

DD affects younger cows, with incidence peaking typically in the 1st or 2nd parity, while SU and WLD incidence increases with age to around the 4th lactation (Oikonomou et al., 2013).

These data therefore support an approach to lameness control that encompasses the life-cycle of the cow, starting during the heifer rearing period, with strategies that are lesion specific and age-specific, tailored to the type of lesions that are most prevalent on each farm. Understanding the motivation for farmers to implement change is critical for consultants (Leach et al., 2010). However, it would seem likely that with the growth and expansion of welfare audits globally, they will have little choice but to comply. Ultimately, producers that have succeeded in their control of lameness will become the best salesmen of prevention programs to the others that lag behind, and these producers will increasingly need an effective roadmap to expedite change.

Herd Risk Factor Oriented Strategies

Herd level risk factors for lameness have been studied in multiple countries and in a variety of production systems in recent years. A number of consistent findings have emerged from these studies. Factors which appear to be associated with lower lameness risk include: less time standing on concrete (Bell et al., 2009), deep bedded comfortable stalls (Chapinal et al., 2013; Cook, 2003; Dippel et al., 2009; Espejo et al., 2006; Rouha-Mulleder, et al., 2009; Solano et al., 2015), access to pasture or an outside exercise lot (Chapinal et al., 2013; Hernandez-Mendo et al., 2007; Popescu et al., 2013; Rouha-Mulleder, et al., 2009), prompt recognition and treatment of lameness (Barker at al., 2010), higher body condition score (Dippel et al., 2009; Espejo et al., 2006 Randall et al., 2015), use of manure removal systems other than automatic scrapers (Barker at al., 2010), use of non-slippery, non-traumatic flooring (Barker et al., 2010; Sarjokari et al., 2013; Solano et al., 2015a), and use of a divided feed barrier (rather than a post and rail system), with a wider feed alley (Sarjokari et al., 2013; Westin et al., 2016).

It should be expected that routine professional hoof-trimming, access to a trim-chute for treatment and use of an effective footbath program would deliver improvements in lameness (eg. Pérez-Cabal and Alenda. 2014), but these effects are often confounded in associative observational studies (eg. Amory et al., 2006). It is also true that many poorly trained hoof-trimmers cause more harm than good, and many footbath routines are ineffective through poor design and management (Cook et al., 2012; Solano et al., 2015b). Similarly, several studies point to restrictive neck rail locations, high rear curb heights, and lunge obstructions as risk factors for lameness (eg. Chapinal et al., 2013; Dippel et al., 2009; Rouha-Mulleder, et al., 2009; Westin et al., 2016), however correct neck rail location and curb height is stall design specific and care should be taken in interpretation of these findings. Most recently, stall width has emerged as a significant factor impacting lameness (Westin et al., 2016)

High Production and Low Levels of Lameness

While we know that Holstein cows are perhaps more susceptible to lameness (eg. Sarjokari et al., 2013), and there appears to be a genetic component to the development of DD, SU and WLD, with a link to higher milk production (Oikonomou et al., 2013), I do not believe failure is inevitable.

We had the opportunity to visit 66 high performance Wisconsin herds that have been implementing strategies to prevent lameness for over a decade (Cook et al., 2016). These herds had a mean herd size of 851 cows, were confinement housed in freestalls and produced more than 40 kg energy corrected milk per cow per day on average. The prevalence of clinical lameness averaged 13.2% - which would rival the degree of lameness identified in grazing herds (e.g. 8.3% as reported by Fabian et al., 2014), and mixed housing and grazing or organic management systems elsewhere (e.g. 16.5% in Amory et al., 2006; 17.2% in Rutherford et al., 2008). Interestingly, it is lower than the prevalence found in similar herds in the Midwest a decade or more ago (e.g. 22.5% in Cook, 2003; 24.6% in Espejo et al., 2006), suggesting that the overall degree of lameness in the region may be improving. Severe lameness was also uncommon at a mean of 2.5%. This average is lower than that found in the majority of previous freestall surveys (e.g. 5.3% in Barker et al., 2010; 16% in Dippel et al., 2009; 4.8% in Husfeldt et al., 2012). Thus it would appear that high performance can be compatible with acceptable lameness levels, if we manage cows correctly. Table 2 highlights some of the management characteristics of these herds pertaining to lameness management.

Table 2. *Management characteristics of the high producing multiparous group cows in elite housed dairy herds in Wisconsin (from Cook et al., 2016).*

Management Characteristic	***% Herds or Mean***
% Sand bedded stalls (deep loose bedding including manure solids)	62 (70)
% 2-row stall layout pens (vs 3-row)	61
% Use of headlocks at the feedbunk	83
Milking Frequency (% 3 times a day)	67
% Use of rBST	67
% Solid floor (vs slatted)	100
% Rubber floors in freestall alleys	5
% Rubber floors in transfer lanes	15
% Rubber floors in holding areas	41
% Rubber floors in parlors	68
% Manual manure cleaning from the alleys	73
% Use of fans over the resting area	96
% Use of water soakers in the pens	79
% Allow access to the outside to roam	9
% Trimming at least once per lactation	88
% Trim cows at least twice per lactation	65
% Trim heifers before calving	49
Mean footbath frequency (milkings per week)	4.5
Mean cows per full time equivalent (FTE) worker	62

When examining the management strategies with high levels of adoption in Table 1, there are consistencies with the herd level risk factors documented previously. These herds use deep loose bedded stalls, have 2-row pen layouts with headlocks, and have solid flooring with strategic use of rubber floors, especially around the milking center. Notably, these herds were not using rubber flooring in their pens to control lameness. They clean manure from the alleys when the cows are outside the pen, and have aggressive hoof care, heat abatement and footbath programs. Two thirds of herds use rBST and milk three times daily, and perhaps surprisingly, 9% let their high producing cows outside the barn strategically – not to graze, but to spend time away from concrete floors inside the barn. In a multivariate model, deep bedded stalls, pasture access and fewer cows per FTE worker significantly reduced the risk for lameness overall.

Lameness management will continue to be refined, but these herds prove that we know enough right now to implement positive change in the dairy industry and achieve acceptably low levels of lameness, even in cattle which may be inherently more susceptible.

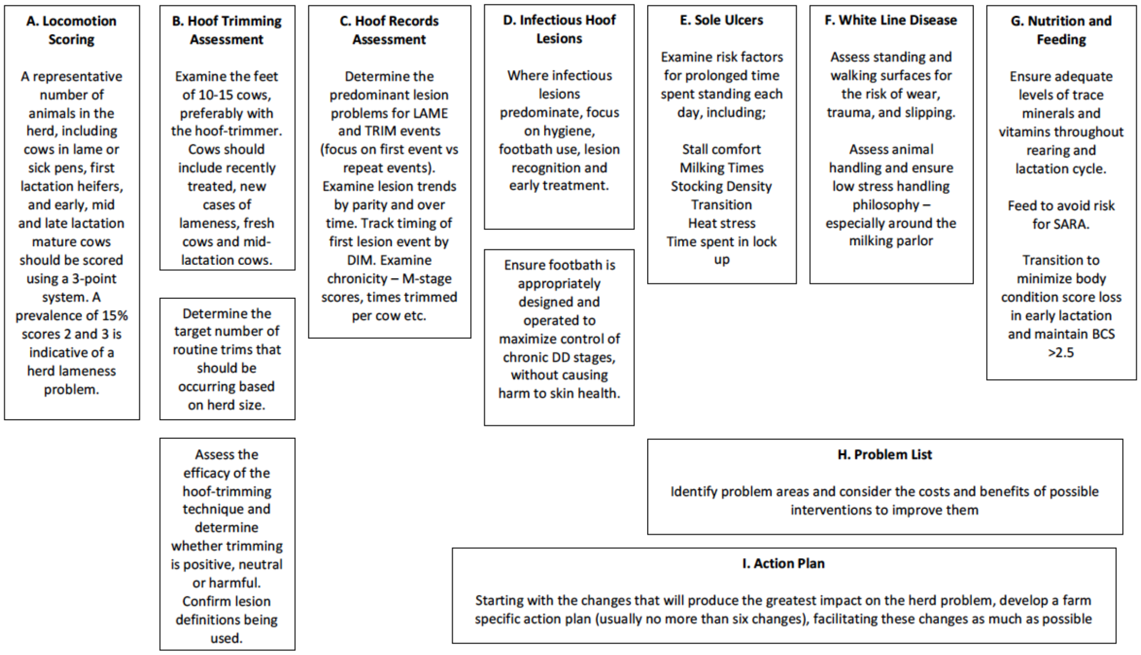
A Structured Approach to Lameness Prevention

When troubleshooting lameness problems, I use a structured approach starting with locomotion scoring, lesion analysis and assessment of the routine hoof-trimming and lame cow surveillance program. It is essential that the hoof-trimming is a component of prevention rather than a risk factor in itself. I then examine the risk factors for each of the key hoof lesions and finish with a review of feeding practices. From this examination, we can create a herd specific action plan designed to maximize impact on the key hoof lesions on the farm.

For DD prevention, we focus on the early identification of acute lesions (before the cattle are lame) and prompt effective treatment, starting around breeding age in replacement heifer pens and continuing throughout the life of the animal, coupled with an effective footbath program to control the chronic lesions and hold them in check. Trace mineral supplements have a significant role to play, particularly during the rearing period. For SU prevention we target risk factors that extend daily standing times – stall design and surface cushion, stocking density, milking times, heat abatement and lock up time for management tasks. We optimize the transition period to maximize rest and reduce BCS loss in early lactation. Finally, for WLD control, we examine areas of the farm where flooring puts the cow at risk of slipping, trauma and excessive hoof wear, and watch workers to ensure low stress handling – especially around the parlor operation.

The overall approach is summarized in Figure 2. Each assessment results in a problem list which can then be used to develop a targeted action plan for the herd.

Figure 2. Herd lameness troubleshooting plan



Conclusion

In this article, I have made the case, that while we still have knowledge gaps to fill in our understanding of lameness, the global crisis that we face with 1 in 4 cows walking with a painful limp can be solved by implementing our current knowledge targeted at the key hoof lesions; DD, WLD and SU. The challenge we face is one of creating a simple roadmap targeted at an individual producers most significant problems and motivating that producer to implement the changes necessary. Dairy producers that have already achieved success in lameness prevention will serve an important role motivating others to follow in their foot-steps.

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Footbaths: Solution to a Problem or a Problematic Solution?

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Disinfecting feet to help prevent infectious claw lesions, such as digital dermatitis (D), interdigital dermatitis (I) and heel horn erosion (E), can be improved through the use of a footbath. The footbath may still be considered a crude and unsophisticated tool given there's a minimal amount of research that exists to establish the optimum solution and management practices for greatest efficacy. However, it is the best solution that we have available at this time. The goals of footbathing should include: 1) prevent infectious claw lesions, such as D, I and E, 2) not compromise skin integrity, 3) not harm cattle or people, and 3) be reasonably priced, while doing no harm to equipment, structures during storage, during use and after disposal.

Digital Dermatitis Basics

Digital dermatitis results from a primary breakdown in the innate immune system. The infection begins with compromised skin integrity, which allows an opportunity for bacteria to enter the skin and begin to colonize. To flourish, the affecting bacteria require a low-oxygen environment often resulting from manure accumulation on the skin and claw of the foot. Research at the University of Wisconsin showed that placing bacteria that cause digital dermatitis on healthy skin did not result in development of digital dermatitis lesions.

Digital dermatitis is often classified using a 5-point M-stage scoring system (M0 – Normal healthy claw; M1 – Early subclinical, small lesions < 0.75"; M2 – Painful acute ulcer, red active lesion > 0.75"; M3 – Healing lesion, firm and scab-like; M4 – Chronic lesion, hyperkeratotic or proliferative "hairy warts"; M4.1 – Chronic lesion with new active M1 lesions on the surface).

When To Use A Footbath

The primary goal of a sound foot bathing program is to aid in prevention of the initial infection, while helping reduce development of M1's into more active and painful M2 stage lesions. Footbaths are ineffective at treating M2 stage lesions (raw, red painful lesions) which means M2 lesions must be treated topically with an antibacterial. However, footbaths may be effective at inhibiting the transformation of chronic M4.1 stage lesions back into raw, red M2 stage lesions.

Unfortunately, poorly managed footbaths may increase foot health problems and the incidence of infectious claw lesions. Common reasons for footbath failure or contribution to increased disease development include: poor design (length, depth, width, flooring), weak chemical solutions, inconsistent use, areas of manure/urine accumulation after the footbath, chemical solution pH is too low, side stepping the bath, and others.

Footbath Design Matters

What is the correct footbath size? Research conducted by Dr. Nigel Cook et al., at the University of Wisconsin School of Veterinary Medicine showed that cows will achieve at least two dunks in the treatment solution per rear foot per pass when the footbath length is 10 feet to 12 feet (or greater). These researchers also reported improvement in steps per bath when the in-step and exit curb heights were at least 10 inches. The higher in-step curb height forces cows to step up and over into the bath while the higher exit step curb height prevents cows from striding through the bath. In comparison, cows moving through a typical 6 foot bath usually achieve only 1 to 1.5 dunks per rear foot in the treatment solution.

Most dairies desire to have a single-pass footbath while minimizing their investment in treatment solution. One way to achieve this goal is through the use of a 12 foot long by 1.5 foot wide footbath width at the base (note: 36 inch width at hip height) as this will achieve nearly twice the number of dunks per foot vs. the conventional 6 foot by 3 foot bath. However, when designing and placing a longer bath, it is critical to ensure the bath is located on a level surface. For example, a 10 foot bath located on a 4% slope will be 4.8 inches lower in elevation from one end to the other (possibly more than the depth of the bath). For larger dairies, with rapid exit parlors, it is often necessary to design wider baths to allow multiple animals to pass at one time through the treatment solution. We have seen baths up to 12 feet wide work quite well, as long as a length of 10 feet to 12 feet is maintained. The footbath should also have solid sides (36 inches to 54 inches high or more) with absolutely no place for a cow to put her foot other than in the bath. Other important footbath features to improve performance consistency include: 1) a large drain (4 inches) on one end built into the floor of the bath, 2) 2 inch or larger water supply line or hose located on the upper end of the bath to flush and fill quickly, 3) no low spots in the concrete or areas allowing for manure, urine or foul water accumulation upon exit from the footbath, 3) build and locate the footbath to account for inclement weather by adding floor heat under the bath, infrared heat over the area, warm storage area for chemicals such as formaldehyde and any other premixes that need protection from freezing. The use of auto baths can work well too. Another option is to use a large electric pump to turbo blast out the bath (note: this does require a sloped curb on the exit). Other necessary features to improve footbath efficacy include: a smooth floor in the bath that does not cause trauma to the claws (epoxy or rubber) and ensuring that cows are permitted to bypass the bath when it is not in use. Also be sure there are no reasons why the footbath could not be used 365 days per year (if necessary).

Hygiene and Footbath Frequency Considerations

Foot wash systems are often used to clean off the feet and there are many different forms available. One advantage of cleaning off the feet and claws using this method is that it exposes the skin to oxygen, which may in turn help reduce the frequency of foot bathing required per week. However, using a washer system is not without its challenges. For example, it increases the amount of waste water created, thus increasing manure volume and handling costs.

Factors affecting footbath efficacy in controlling infectious claw lessons include:

- Number of times used per week
- Cow passes per bath
- Cow hygiene

- Claw contact time with treatment solution (time the feet are in the bath, time on feet before the claws get diluted with other "stuff")

Frequency of footbath use per week should be determined by hygiene of the feet and legs of the cow. Cow hygiene scores are as follows:

1. Clean: little or no manure contamination on the lower limb
2. Slightly dirty: the lower limb lightly splashed with manure
3. Moderately dirty: there are distinct plaques of manure on the foot, progressing up the limb
4. Very dirty: confluent plaques of caked-on manure on the foot and higher up the lower limb

There is a very strong relationship between leg hygiene score and infectious claw disease. The chart below compares cow hygiene scores to suggested frequency of footbath use:

Proportion of cows with hygiene scores of 3 and 4	Suggested footbath frequency **
<25 %	As required
25-50 %	2 days/week
51-75 %	5 days/week
>75 %	7 days/week

** Footbath frequency guidelines serve only as an initial recommendation given that control of infectious claw lesions is influenced by many factors.

Other Considerations

Selecting an effective footbath chemical can be a daunting task. Chemical concentration is one of the greatest issues of concern in footbath management. But first, when determining footbath concentration it is important to determine how full is full for the bath? If the goal is a minimum of 4.5 inches of solution depth, employees must be able to easily assess solution depth to determine the need for additional solution or complete replacement. However, when baths vary from 3 to 10 (or more) inches in depth, it is imperative that a quick and easy system to measure solution depth be provided, as manure and urine can quickly dilute chemical treatments while solution is splashed from the bath. There are a number of systems used to aid with this concern: mount a 4.5 inch length of 2x4 by the curb, mount a 4.5 inch stainless steel marker on the side of the bath, or our favorite option which is using a 4.5 inch length of small PVC pipe mounted to the side of the bath. As the frequency of more concentrated products increases, such as footbath acidifiers, monitoring of footbath depth will become a greater issue.

A second system that helps to get and keep footbath chemical concentrations accurate is to use a premixing system. These systems do not need to be complex, as an old bulk tank or plastic barrel with an agitator and a transfer pump are all that is needed. These systems can improve accuracy of mixing, allow for mixing of greater solution volume, reducing labor needed to prepare footbath solutions and in addition, may improve worker safety too. During use, these systems often save considerable time in refilling the bath and/or allow for greater use of automated filling systems too.

One of the greatest concerns of dairy producers is determining what footbath solution will be most efficacious in their operation. Key points of consideration are economics, effectiveness, and environmental impact. Water composition can affect how much chemical is needed as mineral contaminants and pH affect chemical solubility and efficacy. Water is the primary solution within the bath and thus should not be ignored as it often varies by location and possibly by season. One of the most common solutions utilized in footbaths is a 2% to 3% formalin solution. However, as with many chemical solutions, more is not better. Formalin solutions tend to be the least expensive products used for control of digital dermatitis and other common infectious claw lesions. Fortunately, bacteria are not able to develop resistance against formalin mixtures. Advantages to using formalin solutions include that it mixes well (soluble) in water and is highly researched and proven to reduce incidence and severity of claw lesions. Fortunately, when diluted by manure, urine and waste water, formalin solutions will become inactive as they are converted to CO_2 and H_20 and do not create an environmental hazard. However, formaldehyde has some disadvantages too. It is a suspected carcinogen, while the International Agency for Research on Cancer has concluded that there is limited evidence for the carcinogenicity of formaldehyde in human beings (IPCS INTERNATIONAL PROGRAMME ON CHEMICAL SAFETY, Health and Safety Guide No. 57). All formalin solutions should be handled with protective clothing, gloves and goggles or a face shield to protect exposed skin. Formaldehyde is not effective below 45^o F and should be protected from freezing while in storage or prior to use. It is not suitable for application to open wounds, such as an active M2 digital dermatitis lesion. It is relatively easy to create formaldehyde burns with high concentrations harming skin, cow's feet and teats as this chemical replaces the water in living cells with a gel-like matrix.

Copper sulfate at a 3% to 5% concentration is an effective antibacterial and hardening agent. Copper sulfate is relatively inexpensive but more costly than formalin. While copper sulfate will go into suspension somewhat easily in water, dilution can be improved through acidification and use of warmer water. Acidifiers (such as inorganic and organic acids) tend to improve copper ionization and may allow for less (up to 50%) copper sulfate needed to achieve effective digital dermatitis control. However, lower footbath solution pH is better only to a point. Normal pH of the bovine skin is around 3.6. When there are issues with foot rot and proliferative DD lesions, footbath solution pH should not be below 3.0. We have observed multiple herds with increased frequency of foot rot and development of proliferative digital dermatitis lesions (out of control infections) when footbath pH solution was below 3.0 due to use of acidification products. Research conducted by Dr. Dorte Dopfer and associates at the University of Wisconsin School of Veterinary Medicine documented the negative effects of excessively low footbath pH. To evaluate the effects of footbath solutions on digital dermatitis control, we need to start recording not only the number of cows with digital dermatitis lesions but also the state of lesion chronicity (hyperkeratotic or proliferative) as cows with proliferative lesions are chronically infected with very contagious M2 and/or M4.1 lesions. Fortunately, if the footbath is working properly we should be able to find signs of the digital dermatitis lesion healing. During trimming events or in the parlor, look for loose flaps on the digital dermatitis lesions reflecting healing. These flaps are layers of loose healing skin sluffing from the wart surface as it progresses through the healing process. Lastly, disposal of copper sulfate solutions is an environmental concern and may negatively affect performance of manure composting and energy creating systems.

Zinc sulfate at a 10% to 20% solution can work nearly as well as copper sulfate while at 75% of the cost of copper sulfate. However, zinc products do not readily go into solution but acid (lower pH) and hot water helps. One advantage to using zinc in footbaths is that it is required by corn well above what we would put out on the soil thus reducing environmental concerns when compared to copper sulfate. Copper has also been documented to reduce corn yield as it increases in soil concentration. Controlled research in control of digital dermatitis is however lacking with zinc sulfate.

Soap and water should also be considered in most footbath management regimes. A soap and water solution should be part of a normal footbath rotation schedule. Herds that have significant accumulation of mud or manure on the claws benefit by using a 1% solution (1 quart of soap per 25 gallons of water) on a routine basis.

There are many factors affecting the frequency of changing a footbath solution:

- Manure/organic matter load
- Size of bath (length, width, depth)
- Water conditions, including temperature (mineral contaminants, pH)
- Solution pH
- Chemicals used
- Chemical concentration used
- Many others…

Recently a test was developed by Zinpro Corporation and the University of Wisconsin School of Veterinary Medicine to help answer the question of footbath chemical efficacy in control of growth of aerobic and anaerobic bacteria (those responsible for development of digital dermatitis). The process requires repeated sampling of the footbath for aerobic and anaerobic bacterial load as the number of cow passes increases. In general, when the aerobic bacteria counts reach above 100,000 cfu/mL, it is time change the footbath solution. The program shows when the bacterial counts increase in response to cow passes and thus when the solution is no longer effective. The goal is to achieve optimal control of infectious bacteria and thus claw lesions while at the same time achieving maximum utilization of the treatment solution. This test now allows us to accomplish both tasks. Field experience has demonstrated that in some cases producers have been able to cut footbath costs by 50% and just as importantly lower the amount of copper excretion on their land. For example, producers have gone from 7 lbs $CuSO_4$ /cow/year down to as low as 2.5 lbs /cow/year. This is significant given the major effects of copper on reducing crop yields. This should be of particular significance to some dairymen as there are certain parts of the USA that have naturally high soil copper concentrations.

Trimming records, pen walks or parlor evaluations are effective means of monitoring the results of any footbath program and especially for evaluation of changes to a footbath system and/or changing a footbath chemical. Records are essential in any effort to adequately evaluate if digital dermatitis remains under control and/or if a change worked or not. Often times it only takes 2 to 4 weeks before you're able to identify a difference in your trimming records. But beware that digital dermatitis is a long-term infection and true changes in digital dermatitis control must be evaluated over a period of 6 to 12 months in order to accurately assess digital dermatitis control. Do not accept research from any company showing results over a period of only 2 to 8 weeks.

Conclusion

Footbaths need more science to determine chemical choice, solution concentration, frequency of use and ultimately digital dermatitis control efficacy. Fortunately the base of solid scientific evidence is growing. A well-placed and managed footbath can prevent new digital dermatitis lesions and reoccurrence but we must treat M2's topically. Installation of a level 10 to 12 foot long bath with 10 inch curbs and splash guards on the sides will achieving more dunks of the rear feet and increase effectiveness with no more than a conventional 6 foot fiberglass bath.

As herdsmen, we must strive to keep our cows clean thus reducing the need for increased footbath use. Make sure your system is setup to be very user-friendly and repeatable to ensure it gets changed on a timely basis. Make the system safe for people, cows, and the environment. Testing your footbath solution is now possible and can either help increase efficiency or reduce costs along with reducing chemical contamination of the environment. Please use trim records or pen walks to decide if your change worked or not in controlling digital dermatitis or other common infectious claw lesions.

References available upon request.

Notes:

Producer's Experiences with Robotics on Larger Dairy Operations

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Automatic milking systems have been increasing in popularity around the world. In the last few years, we have seen the rapid expansion of this technology in the US and Canada. This trend is expected to continue over the next 10 years. Larger farms with more than 1,000 cows are adopting this technology. This panel will feature four farms that have adopted this technology. Each farm will provide a brief description of their operation and then answer a few questions about their experiences with automated milking. In addition, they will address some key issues they have faced as they have transitioned from conventional milking to automated milking.

Groshek Dairy is located near Amherst Junction, WI. They added a DeLaval robot milking barn in 2014. The new barn contains 4 robotic milking units and has capacity for 240 cows. This herd currently has a daily average of 90 lbs. of milk per cow. Keith Groshek will join the discussion and describe his 2-year long planning process to develop the plans for the current facility. He carefully consider both free-flow and guided or milk first barn designs. He settled on the milk first design as he felt it was a better fit for the flexibility in time management he desired for family and other activities. After considerable evaluation, he chose to build a new facility rather than attempt to remodel existing facilities. While it was a difficult decision, building a correctly designed barn offers many advantages for cow comfort and cow flow.

Halarda Farms is located near Elm Creek, Manitoba, and includes about 4,500 acres and an 850 cow dairy. They transitioned to a Lely Automatic Milking System in 2009 with an original 8 units and later added six more units. Today, the 14 Lely robots milk 800 cows each day. The Borst family has worked hard to organize their labor and procedures to keep the many areas of their operation working smoothly and efficiently. Nearly everything is done based on a set schedule with specific areas of responsibility for employees with the flexibility to move labor to address seasonal needs of various portions of the operation. Anton Borst will share their experience with the robotic milking system, how it has changed their herd management and how it has given them flexibility with labor.

Located near Dorchester, WI, JTP Farms transitioned from a remodeled stanchion barn with small freestalls with mattresses and a double-four flat barn parlor to a new facility featuring DeLaval Voluntarily Milking Systems in 2012. During the first two years of operating the new facility, daily per cow production moved from 72 pounds per cow to over 100 pounds. The current herd of 247 cows has responded to the premium the farm has placed on cow comfort and animal welfare as they designed the new facility. Jake Peissig will join us in our discussion and share his experience as he transitioned from older facilities into the current facility.

Swisslane Farms, located near Alto, Michigan has been home to the Oesch family for a century. Over the years, many changes have occurred as the farm grew from 91 acres to the current farm of 5,000 acres and 2,150 cows. Currently, 1,650 cows are milked 3X in a double 16 parallel parlor. A robotic milking facility, SwissLane 2 was added in 2011. It contains 8 Lely Automatic Milking Systems which milk 500 cows each day. Thomas Oech, Jr. will join us in our discussion on managing cows in a robotic milking facility.

Notes:

Fresh Cows – Management for Best Behavior!

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Introduction

Promoting feed intake by lactating dairy cows, particularly those in early lactation, is critical for the improvement and maintenance of milk production and health. Many dairy cows are capable of producing quantities of milk in much greater amounts than which can be maintained by nutrient intake in early lactation. Research in dairy cattle nutritional management has resulted in many discoveries and improvements in dairy cow health and production. Despite many advances in this field we are still faced with the challenge of ensuring adequate dry matter intake (DMI) to maximize production and prevent disease, particularly in dairy cows during the early lactation period.

Field observations, in addition to empirical evidence, suggest that housing and management can play as large of a role as nutrition in the performance and health of early lactation dairy cows. Much of that impact is mediated through the effects of those factors on the behavior of dairy cows. This paper will, thus, describe the importance of understanding cow behavior in early lactation and how knowledge in this area of science can be used to evaluate nutritional management and housing strategies. In particular, focus will be on allowing cows the time to perform behaviours they require, dietary transition, feeding management, stocking density, and grouping strategies. It is anticipated that with an improved understanding of the behavioral patterns of these cows, combined with proper nutrition, dairy producers can manage their fresh cows to optimize health and production.

Do Cows have Time to Behave Properly?

A dairy cow has a number of things that she needs to accomplish every day. Dairy cows, fed a TMR and kept in free-stall housing, will spend 3-5 h/d at the feed bunk, 0.5 h/d drinking, 10-13 h/d lying down, 2.5-3.5 h/d outside the pen (milking), and 7-9 h/d ruminating. While every 24-h day should be enough time to allow cows to do these things, we know that any factor which may impinge of the cow's ability to devote her time to those activities may have negative consequences. This is particularly problematic in early lactation, as at calving, feeding, resting, and ruminating activity all decrease, while standing time increases.

Dairy cows are motivated to spend approximately half of their day lying down; Jensen et al. (2005) demonstrated that cows have an inelastic demand for about 12-13 h/d of rest. Other researchers have shown that when opportunities to perform behaviors are restricted, lying behavior takes precedence over eating and social behavior (Munksgaard et al., 2005). Adequate lying time has not only been linked to ensuring good milk production (Grant, 2004), but prevention of cows spending too much time standing has also been linked to prevention of hoof pathologies (Proudfoot et al., 2010) and resultant lameness. In fact, factors that are linked to encouraging resting time in dairy cows, such as larger, less-restrictive stalls, use of well-maintained, deep-bedding, have all been linked to lower prevalence of lameness (Chapinal et al., 2013). Thus, anything that limits the ability of cows to devote the time she needs to lying down, may have negative consequences.

One of the behavioral challenges that dairy cows face at freshening is the sudden increase in time devoted to milking and being outside of her pen. The more time that cows are required to be away from their pen and resources (feed, water, rest), the more they are forced to reduce the amount of time that they devote to things like resting or eating, with consequence. Field studies have shown that cows are often outside of their pens for 4+ h/d (Espejo and Endres, 2007; von Keyserlingk et al., 2012). Espejo and Endres (2007) reported a positive association between the prevalence of lameness in high-producing pens and greater time spent outside the pen. Matzke (2003) demonstrated that mature cows and first-lactation heifers gained + 2 and 4 h/d of rest and 2.3 and 3.6 kg/d of milk when they were outside the pen for only 3 versus 6 h/d.

The feeding behavior of dairy cows is also important factor to consider, as it directly relates to the DMI level of the cow, as well as to her rumen health and digestion. The feed intake of a dairy cow is simply a function of her eating behavior. The total DMI (kg/d) of a cow is the result of the number of meals consumed daily (#/d) and the size of those meals (kg/meal). Similarly, the DMI can be expressed as a function of the total time a cow spends feeding per day (min/d) multiplied by the rate (kg DM/min) at which she consumes that feed. Thus, if a cow is to consume more feed, she needs to adjust some aspect of her feeding behavior. In recent analyses, we have demonstrated that gains in DMI may be more consistent by getting cows to spend more time feeding at the bunk, broken up into more frequent meals (Johnston and DeVries, 2015). Thus, maximizing time available to eat, to ensure high levels of DMI, is critical. This is particularly important for fresh cows, who often cannot keep up their nutrient intake in early lactation to match meet production and maintenance demands. An excessive or prolonged drop in DMI after calving may result in non-adaptive negative-energy balance, which may lead to subclinical ketosis (SCK), which is estimated to affect ~40% of dairy cows (McArt et al., 2012).

Maximizing time spent feeding at the bunk, in smaller meals, is also important for keeping the rumen stable, by avoiding large post-prandial drops in rumen pH associated with large meals and resultant risk of sub-acute ruminal acidosis (SARA)(Krause and Oetzel, 2006). Not only how cows eat, but also what they eat is important. Sorting of a TMR by dairy cows can result in the ration actually consumed by cows being quite different from that intended. As result, cows do not consume the predicted levels of effective fiber, thereby increasing the risk of depressed rumen pH (DeVries et al., 2008) and low milk fat (DeVries et al., 2011). Further, imbalanced nutrient intake and altered rumen fermentation, as result of sorting, has the potential to impact the efficiency of digestion and production (Sova et al., 2013).

The importance of devoting sufficient time to rumination should also not be overlooked. Dairy cows rely on the process of rumination to fully digest their food. Rumination serves to assist in the breakdown of particles, which not only also for greater microbial activity, thus increasing the rate of fermentation (Welch, 1982). It also assists in passage of material from the rumen. Thus, rumination also contributes to ability of cows to maximize their DMI. Rumination also serves to stimulate saliva production and, therefore, assist in rumen buffering and maintenance of a stable rumen environment (Beauchemin, 1991). While rumination time is largely dictated by the diet consumed (and its amount), factors which influence the daily activity patterns of cows have the potential to influence rumination. Dairy cows typically ruminate in a diurnal pattern during the time periods when the animal is not active (feeding, milking), but when at rest (lying down). As such, most rumination activity occurs at night, with other major bouts of rumination occurring during the middle of the day in-between other periods of activity (DeVries et al., 2009). As a result, a disruption to a cow's normal rest time due to other factors (for example: poor stall comfort or availability, increased need to walk, activity related to social agitation) may result in a decrease in rumination time.

What are the Benefits of Monitoring Behavior?

Given the link between feeding behavior and DMI, there is evidence that monitoring feeding behaviors may be important for the detection of health problems in dairy cows. In work by Goldhawk et al. (2009), cows diagnosed with SCK during the week after calving showed differences in feeding behaviour and DMI at the time of diagnosis. Interestingly, those differences were apparent as early as 1 wk before calving. Those researchers estimated that for every 1 kg decrease in DMI and 10 min decrease in feeding time during the week prior to calving, the odds of developing SCK increased by 2.2 and 1.9 times, respectively (Goldhawk et al., 2009).

Another behaviour which may be important to monitor during the transition period is rumination behavior. Shorter rumination times may be indicative of low DMI (Clement et al., 2014), and risk of negative energy balance, during the post-fresh period. For example, Calamari et al. (2014), studying a small group of cows (n=23), reported that cows that were diagnosed with at least one clinical disease postpartum had a lower rumination time in the first week after calving and their increase in rumination time after calving was slower compared with healthy cows. In a larger study by Liboreiro et al. (2015), cows diagnosed with SCK had reduced rumination time from calving to 8 d postpartum, as compared with healthy cows. In a recent study by our group, we demonstrated that multiparous cows who developed SCK, not only had reduced rumination time during the first weeks after calving, but also during the week prior to calving, compared to those cows that remained healthy (Figure 1; Kaufman et al., 2016). These differences were accentuated in those cows that not only were diagnosed with subclinical ketosis, but also with one or more other health problems post-partum.

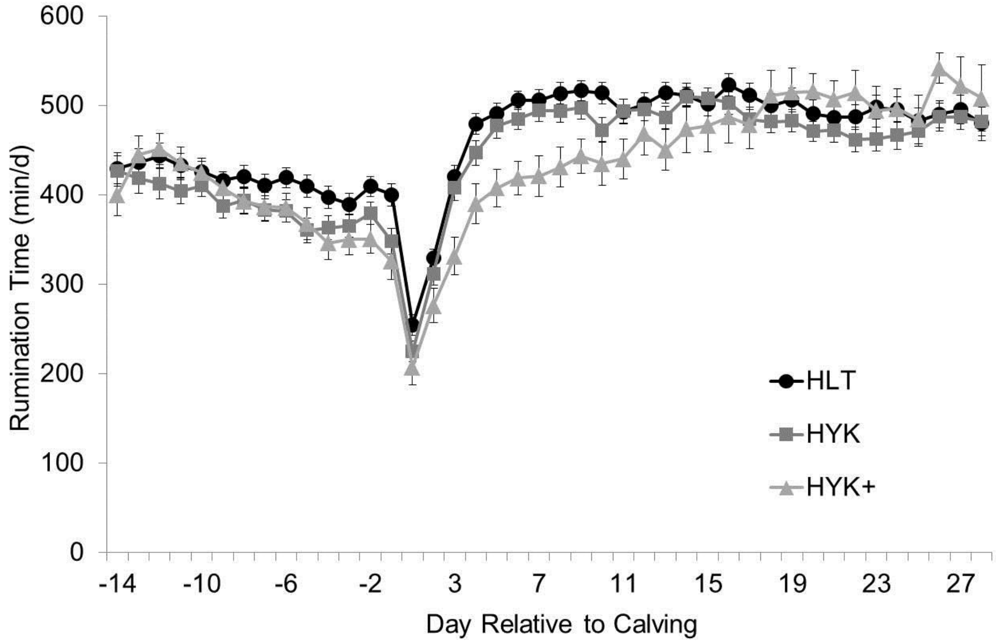

Figure 1. *Daily rumination time over the transition period for multiparous cows that were: healthy with no other recorded illnesses (HLT; n = 87), subclinically ketotic with no other health problems (HYK; n = 76) and subclinically ketotic with other health problems (HYK+; n = 39) (adapted from Kaufman et al., 2016*).

The results of these studies suggest that careful monitoring of cow behavior in the post-fresh period, as well as before calving, may be useful for identifying cows experiencing illness, or even at risk for illness. This is becoming a reality on many dairy farms with the development, validation, and commercialization of various technologies to automatically capture such behavioral changes (Schirmann et al., 2009; Bikker et al., 2014).

How Does Diet Affect Behavior?

One of the most notable changes for the dairy cow at calving is the transition from the dry to lactating diet. It is well established that cows take anywhere from 7 to 14 days to adjust their DMI in response to a dietary change (Grant et al., 2015). Given the difference in composition of dry cow and fresh cow diets, an associated lag in DMI is not always surprising. The susceptibility of dairy cows to SARA is also highest in early lactation (Penner et al., 2007), but also highly variable between cows, despite similar feeding management and transitioning strategies (Penner et al., 2007). Moving from a high-forage dry cow diet to a lower forage, higher NFC fresh-cow diet will not only directly impact the rumen environment, but have impacts on the eating behavior of cows. It is plausible that some of variability may be due to the eating behavior of said diets in early lactation. As compared to eating a dry cow diet, a fresh cow diet will be consumed much faster and in larger meals (DeVries et al., 2007). Such diets are also sorted to a greater degree (DeVries et al., 2007; 2008) and, as result of lower fibre content and particle size, ruminated for shorter periods of time per unit of feed consumed. Therefore, formulations for fresh cow diets should be aimed at minimizing these impacts on the eating behavior of the cows, by providing adequate physically-effective fiber, while limiting the use of highly fermentable starch sources.

Given that fresh cow diets still require a significant amount of highly-fermentable feed sources to ensure sufficient DMI and to meet nutrient requirements, other opportunities to modify the feeding patterns and rumination of cows on such rations need to be explored. Feed additives that have a positive impact on the rumen environment can also have concurrent benefits for feeding and rumination behavior. We demonstrated that supplementing peak-production lactating cows with a live strain of *Saccharomyces cerevisiae* yeast had beneficial impacts on meal patterning (DeVries and Chevaux, 2014): cows had more frequent meals that were smaller and occurred closer in time together. This research supported previous work by Bach et al. (2007) whereby similar effects on feeding behavior were seen as well as a positive impact on raising and stabilizing rumen pH. In DeVries and Chevaux (2014), cows supplemented with live yeast tended to ruminate longer and have less periods of elevated rumen temperature, which could be associated with less long bouts of depressed rumen pH. Likely, as result of these improvements in nutrient flow, rumination, and stabilized rumen, the live yeast-supplemented cows tended to have higher milk fat content and yield. Yuan et al. (2015) demonstrated that feeding a yeast culture-enzymatically hydrolyzed yeast product to cows during the dry period and early post-partum period has similar impacts on feeding behavior, with dry cows having more frequent, smaller meals.

Similar results have been demonstrated with other feed additives – including monensin. Lunn et al. (2005) demonstrated that providing monensin increased meal frequency in lactating cows experiencing sub-acute ruminal acidosis. Similarly, Mullins et al. (2012) found that feeding monensin in the first few days after dairy cows were transitioned to a lactation ration resulted in increased meal frequency and decreased the time between meals.

The common thread in all of these studies is an association between favorable meal patterns and a reduction in ruminal pH variation. Whereas meal patterning may, in itself, affect ruminal pH, it is likely that feed additives, such as live yeast or monensin, that have the potential to stabilize ruminal pH and fermentation, affect meal patterning as a secondary effect. Specifically, a more consistent fermentation pattern should result in less variation in volatile fatty acid production, improved fiber digestibility, and quicker return to eating. Feed additives that promote healthy eating patterns and have a positive impact on the rumen environment and rumination are then particularly useful for early lactation cows, which are at greater risk of experiencing SARA. For these cows, the use of such additives, in addition to proper feed bunk management (as described below), will allow cows to optimize the potential of the feed provided to them and remain healthy and productive during this critical period of time.

How Does Feed Availability Affect Behavior?

Beyond the diet provided, management of fresh cows must be focused on stimulating eating activity to help cows meet their lactational demands. In a series of studies we have shown that for TMR-fed dairy cattle, feed delivery acts as the primary stimulant on their daily feeding activity patterns (DeVries et al., 2003; DeVries and von Keyserlingk, 2005; King et al., 2016). Therefore, the frequency and timing of delivery of fresh feed are important factors for stimulating intake in fresh cows.

More frequent feed delivery (than 1x/d) results in cow more evenly distributing their intake across the day (DeVries et al., 2005; Mantysaari et al., 2006) as well as improving access to fresh feed by subordinate cows (DeVries et al. (2005). Further, providing more than 1x/d has been demonstrated to reduce the amount of feed sorting (DeVries et al., 2005; Sova et al., 2013), which further contributes to more consistent nutrient intakes over the course of the day. Such desirable feeding patterns are conducive to more consistent rumen pH and likely contributes to improved milk fat (Rottman et al., 2014), fiber digestibility (Dhiman et al., 2002), and the increased production efficiency (Mantysaari et al., 2006) observed when cows are fed more frequently than 1x/d. Improvement in DMI (Hart et al, 2014) and milk production (Sova et al., 2013) are also possible with more frequent feed delivery; however, less expected.

While moving to more frequent feed delivery may be difficult to operationalize on some farms, there is potential to alter the timing of feed delivery to increase the distribution of feed intake across the day. While the delivery of fresh TMR has the greatest impact of stimulating feeding activity, cows are also prone to eat around the time of milking, as well as around other management events during the day. It is possible then to stimulate more meals across the day by staggering these management events, for example, by moving the time of feed delivery away from milking. King et al. (2016) recently shifted feed delivery (2x/d) ahead of milking (3x/d) by 3.5 h and found that this resulted in cows consuming their feed more slowly in smaller, more frequent meals across the day (Figure 2), improving the efficiency of milk production.

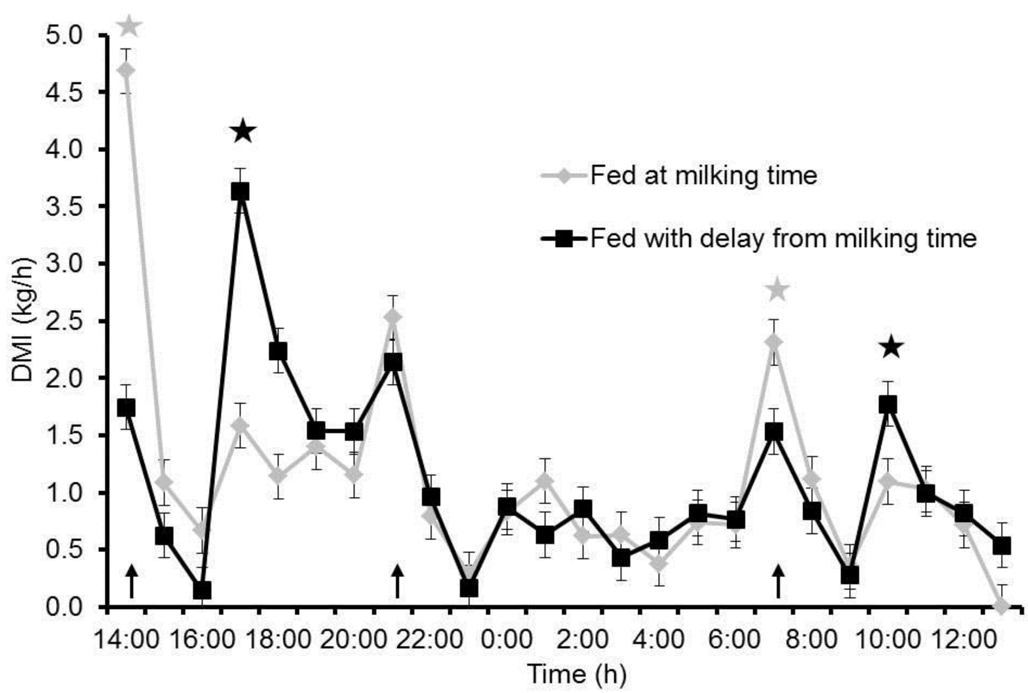

Figure 2. *Hourly average DMI (kg) of lactating dairy cows fed 2x/d: 1) at milking time (at 1400 and 0700 h, denoted with) or 2) fed with delay from milking time (at 1730 and 1030 h, denoted with). Cows were milked 3×/d at 1400, 2100, and 0700 h (denoted with ↑) (adapted from King et al., 2016).*

Feed push-up is another important factor in ensuring feed availability throughout the day. It must be noted, however, that we have no research evidence to say that feed push-up has the same stimulatory impact on feeding activity as does the delivery of fresh feed (DeVries et al., 2003). There is also no scientific evidence to suggest that pushing up feed more frequently will stimulate more DMI. That being said, feed push-up needs to occur frequently enough such that any time a cow decides to go to the feed bunk, there is feed available to her at that time. This ensures that DMI is not limited. By mixing up the feed that is no longer in reach, pushing it up will also help minimize the variation in feed consumed. Thus, pushing up feed frequently is necessary, particularly in the first few hours after feed delivery, when the bulk of the feeding activity at the bunk occurs.

Do Cows Have Space to Behave Properly?

One of the key components to ensuring that cows devote the proper amount of time to the behaviors they need to perform each day is to provide them adequate access to the resources they desire (i.e. feed, water, and lying areas). This is particularly true given that dairy cattle are allelomimetic, that is, they like to perform similar behaviors at the same time (i.e. synchronized).

When dairy cattle are overcrowded (i.e. situations where there are more cows than available feeding and/or lying spaces), they do not simply shift their eating and lying patterns to accommodate, but rather reduce the time they devote to those activities.

There are several studies where a reduction in lying time associated with lower stall availability has been described. For example, Fregonesi et al. (2007) demonstrated that increasing stocking density from 100 to 150% (1.5 cows per stall) reduced lying time by ~2 h per day. Similarly, Krawczel et al. (2012) demonstrated that for cows averaging 13 h/d of lying at a stocking density of 100%, increasing free-stall and feed bunk stocking density simultaneously from 100 to 142% resulted in a decrease of lying time of 42 to 48 min per day (Krawczel et al., 2012). Reduced lying time associated with overcrowding forces cows to spend more time standing on potentially hard, wet floors, which is tough on hoof health and may increase risk of lameness (Westin et al., 2016). Further, overcrowding may lead to reductions in rumination behavior. Krawczel et al. (2012) demonstrated that increasing free stall and headlock stocking density from 100 to 142% resulted in a drop of rumination time by 0.4 h/d; this change in rumination was associated with more time spent ruminating while standing and less time spent ruminating while lying down. These may all cumulate, then, in reduced milk production; Bach et al. (2008) demonstrated in a cross-sectional study of 47 herds, all with similar genetics and feeding the exact same TMR, a positive association ($r = 0.57$) between the stalls/cow and milk yield.

Similarly, overcrowding at the feed bunk results in increased aggressive behavior, and may limit the ability of some cows to access feed at times when feeding motivation is high, particularly after the delivery of fresh feed (DeVries et al., 2004; Huzzey et al., 2006). As a result, increased feed bunk competition will increase feeding rate at which cows feed throughout the day, resulting in cows having fewer meals per day, which tend to be larger and longer (Hosseinkhani et al., 2008). Feed bunk competition may also force some cows to shift their intake patterns by consuming more feed later in the day after much of the feed sorting has already occurred. Alternatively, reducing feed bunk competition, by providing adequate feed bunk space, particularly when combined with a physical partition (e.g. headlocks or feed stalls), will improve access to feed, particularly for subordinate dairy cattle (DeVries and von Keyserlingk, 2006; Huzzey et al., 2006). This, in turn, will contribute to more consistent DMI patterns, both within and between animals, as well as promote healthy feeding behavior patterns. It is not surprising that Sova et al. (2013) found in a cross-sectional study of parlor-milked, free-stall herds in Canada that every 4 inch [10 cm]/cow increase in bunk space (mean = 21 inch/cow; range = 14 to 39 inches/cow) was associated with 0.06 percentage point increase in group average milk fat and a 13% decrease in group-average somatic cell count. With greater bunk space available, cows are able to consume their feed in a manner more conducive to maintaining stable rumen fermentation, and thus have greater milk fat production. This may be particularly important for early lactation cows, which as described above, are at greatest risk of experiencing SARA during this time period. Also, with more bunk space (and lying space) cows are not forced to choose to lie down too quickly after milking rather than compete for a feeding or lying spot (Fregonesi et al, 2007), and thus reduce their risk of intramammary infection from environmental pathogens (DeVries et al., 2010). Finally, reduced feed bunk space has also been linked to compromised reproductive performance (Caraviello et al. 2006; Schefers et al., 2010). To date, much of work on the research on transition cows has focused on available feed bunk space during the close-up pre-partum period, where it has been shown that limiting bunk space can limit DMI (Proudfoot et al., 2009) and increase risk of post-partum disease (Kaufman et al., 2016). There is little research on this factor for the fresh-cow pen. However, given the vulnerability of cows at this time period, it is expected that these effects may be magnified at this time period. Thus, every effort should be made to manage fresh cow pens to provide sufficient space for all cows to each simultaneously (i.e. 30 inches [0.75m] of bunk space per cow).

In addition to access to feed and lying spots, some consideration must also be given to another, typically forgotten, nutrient: water. Water is perhaps the most important nutrient, however its quality and availability is often overlooked. In a recent field study of free-stall herds, Sova et al. (2013) found that milk yield tended to increase by 0.77 kg/d (1.7 lb/d) for every 2 cm/cow increase in water trough space available on the study herds (mean: 7.2 cm/cow; range: 3.8 to 11.7 cm/cow). While cause and effect were not established in that study, this result highlights the importance of water availability for group housed cows and provides further evidence that resource availability has the potential to greatly impact productivity.

How Do Grouping and Pen Movement Affect Behavior?

The optimal grouping of cows, particularly in the post-fresh period, remains a question. Over the years there have been a number of studies highlighting the differences in behavior of first-calf heifers as compared to mature cows. Krohn and Konggaard (1979) found first-calf heifers housed in a free stall separately from mature cows had increased eating time and higher DMI. Phillips and Rind (2001) reported that a mixed group of first-calf heifers and mature cows on pasture grazed for less time than either parity group kept alone. Most recently, Neave et al. (2017) found that, as compared to mature cows, first-calf heifers in mixed-parity groups spent more spent more time feeding, ate more slowly, visited the feed bunk more frequently, explored their feeding environment more, lay down more frequently in shorter bouts, and were replaced at the feeder more often. Given these differences, there appears to be benefits in keeping first-calf heifers and mature cows in separate groups. Phelps (1992) reported that first-calf heifers kept in groups produced 729 kg more milk per lactation than those kept in groups mixed with mature cows. Bach et al. (2006) observed first-calf heifers housed alone, as compared to those mixed with mature cows, to experience lesser loss of bodyweight and greater efficiency of milk production during the first part of lactation, as well as to milk more frequently in a robotic milking system. In a study done on commercial herds, Østergaard et al. (2010) found that keeping first-lactation heifers groups separate from mature cows after calving (for one month) positively affected production and health (with reduced treatments of ketosis) in those animals. Based on these data, it is recommended that first-calf heifers and mature cows are housed separately in early lactation to ensure optimal health and production of those first-lactation animals. However, due to herd size and facility design, this is not always possible. This was recently highlighted in a study by Espadamala et al. (2016) of 45 large herds in California, where ~50% of the herds did not keep first-calf heifers in separate groups. For those herds that do not, or are not able to, keep separate groups, it is important there to be sufficient lying, feeding, and water space, and the lying stalls are designed to fit the largest animals in the pen.

Another important factor to consider in relation to grouping of fresh cows, in the frequency and timing of moving animals into new groups (relocation). It is well established that every time a cow is moved into a new pen, it can disrupt the social complex of the group and have specific negative impacts on the moved individual. The negative effects of relocation can be seen for up to 3 d following placement in a new pen, and include increased competition for feed access, greater feeding rate, and reduced production, DMI, and rumination time (von Keyserlingk et al., 2008; Schirmann et al., 2011). Torres-Cardona et al. (2014) also demonstrated that relocation can reduce milk production on the day of relocation, with a greater impact on first-lactation heifers as compared to mature cows. Talebi et al. (2014) demonstrated that the negative effects of relocation can be reduced by decreasing the stocking density of the pen being introduced into. Further, Tesfa (2013) demonstrated that lactating cows, introduced into new groups of cows as pairs, showed no drop in milk production as seen in previous studies. Therefore, for fresh cows, which inevitably will be moved into a new pen at calving, and potentially again later into another lactating cow pen, steps should be taken to minimize the impacts of such relocation. Examples of this include not overcrowding pens, potentially moving cows with familiar companions, or moving cows into new pens during quieter times of the day (away from time of management events, such as feeding or milking).

Summary

Housing and management play a significant role in the performance and health of fresh cows. Much of the impact is mediated through the effects of those factors on the behavior of dairy cows. Dairy cows need the time and availability of resources to perform those behaviors which are important for them for maintaining good production and health. Fresh cow diets should be formulated to maximize eating time and DMI, while minimizing sorting. Management of that feed should be focused on maximizing opportunities for cows to go the bunk across the day, either by increasing the frequency of feed delivery or by altering the timing of feed delivery, while pushing up feed continually between feedings to ensure constant access. Overcrowding must be avoided for fresh cow pens, so that cows can maximize their eating and lying opportunities. Further, keeping first-lactation heifers in separate groups, as well as minimizing group changes, helps decrease social stress. Finally, behavioral monitoring during the post-partum period may also be important for identification of health issues in early lactation, and also for the evaluation of herd-level management strategies and events.

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Notes:

Reproductive Technologies: Do's and Don'ts

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Introduction

Reproductive management programs for lactating dairy cows that maximize 21-day pregnancy rates integrate technologies for submission of cows for first AI, for early nonpregnancy diagnosis, and for resubmission of nonpregnant cows for second and greater AI. Technologies for submission of cows for first insemination include systems for detection of estrus/activity and hormonal protocols for timed AI. Technologies for nonpregnancy diagnosis include transrectal ultrasonography and measurement of pregnancy-associated glycoproteins in blood or milk. Technologies for second and greater insemination include detection of cows that fail to conceive and return to estrus and hormonal protocols for resynchronization of ovulation. Many new reproductive technologies have the potential to increase reproductive performance if incorporated into a reproductive management program correctly; conversely, they have the potential to decrease reproductive performance if incorporated into a reproductive management program incorrectly. The purpose of this paper is to overview new technologies for submission of cows for first AI, for early nonpregnancy diagnosis, and for resubmission of nonpregnant cows for second and greater AI, and provide some do's and don'ts for incorporation of these technologies into a reproductive management program based on research in these areas.

Technologies for First Insemination

DO consider using a fertility program for first AI
DON'T rely on 100% detection of estrus for first AI

Detection of Estrus/Activity. Despite the widespread adoption of hormonal synchronization protocols that allow for timed AI, detection of behavioral estrus continues to play an important role in the overall reproductive management program on most dairy farms in the U.S. (Caraviello et al., 2006; Miller et al., 2007). Use of detection of estrus alone for submitting lactating dairy cows for first AI generally results in poor reproductive performance. The many challenges of estrous detection on farms include: cows with anovular conditions (Wiltbank et al., 2002); attenuation of the duration of estrous behavior associated with increased milk production near the time of estrus resulting in shorter periods of time in which to visually detect estrous behavior (Lopez et al., 2004); few cows expressing standing estrus at any given time (Roelofs et al., 2005; Palmer et al., 2010); silent ovulations (Palmer et al., 2010; Ranasinghe et al., 2010; Valenza et al., 2012); and reduced expression of estrus due to confinement housing systems (Palmer et al., 2010) with concrete flooring (Britt et al., 1986). Whatever the cause, the low accuracy and efficiency of detection of estrus not only increases time from calving to first artificial insemination (**AI**) but increases the average interval between AI services (Stevenson and Call, 1983) thereby limiting the rate at which cows become pregnant.

Because of the impact of AI service rate on reproductive performance and the problems associated with visual detection of estrus on farms, technologies have been developed and marketed to dairy farmers to enhance detection of estrus by providing continuous surveillance of behavior in the absence or in addition to visual observation of estrus. Increased physical activity is a secondary sign of estrus in cattle, and pedometer systems that detect changes in the number of steps per unit time have been available for many years with some adoption by the dairy industry in the U.S. A new generation of electronic systems that continuously monitor physical activity in cattle (Holman et al., 2011; Jónsson et al., 2011) have been developed and marketed to the dairy industry, and there has been rapid adoption of this new technology in the U.S. over the past several years.

Because of the biological challenges associated with detection of estrus, a combined approach in which AI is based both on activity detected by an activity monitoring system followed by submission of cows not detected with activity to timed AI after synchronization of ovulation may be an effective and economical strategy to submit lactating dairy cows for first AI. We conducted a field trial to compare reproductive performance of lactating dairy cows managed for first AI using timed AI with or without detection of estrus using an activity monitoring system (Fricke et al., 2014). Cows were submitted to a Presynch-Ovsynch protocol for first AI, and activity was monitored in all cows using a commercial activity monitoring system (Heatime, SCR Engineers Ltd., Netanya, Israel) beginning at 24 ± 3 DIM. Cows in treatment 1 with increased activity after the second $PGF_{2\alpha}$ treatment were inseminated based on activity, whereas cows without increased activity were submitted to an Ovsynch protocol beginning 12 d after the second $PGF_{2\alpha}$ treatment of the Presynch protocol and received a timed AI at 75 ± 3 days in milk. Cows in treatment 2 with increased activity after the second $PGF_{2\alpha}$ injection were recorded by the activity monitoring system software but were not inseminated so that all cows in treatment 2 completed the Presynch-Ovsynch protocol and received a timed AI at 75 ± 3 days in milk regardless of whether or not they were detected with increased activity after the second $PGF_{2\alpha}$ injection.

The activity monitoring system detected increased activity in 69% and 70% of cows after the second $PGF_{2\alpha}$ treatment in treatments 1 and 2, respectively (Table 1) which is about 10 to 15 percentage points greater than that reported in studies using tail chalk after the second $PGF_{2\alpha}$ injection of a Presynch-Ovsynch protocol (Stevenson and Phatak, 2005; Chebel and Santos, 2010). Overall, cows in treatment 1 in which inseminations occurred as a combination between AI to activity and timed AI had fewer P/AI compared to cows in treatment 2 in which all cows received timed AI after completing the Presynch-Ovsynch protocol (Table 1). The decrease in P/AI due to inseminating cows with increased activity after the second $PGF_{2\alpha}$ injection was expected because the increase in P/AI due to presynchronization with $PGF_{2\alpha}$ likely results from synchronizing estrus after the second $PGF_{2\alpha}$ injection (Navanukraw et al., 2004) so most cows initiate the Ovsynch protocol on days 5 to 9 of the ensuing estrous cycle thereby increasing P/AI to TAI (Vasconcelos et al., 1999). Inseminating 70% of cows based on activity after the second $PGF_{2\alpha}$ treatment removed the presynchronized cows from the protocol thereby negating the increase in P/AI due to presynchronization. Cows without increased activity after the second $PGF_{2\alpha}$ treatment and submitted to an Ovsynch protocol had P/AI of 33% and 35% for treatments 1 and 2, respectively (Table 1). Pregnancy outcomes of anovular cows subjected to an Ovsynch protocol is generally about 20% compared to about 35% for cycling cows starting an Ovsynch protocol at a random stage of the cycle (Gümen et al., 2003; Stevenson et al., 2008). Thus, cows without activity that received an Ovsynch protocol had a P/AI similar to that of cycling cows starting an Ovsynch protocol at a random stage of the cycle. Thus, aggressive submission of cows to an Ovsynch protocol after failing to be detected with increased activity is an effective management strategy to establish pregnancy in this subgroup of cows.

Table 1. *Effect of treatment on percentage of lactating Holstein cows with activity based on an activity monitoring system, and pregnancies per AI (P/AI) for cows with or without activity and inseminated to activity (AI) or inseminated after synchronization of ovulation (TAI). Adapted from Fricke et al., 2014.*

	Treatment	
Item	1	2
Cows with increased activity, % (n/n)	69 (230/335)	70 (232/331)
P/AI 35 d after AI, % (n/n)		
Cows with activity receiving AI	30^{a} (68/230)	-
Cows with activity receiving TAI	-	41^{b} (96/232)
Cows with no activity receiving TAI	36 (37/104)	35 (35/99)
Overall P/AI 35 d after AI, % (n/n)	32^{c} (105/333)	40^{d} (131/331)
P/AI 67 d after AI, % (n/n)		
Cows with activity receiving AI	27 (62/230)	-
Cows with activity receiving TAI	-	40 (92/232)
Cows with no activity receiving TAI	33 (34/104)	35 (35/99)
Overall P/AI 67 d after AI, % (n/n)	29^{c} (96/333)	38^{d} (127/331)

[a,b]Within a treatment by activity subgroup, statistical contrast differed (P = 0.004).

[c,d]Within a row, percentages with different superscripts differed (P = 0.0454).

[1]Treatments were: 1) cows inseminated based on an activity monitoring system after the second $PGF_{2\alpha}$ injection of a Presynch-Ovsynch protocol with cows not detected with activity receiving timed AI after completing the Presynch-Ovsynch protocol; 2) cows receiving timed AI after a Presynch-Ovsynch protocol.

Overall, 31% of cows in treatment 1, and 100% of cows in treatment 2 were submitted to the Ovsynch portion of the synchronization protocol, and blood samples were collected from a subgroup (~85%) of cows in each treatment at the first GnRH injection of the Ovsynch protocol to determine progesterone concentration at the onset of the protocol (Fricke et al., 2014). Surprisingly, over 50% of these cows had progesterone concentrations ≥ 1 ng/mL at the first GnRH injection of the protocol, and similar results were observed for cows in treatment 2 that were not detected with activity after presynchronization. Thus, many cows without activity after presynchronization likely ovulated in the absence of detectable activity resulting in high progesterone at G1 of the Ovsynch protocol. These results agree with the 10% of cows that ovulated but failed to be detected with activity by the activity monitoring system (Valenza et al., 2012). Results from Fricke et al. (2014) support a management strategy in which the 30% of cows not detected with activity are aggressively submitted to an Ovsynch protocol rather than continuing to detect activity using an activity monitoring system.

Based on two experiments assessing an activity monitoring system on a large commercial dairy farm in the U.S. (Valenza et al., 2012; Fricke et al., 2014), only about 70% of cows were inseminated based on the activity monitoring system. These data underscore the importance of implementing a comprehensive reproductive management program for identification and treatment of cows that would otherwise not be inseminated. Although use of an activity monitoring system to inseminate cows based on activity reduced days to first AI, cows receiving 100% timed AI after completing a Presynch-Ovsynch protocol had more P/AI (Fricke et al., 2014). The trade-off between AI service rate and P/AI was reflected by an economic analysis in which varying levels of estrous detection and three levels of P/AI were compared (Giordano et al., 2012b). When P/AI to detected estrus in a herd is poor, allowing cows to complete the Presynch-Ovsynch protocol and receive a timed AI would be a preferred strategy; conversely, whenever P/AI to AI after a detected estrus is 30% or 35% there was always an economic advantage to inseminating cows detected in estrus across all levels of estrous detection. We conclude that although a variety of strategies can be used to submit cows for first and subsequent AI, synchronization of ovulation and timed AI is a beneficial strategy to inseminate cows not detected by the activity monitoring system.

Fertility Programs. Even though the Presynch-Ovsynch protocol was originally developed to increase the fertility of cows submitted to TAI, many farms inseminate cows detected in estrus after the second $PGF_{2\alpha}$ treatment of a Presynch-Ovsynch protocol followed by submission of cows not detected in estrus to an Ovsynch-56 protocol. A recent meta-analysis, however, supports the idea that incorporation of AI to estrus into a Presynch-Ovsynch protocol decreases P/AI for cows not detected in estrus and submitted to timed AI than when all cows were allowed to complete the protocol and receive timed AI (Borchardt et al., 2016). This decrease in P/AI to timed AI occurs because cycling cows that would have been presynchronized so that G1 occurred at an optimal time of the estrous cycle are removed from the protocol after AI to estrus thereby negating the presynchronization effect. Further, anovular cows submitted to a Presynch-Ovsynch protocol have decreased P/AI than their cycling herd mates. Because anovular cows lack a CL and therefore do not respond to the two initial $PGF_{2\alpha}$ treatments of a Presynch-Ovsynch protocol, G1 occurs in a low progesterone environment resulting in fewer P/AI to timed AI. Because anovular cows represent nearly 1 in 4 cows submitted for first timed AI, presynchronization strategies using $PGF_{2\alpha}$ alone with or without inclusion of detection of estrus do not yield high P/AI to Timed AI.

Two limitations of presynchronization strategies that use $PGF_{2\alpha}$ alone (e.g., Presynch-Ovsynch) are that 1) $PGF_{2\alpha}$ does not affect anovular cows or resolve the anovular condition before G1 of the Ovsynch protocol, and 2) follicular growth is not tightly synchronized after two sequential $PGF_{2\alpha}$ treatments administered 14 d apart. By contrast, presynchronization strategies that combine GnRH and $PGF_{2\alpha}$ overcome both of these limitations thereby increasing fertility to TAI. For example, when an Ovsynch protocol was used to presynchronize cows before G1 of an Ovsynch protocol (i.e., a **Double-Ovsynch** protocol), cows submitted to the Double-Ovsynch protocol had more P/AI than cows submitted to a Presynch-Ovsynch protocol (Souza et al., 2008; Herlihy et al., 2012). Presynchronization strategies tested to date have used a combination of GnRH and $PGF_{2\alpha}$ 6 to 7 d before G1 (i.e., **G6G**; Bello et al., 2006).

Several experiments have assessed the effect of an additional $PGF_{2\alpha}$ treatment within a Double-Ovsynch protocol to decrease progesterone at G2 (Brusveen et al., 2009; Wiltbank et al., 2015). Adding a second $PGF_{2\alpha}$ treatment 24 h after the first $PGF_{2\alpha}$ treatment during the second Ovsynch portion of a Double-Ovsynch protocol for first TAI dramatically increased the proportion of cows undergoing complete luteal regression thereby increasing the proportion of pregnant primiparous cows by 4.6% and the proportion of pregnant multiparous cows by 23% (Table 2; Wiltbank et al., 2015). Thus, the treatment by parity effect on P/AI to timed AI after a Double-Ovsynch protocol discussed previously can at least partially be explained by a lack of luteal regression in multiparous cows that can be overcome by adding a second $PGF_{2\alpha}$ before G2 of the protocol.

Table 2. *Effect of 1 vs. 2 prostaglandin $F_{2\alpha}$ (PGF) treatments on pregnancies per AI (P/AI) in lactating dairy cows (adapted from Wiltbank et al., 2015).*

	P/AI, % (n/n)			
Item	1 PGF	2 PGF	Difference (%)	P-value
Primiparous	46 (41/89)	48 (40/83)	5	0.45
Multiparous	37 (37/101)	45 (45/100)	23	0.14
P-value	0.24	0.77		
Overall	41 (78/90)	46 (85/183)	13	0.17

Taken together, these data support that ~50% of cows become pregnant to first TAI after a modified Double-Ovsynch protocol. The advantages of using 100% TAI after a modified Double-Ovsynch protocol for first timed AI include precise control of the interval from calving to first AI such that all cows in the herd receive timed AI within 7 d of the end of the VWP (in herds in which timed AI is conducted weekly) and yielding exceptionally high fertility to first timed AI. When optimized, these two factors dramatically increase the 21-d pregnancy rate. Presynchronization strategies that combine GnRH and $PGF_{2\alpha}$ to resolve anovular conditions and optimize timing of initiation of G1 and addition of a second $PGF_{2\alpha}$ treatment 24 h after the first $PGF_{2\alpha}$ treatment within an Ovsynch protocol currently represents the most aggressive method for submitting cows for first AI while also yielding high P/AI to timed AI.

Technologies for Nonpregnancy Diagnosis

DO identify nonpregnant cows early after AI
DON'T identify nonpregnant cows TOO early after AI

Transrectal Ultrasonography. As a pregnancy diagnosis method, transrectal ultrasonography is accurate and rapid, and the outcome of the test is known immediately at the time the test is conducted. Transrectal ultrasonography has begun to displace transrectal palpation as the direct method of choice by veterinarians for pregnancy diagnosis (Caraviello et al., 2006). Because many experienced bovine practitioners can accurately diagnose pregnancy as early as 35 days after AI using transrectal palpation, pregnancy examination using transrectal ultrasonography 28 to 34 days after AI only reduces the interval from insemination to pregnancy diagnosis by a few days. Although ultrasound conducted at ≥ 45 days post breeding did not increase accuracy of pregnancy diagnosis for an experienced palpator, it may improve diagnostic accuracy of a less experienced one (Galland et al., 1994). The rate of pregnancy loss and the efficacy of strategies to reinseminate cows at various stages post breeding also play a role in determining the advantages and disadvantages on the timing of pregnancy diagnosis and resynchronization (Fricke et al., 2003).

To determine the accuracy of early pregnancy diagnosis using transrectal ultrasonography, we conducted a field trial on a commercial dairy farm milking ~2,000 cows (Giordano and Fricke, 2012a). Pregnancy status was determined 29 days after timed AI using transrectal ultrasonography (Easi-scan, BCF Technology Ltd.) based on the following criteria: presence or absence of a CL, presence, absence, volume and appearance of uterine fluid typical for a 29-day conceptus, presence or absence of an embryo with a heartbeat. Cows were classified as 1) not-pregnant: presence or absence of a CL, absence of uterine fluid, or insufficient uterine fluid, and absence of an embryo; 2) pregnant: CL present, normal uterine fluid, and no embryo; 3) pregnant embryo: CL present, normal uterine fluid, and at least one embryo visualized; and 4) questionable pregnant: CL present, and one or more of the following: uterine fluid, insufficient uterine fluid, and either no embryo or a non-viable embryo. At 39 and 74 days after timed AI, pregnancy status was determined using transrectal palpation, and pregnancy loss occurring between each pregnancy examination was calculated.

Results from this experiment are shown in Table 3. Overall, 802 cows were classified not-pregnant 29 days after timed AI, whereas 799 cows were classified not-pregnant 39 days after timed AI resulting in a not-pregnant misdiagnosis rate of 0.5% (4/802) for transrectal ultrasonography 29 days after timed AI. At 29 days after timed AI, 1,116 cows were classified as either pregnant with an embryo visualized (68%), pregnant based on uterine fluid alone (29%), or questionable pregnant (3%). Among questionable pregnant cows, 69% were classified as not pregnant 39 days after timed AI, and an additional 46% were classified as not pregnant 74 days after timed AI. For cows classified pregnant 29 days after timed AI, more ($P < 0.01$) cows diagnosed based on uterine fluid only than fluid and the presence of an embryo were classified as not pregnant using transrectal palpation 39 days after timed AI. Similarly, more cows diagnosed pregnant based on uterine fluid alone than cows diagnosed pregnant based on visualization of an embryo with a heartbeat were classified as not pregnant using transrectal palpation 74 days after timed AI. From the initial pregnancy examination at 29 days to the last examination 74 days after timed AI, more cows diagnosed pregnant based on uterine fluid alone than cows diagnosed pregnant based on visualization of an embryo with a heartbeat were classified as not pregnant using transrectal palpation 74 days after timed AI. Cows classified pregnant based on uterine fluid alone 29 days after timed AI were 3.8 (95% CI = 2.7 to 5.4) times more likely to be classified not-pregnant 74 days after timed AI than cows diagnosed pregnant based on visualization of an embryo with a heartbeat.

Table 3. *Pregnancy loss by pregnancy classification for lactating Holstein cows diagnosed pregnant using ultrasonography 29 d after timed AI (adapted from Fricke et al., 2016).*

	Pregnancy classification[1]		
Item	Pregnant	Uterine fluid	Questionable
	---------- %, (n/n) ----------		
29 d after timed AI	68 (758/1,116)	29 (322/1,116)	3 (36/1,116)
Pregnancy loss			
29 to 39 d	4^a (30/758)	18^b (57/322)	69^c (25/36)
39 to 74 d	5^a (39/728)	12^b (32/265)	46^c (5/11)
Total loss	9^a (69/758)	28^b (89/322)	83^c (30/36)

[a,b,c]Within a row, proportions with different superscripts differ ($P<0.001$).

[1]Lactating Holstein cows diagnosed pregnant were classified based on the following criteria using transrectal ultrasonography: Pregnant: visualization of a CL ipsilateral to the gravid uterine horn, visualization of an amount of non-echogenic uterine fluid in accordance to stage of pregnancy, and visualization of an embryo with a heartbeat; Uterine fluid: visualization of a CL ipsilateral to the gravid uterine horn, visualization of an amount of non-echogenic uterine fluid in accordance to stage of pregnancy but without visualization of the embryo; Questionable: visualization of a CL ipsilateral to the gravid uterine horn with insufficient uterine fluid for the stage of pregnancy.

Based on these data, we concluded that the accuracy of pregnancy outcomes using transrectal ultrasonography increase dramatically when an embryo with a heartbeat is visualized compared to outcomes based only on the presence of a CL and the volume of uterine fluid in the absence of a visualized embryo with a heartbeat. The presence of a large proportion of cows with a CL and fluid was visualized in the absence of an embryo with a heartbeat is likely due to a high degree of early pregnancy loss in dairy cows. In one experiment, 44% of dairy cows diagnosed not pregnant 32 days after timed AI had extended luteal phases (Ricci et al., 2014). Based on our results, early pregnancy diagnosis should not be conducted earlier than an embryo with a heartbeat can be rapidly and reliably detected in pregnant cows under on-farm conditions using transrectal ultrasonography (~30 days after AI) to reduce the negative impact of false positive results.

Pregnancy-Associated Glycoproteins. Pregnancy-associated glycoproteins belong to a large family of inactive aspartic proteinases expressed by the placenta of domestic ruminants including cows, ewes, and goats (Haugejorden et al., 2006). In cattle, the PAG gene family comprises at least 22 transcribed genes as well as some variants (Prakash et al., 2009). Mean PAG concentrations in cattle increase from 15 to 35 d in gestation; however, variation in plasma PAG levels among cows precludes PAG testing as a reliable indicator of pregnancy until about 26 to 30 d after AI (Zoli et al., 1992; Humblot, 2001). Assessment of pregnancy status through detection of placental PAG or PSPB levels in maternal blood (Sasser et al.,1986; Zoli et al 1992; Green et al 2005) is now used to evaluate pregnancy status within the context of a reproductive management scheme on commercial dairies (Silva et al., 2007, 2009; Sinedino et al., 2014). A commercial test for detecting PAG levels in milk (The IDEXX Milk Pregnancy Test, IDEXX Laboratories, Westbrook, ME) has been developed and marketed to the dairy industry.

Few studies have compared factors associated with PAG levels in blood and milk of dairy cows early in gestation and the impact these factors may have on the accuracy of pregnancy diagnosis. We conducted an experiment to determine factors affecting PAG levels in blood and milk of dairy cows during early gestation (Ricci et al., 2015). Lactating Holstein cows were synchronized to receive their first AI at a fixed time. Blood and milk samples were collected 25 and 32 d after TAI, and pregnancy status was determined 32 d after TAI using transrectal ultrasonography. Cows diagnosed pregnant with singletons continued the experiment in which blood and milk samples were collected and pregnancy status was assessed weekly using transrectal ultrasonography from 39 to 102 d after TAI. Plasma and milk samples were assayed for PAG concentrations using commercial ELISA kits.

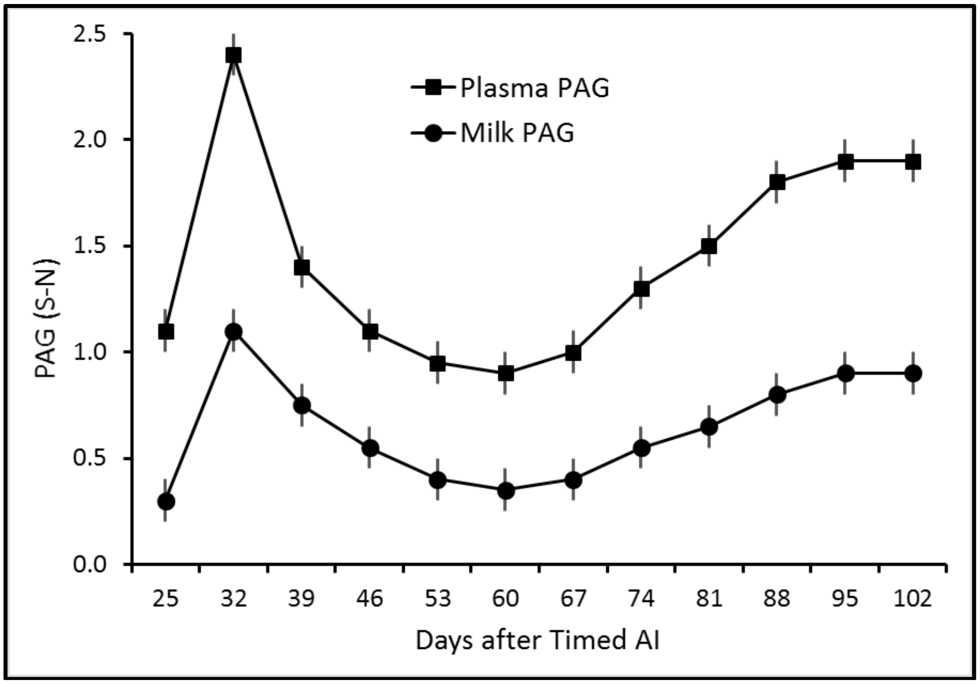

***Figure 1**. Plasma and milk pregnancy-associated glycoprotein (PAG) profiles for Holstein cows (n = 48) that maintained pregnancy from 25 to 102 d after AI. ELISA outcomes were calculated from the optical density (OD) of the sample (corrected by subtraction of the reference wavelength OD of the sample (S) minus the OD of the negative control (N) at 450 nm with both values corrected by subtraction of the reference wavelength OD of the negative control), which resulted in an S-N value. Plasma and milk PAG levels were affected by week after AI (P < 0.01). Adapted from Ricci et al., 2015.*

The incidence of pregnancy loss from 32 to 102 d after AI among cows bearing a singleton was 13% (7/55), which is similar to the 13% pregnancy loss between 29 ± 2 and 44 ± 6 d after AI reported in a summary of 14 studies (Santos et al., 2004). For the plasma PAG ELISA, all but one cow that underwent pregnancy loss tested positive, whereas all cows undergoing pregnancy loss tested positive at one or more time points for the milk PAG test. Similarly, 5 of 7 cows that had inconclusive results based on the plasma PAG test before the loss occurred compared with 3 of 7 cows based on the milk PAG test. Thus, PAG levels detected by these ELISA tests in the present study have a half-life in maternal circulation resulting in a 7 to 14 d delay in identification of cows undergoing pregnancy loss based on plasma or milk PAG levels compared with transrectal ultrasonography.

Profiles of PAG in plasma and milk of cows that maintained pregnancy from 25 to 102 days in gestation are shown in Figure 1. Factors associated with PAG levels in dairy cows included stage of gestation, parity, pregnancy loss, and milk production. Based on plasma and milk PAG profiles, the optimal time to conduct a first pregnancy diagnosis is around 32 days after AI coinciding with an early peak in PAG levels. We concluded that because of the occurrence of pregnancy loss, all pregnant cows should be retested 74 days after AI or later when plasma and milk PAG levels in pregnant cows have rebounded from their nadir.

Technologies for Second and Greater Insemination

DO couple a nonpregnancy diagnosis with a strategy to rapidly re-inseminate cows
DON'T submit nonpregnant cows without a CL to a Resynch protocol

Return to Estrus after AI. Accurate identification of cows returning to estrus from 18 to 24 days after AI is the easiest and least costly method for determining nonpregnancy early after insemination. This assumption, however, is being challenged by new research and long-recognized reproductive problems. First, estrous detection efficiency is estimated to be less than 50% on most dairy farms in the United States (Senger, 1994). Only, 51.5% of the eligible cows were detected in estrus and inseminated in a recent study in which detection of estrus was performed through continuous monitoring with activity tags after a previous insemination until pregnancy diagnosis 32 ± 3 d after AI, (Giordano et al., 2015). Second, estrous cycle duration varies widely with a high degree of variability among individual cows (Remnant et al., 2015). Finally, the high rate of pregnancy loss in dairy cows can increase the interval from insemination to return to estrus for cows that establish pregnancy early then undergo pregnancy loss later during gestation (Ricci et al., 2014).

Resynch. Whereas presynchronization strategies have yielded significant increases in fertility to first TAI, many herds struggle with poor fertility to an Ovsynch protocol used for TAI at second and greater services (i.e., **Resynch**). Based on progesterone profiles during the Ovsynch protocol, the best indicator of poor fertility to timed AI is low progesterone (i.e., cows lacking a CL) at the $PGF_{2\alpha}$ treatment. One of the first strategies to optimize fertility to Resynch TAI attempted to determine the optimal interval after an initial TAI to initiate G1 based on the physiology of the estrous cycle (Fricke et al., 2003). Assuming an estrous cycle duration of 21 to 23 d, initiating a Resynch protocol 32 d after AI corresponds to starting the Resynch protocol around day 6 to 14 of the estrous cycle, a stage of the estrous cycle when a dominant follicle capable of ovulating and a CL with mid-level progesterone should be present. Cows identified not pregnant 32 days after AI with a CL at G1 have greater fertility to TAI than cows without a CL (Giordano et al., 2012c; Lopes et al., 2013). In several studies however, 16%, 22%, and 35% of cows diagnosed not pregnant 32 days after TAI and that did not receive a GnRH treatment 7 days before pregnancy diagnosis lacked a CL at G1 (Fricke et al., 2003; Giordano et al., 2015). When cows were synchronized for first timed AI and progesterone profiles and CL diameter was measured until a pregnancy diagnosis 32 days later, 19% of cows diagnosed not pregnant lacked a CL > 10 mm in diameter (Ricci et al., 2014). Thus, G1 occurs in a low-progesterone environment in up to one-third of nonpregnant cows submitted to a Resynch protocol which leads to a lack of complete luteal regression after treatment with $PGF_{2\alpha}$ 7 d later and low fertility to TAI.

Table 4. *Effect of 1 vs. 2 $PGF_{2\alpha}$ treatments during an Ovsynch protocol on luteal regression and pregnancies per AI (P/AI) for Holstein dairy cows with low vs. high progesterone (P4) concentrations at the first GnRH treatment of an Ovsynch protocol (G1)[1]. Adapted from Carvalho et al., 2015.*

	Treatment	
Item	1 $PGF_{2\alpha}$	2 $PGF_{2\alpha}$
	-------------------- % (n) --------------------	
Cows undergoing complete luteal regression		
Low P4 (<1.0 ng/mL) at G1	70[a] (76)	96[b] (74)
High P4 (>1.0 ng/mL) at G1	89[a] (236)	98[b] (214)
Overall	83[a] (312)	98[b] (288)
P/AI 32 days after TAI		
Low P4 (<1.0 ng/mL) at G1	33[c] (107)	46[d] (110)
High P4 (>1.0 ng/mL) at G1	33 (312)	37 (289)
Overall	33[c] (419)	39[d] (399)

[1]Adapted from Carvalho et al., 2015.
[a,b]Proportions differ (P < 0.01).
[c,d]Proportions differ (P < 0.05).

We conducted an experiment to determine the effect of adding a second $PGF_{2\alpha}$ treatment 24 hours after the first within an Ovsynch protocol would increase P/AI to TAI after a Resynch protocol (Carvalho et al., 2015). A greater proportion of cows receiving 1 $PGF_{2\alpha}$ treatment had incomplete luteal regression (≥ 0.4 ng/mL) than cows receiving 2 $PGF_{2\alpha}$ treatments regardless of P4 concentrations at G1 (Table 4). For cows with P4 concentrations < 1.0 ng/mL at G1, cows receiving 2 $PGF_{2\alpha}$ treatments had more P/AI than cows receiving 1 $PGF_{2\alpha}$ treatment, whereas for cows with P4 concentrations ≥ 1.0 ng/mL at G1, P/AI did not differ ($P = 0.46$) between cows receiving 1 vs. 2 $PGF_{2\alpha}$ treatments (Table 4).

A benefit of transrectal ultrasonography over transrectal palpation for nonpregnancy diagnosis is the opportunity to more accurately determine the ovarian status of cows at a nonpregnancy diagnosis facilitating the assignment of cows to different treatment alternatives. For example, use of an Ovsynch protocol for resynchronization of cows identified not pregnant 32 days after AI resulted in greater conception rates when cows were identified with a CL compared to cows without a CL at the first GnRH treatment of the protocol (Giordano et al., 2012c; Lopes et al., 2013). Treatment of cows without a CL at the first GnRH treatment of an Ovsynch protocol with exogenous progesterone (i.e., a CIDR insert) increased fertility at first as well as resynch timed AI in lactating dairy cows (Chebel et al., 2010; Bilby et al., 2013). Treatment of cows with a CL ≥20 mm at nonpregnancy diagnosis with a PGF injection increased the overall proportion of cows inseminated after a detected estrus for second and subsequent AI services (Giordano et al., 2015). Based on these data, many veterinarians now use the presence or absence of a CL at a nonpregnancy diagnosis to improve outcomes to timed AI protocols used to resynchronize nonpregnant cows or to increase the proportion of cows inseminated in estrus after a previous insemination.

Conclusions

Reproductive management programs that successfully integrate new technologies for submission of cows for first AI, for early nonpregnancy diagnosis, and for resubmission of nonpregnant cows for second and greater AI can now yield reproductive performance that is unprecedented in herds of high-producing Holstein dairy cows. Although correct integration of these technologies is important for achieving a high 21-day pregnancy rate, cows must be healthy to achieve high fertility. Many cow health factors have been reported to decrease P/AI to TAI including the incidence of mastitis between TAI and the first pregnancy diagnosis (Fuenzalida et al., 2015), a decrease in body condition score during the first 21 days after calving (Carvalho et al., 2014), and poor uterine health (Lima et al., 2013).

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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's four years later. What have we learned? According to the most recent NAHMS Survey 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.

Management areas

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 (500g) 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^{o}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 three 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 dairies is not feasible given the labor situation.

Labor management is and will continue to be a growing challenge on dairies. 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 is a growing concern in animal agriculture. We, in the dairy industry, 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 has 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, <u>group housing</u> 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 – 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 which optimize the likelihood that calves receive adequate colostrum intake. This is achieved by the timely intake of at least 150 g of 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, and fresh cows milked into clean receptacles and colostrum 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 – 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 use of software to aid in developing facilities for young calves and heifers.

Behavior of group-housed calves. Workers in Denmark and Canada have conducted numerous behavioral studies which 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 which 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 – 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.

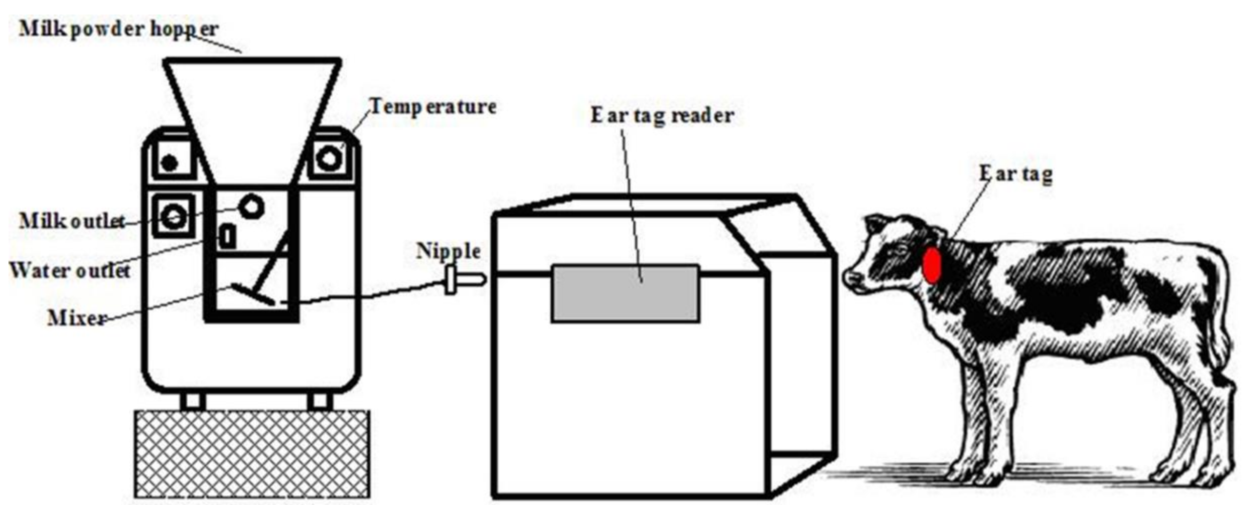
- Mob feeding
- Free choice acidified milk or milk replacer
- Computer controlled automatic feeders.

Mob feeding of calves is a common practice in grazing dairies practicing seasonal calving. However, conventional dairies 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 which 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 dairies. 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 – 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 shown in the illustration below (Biotic Industries, Bell Buckle, TN).



These systems vary widely in sophistication and price ranging from systems which 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 which contain a device enabling electronic identification of calves. Most new systems utilize the 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.

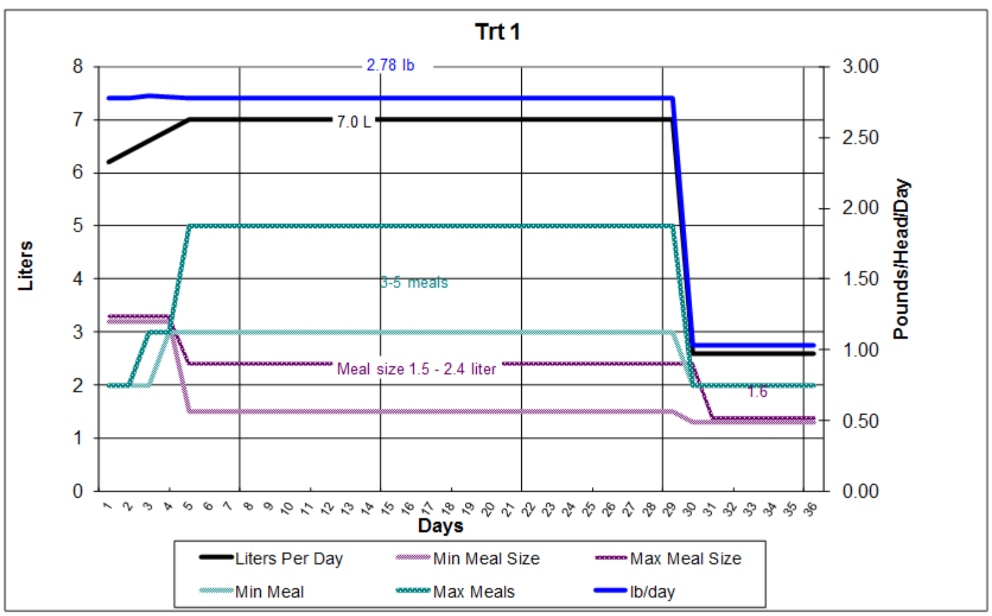
The work conducted by Jensen (2004, 2005) and von Keyserlingk et al (2004) has resulted in the recommendations for stocking rates given by major manufacturers of calf autofeeder systems. General relationships are what would be expected in group housing situations. More calves per feeder results in greater 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 or. 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 – 7 days during 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 – 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 – 1225g) of milk solids per calf per day. On a volume basis this amounts to 1.4 to 2.6 gallons (5.3 – 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 (.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 .33-liter allocation for each hour of the day. They must accrue enough "credits" to achieve their minimum meal size specified by the system which might be 1.5 liters. This would mean that

there must be a minimum of about 5 hours between feedings. The feeder mixes milk replacer or delivers milk in .5L 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 L as calves' age.

- When milk replacer is used, powder is diluted with water to approximately 13 – 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, 150g 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, 150g of powder/1150g 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 more sophisticated systems consume ~4 – 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 below. (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 may be accommodated.



More sophisticated systems 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 of time in the group pen (usually 28 days). Then the liquid diet daily allocation is reduced to 8L/day to stimulate starter grain consumption. Allocation is held constant until gradual weaning over 7 – 10 days in accomplished beginning at approximately 42 days

- More sophisticated systems enable dispensing additives in either the liquid or 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 dairies has shown that these systems don't 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, 2011; Dietrich, 2015, Jorgensen et al, 2015, Knauer et al, 2016 in press). As expected there are a wide variety of installations and management practices. Maintenance of equipment to follow manufacturers' 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 which appears to be related to earlier detection of disease which was predominantly diarrhea and was treated with electrolytes. Mortality was less than 1.5% in these field studies which 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 which might be used to "flag" calves which would require further closes evaluation.

Risk factors for disease in autofeeder systems (Endres and James, 2017 in press).

- 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 – 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 system 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^{o}F). Utilization of milk replacers requiring higher mixing temperatures will not work well in autofeeder systems!
- More sophisticated machines 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:
  - They are data oriented and should evaluate the intake and other management information provided each morning and periodically throughout the day.
  - Calf managers should "walk" the pens periodically to evaluate calf behavior and detect illnesses prior to viewing computer reports of calf feeding behavior.
  - 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 tends 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 which 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's 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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Notes:

Dairy Farm Sustainability Award Winners

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When one considers the term “sustainability” the first thing that may come to mind pertains to sustaining our environment, which is undoubtedly extremely important. Nearly all farms strive to be good stewards of their environment. However, other factors need to be considered as well if the farm is to grow and prosper in the future. The environmental practices need to be economically sustainable as well. Sustainability also means that the farm must be well managed financially to continue its operation for years to come under very varying economic conditions that have become more common in our global dairy industry. Farms also need to be good neighbors and members of their community which has become increasingly important as our population grows and farms are increasingly faced with urban and suburban encroachment. Finally, in order to be sustainable the farm should have some farm succession plan. How will this operation continue to operate as business partners or family members age? Do conditions exist for the younger generation want to “sustain” the farm. I am pleased to present three recipients of the U.S. Dairy Sustainability Awards presented by the Innovation Center for U.S. Dairy. These awards are sponsored by Delaval, U.S. E.P.A., Elanco, World Wildlife Fund, Academy of Nutrition and Dietetics, Syngenta, CTIC, DSM, Milk PeP and the National Council of Farmer Cooperatives. These panel members will share what makes them passionate about the future for their farm and the dairy industry.

Werkhoven Dairy – Monroe, Washington.
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Daryl Williams – Tulalip Tribe
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Werkhoven Dairy was faced with rising land values and encroachment of suburbia from Seattle just to the south of their farm. Today, the Werkhoven family is thrilled to be part of an alliance with the local Tulalip Tribe to form Qualco, a nonprofit organization with the goal to generate revenue through tipping fees and power generation to pay for multiple projects. These projects include recycling waste material, fish and wildlife habitat restoration, generation of renewable energy and the adoption of state of the art farming practices. Andy and Daryl will share their experiences in establishing this joint effort which has seen benefits to the environment, wildlife, Werkhoven Dairy, the Tulalip Tribe and the community. Through his involvement with the Werkhoven’s, Daryl has become more informed about agriculture which has led to his involvement with environmental policy and issues on a local and statewide level. The Werkhoven’s love the slogan: “Cows are better than condo's". Through Qualco Energy, cows and people do their jobs to help preserve the land for agricultural use and the environment.

Bateman's Mosida Farms – Elberta, UT
Jason Bateman
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The Bateman's have a history of dairy farming in Utah that spans 150 years. They have grown their dairy to be the largest in Utah with over 7,000 milking cows. Along with their father, four brothers currently own and operate the farm. They have a philosophy of continuing improvement which has led to numerous improvements to their operations sustainability. Recognizing the importance of close up and fresh cow comfort and management they constructed a state of the art, environmentally controlled maternity barns that has improved health of fresh cows, heifers and calves. A dual manure management and sand reclamation system allows them to more effectively utilize manure nutrients for cropping, improve cow comfort and recycle sand thereby reducing costs and fuel use. Looking towards the future and to make the farm more attractive for future generations a solar energy project is underway. The Bateman's use farm tours to demonstrate that large dairy farms can be excellent stewards of the environment and provide excellent animal care.

Homestead Dairy – Plymouth, IN
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Our mission is to supply the highest quality agricultural products in a sustainable way, while creating a positive impact for cows, business and community. This mission statement from Homestead Dairy is a great indicator of why this family farm was selected for a 2016 sustainability award. Over the years the farm has expanded to its current size of 2,400 milking cows, bringing in four next generation families in what comprises a spirit of continuous improvement using a wide range of technologies including:

- Converting to 100% renewable bedding materials.
- Creating 800 kilowatts of energy daily from cow manure.
- Increasing efficiencies of young calf growth and management by converting to automatic calf feeders.
- Communicating the farm's dedication to sustainability by hosting farm tours and being active members of the local community.

Optimizing Nutrition and Management of Calves and Heifers for Lifetime Productivity

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Take Home Messages

1. The pre-weaning period is a period of life where the calf is undergoing significant developmental changes and this development is directly linked to future productivity in the first and subsequent lactations.
2. Pre-weaning growth rate and primarily protein accretion appears to be a key factor in signaling/communicating with the tissues that enhances lifetime milk yield.
3. Anything that detracts from feed intake and subsequent pre-weaning growth rate reduces the opportunity for enhanced milk yield as an adult.
4. Nutrient supply, both energy and protein, are important and protein quality and digestibility are essential.
5. There are no substitutes for liquid feed prior to weaning that will enhance the effect on long-term productivity.
6. Factors other than immunoglobulins in colostrum modify feed intake, feed efficiency and growth of calves and can enhance the effect of early life nutrient status.
7. As an industry and as nutritionists we need to talk about metabolizable energy and protein intake and status relative to maintenance and stop talking about cups, quarts, gallons, buckets and bottles of dry matter, milk, milk replacer, etc. The calf has discrete nutrient requirements not related to dry matter and liquid volume measurements.
8. The effect of nurture is many times greater than nature and the pre-weaning period is a phase of development where the productivity of the calf can be modified to enhance the animal's genetic potential.
9. Adhering to specific growth targets throughout the rearing period and calving as early as feasible is essential to ensure optimum economic returns in the first lactation within the management system.

Lactocrine Hypothesis: Colostrum's role

It has been well recognized that the phenotypic expression of an individual is affected by both genetic ability as well as environment. The environment contains multiple external signals that affect the development and expression of the genetic composition of an animal. While in the uterus, the mother controls the environment in which the fetus is developing, influencing in this way the expression of the genetic material and there is good evidence that the environment can play a role in long-term productivity in beef cattle (Summers and Funston, 2012). Similarly, data from an evaluation of the DHIA database published by Hinde et al. (2013) demonstrated that fetal sex had a significant impact on the volume of milk produced by the dam. In this study, a heifer or cow carrying a female fetus instead of a male fetus responded by producing about 500 pounds more milk in the first lactation and did the same in the second lactation if again carrying a heifer in the second pregnancy. The dam receives signals once the sex is determined in utero and is programmed to produce more nutrients for the female during lactation. It is interesting that the dam will provide more nutrients to the heifer calf given the typically smaller body weight and lower maintenance requirements and suggests the heifer should be made more anabolic through maternal nutrition, which follows on the long-term productivity data that has been generated over time.

The effect and extent of maternal influence in the offspring's development does not end at parturition, but continues throughout the first weeks of life through the effect of milk-born factors, including colostrum, which have an impact in the physiological development of tissues and functions in the offspring. A concept termed the "lactocrine hypothesis" has been introduced and describes the effect of milk-borne factors on the epigenetic development of specific tissues or physiological functions in mammals (Bartol et al., 2008). Data relating to this topic has been described in neonatal pigs (Donovan and Odle, 1994; Burrin et al., 1997) and calves (Baumrucker and Blum, 1993; Blum and Hammon, 2000; Hammon et al., 2012). The implication of this hypothesis and the related observations are that the neonate can be programmed maternally and postnatally to alter development of a particular process and potentially modify genetic ability of the animal.

Colostrum is known to be rich in a variety of nutrients, but also non-nutritive factors, such as hormones, growth factors and other bioactive factors capable of exerting some positive developmental effect on the neonate (Table 1) and this has been extensively researched and reviewed (Odle et al., 1996; Blum and Hammon, 2000; Steinhoff-Wagner et al. 2011; Hammon et al. 2012). For example, colostrum feeding has been shown to positively affect the development of the gastrointestinal tract (GIT) and enhance energy metabolism of the calf. Adequate intake of these non-nutritive factors appears to be important for establishing gastrointestinal development for enhanced nutrient intake and nutrient utilization (Blum and Hammon, 2000; Hammon et al. 2012). The data from Steinhoff-Wagner et al. (2011) clearly demonstrated that colostrum feeding as compared to iso-nutrient levels of a milk-based formula enhanced the glucose uptake of calves fed solely colostrum for up to four days of life. In that experiment, first milking colostrum was fed as the first meal and second, third and fourth milking colostrum was fed over the next three days, respectively, to examine differences in dietary glucose uptake, insulin responsiveness and endogenous glucose production. Calves fed colostrum had higher levels of plasma glucose, similar endogenous glucose production and higher plasma insulin concentrations post feeding, suggesting that colostrum enhanced the absorption of glucose and the insulin in the colostrum was absorbed by the GIT and contributed to the endogenous insulin production. It is also important to note that glycogen reserves were greater in the calves fed colostrum and that serum urea nitrogen was lower and amino acid concentration was greater, implying a more anabolic state with colostrum intake as compared to similar nutrient intake from formula. Thus, it appears that in addition to the Ig's, the other non-nutritive factors in colostrum are important to establish enhanced energy utilization and GIT development in newborn calves and these potential effects should be considered when evaluating and diagnosing differences in calf performance under similar management and nutritional conditions.

Table 1. Nutrients, energy, immunoglobulins, hormones and growth factors in colostrum and milk.

Components	Units	Colostrum	Mature Milk
Gross Energy	MJ/L	6	2.8
Crude protein	%	14.0	3.0
Fat	%	6.7	3.8
Immunoglobulin G	g/L	81	<2
Lactoferrin	g/L	1.84	Undetectable
Insulin	µg/L	65	1
Glucagon	µg/L	0.16	0.001
Prolactin	µg/dL	280	15
Growth hormone	µg/dL	1.4	<1
IGF-1	µg/dL	310	<1
Leptin	µg/dL	30	4.4
TGF-α	µg/dL	210	<1
Cortisol	ng/ml	11.2	1.2
17βEstradiol	µg/dL	3.3-4.7	0.54

Several studies have indicated that the amount or presence of colostrum in the first meal has an impact on growth performance of pre-weaned calves. Jones et al. (2004) examined the differences between maternal colostrum and a serum-derived colostrum replacement. In that study, two sets of calves were fed either maternal colostrum or serum-derived colostrum replacement with nutritional components balanced. The colostrum replacer was developed to provide adequate immunoglobulins to the neonatal calf, however the other non-nutritive factors found in colostrum were not considered. The results demonstrated that in the first 7 days of life, the calves fed maternal colostrum had significantly higher feed efficiency that was still apparent at 29 days, compared to calves fed serum-derived colostrum replacement, however the IgG status of the calves on both treatments were nearly identical suggesting that factors in colostrum other than IgG's were important in contributing to the differences. Further, data from Faber et al. (2005) demonstrated that the amount of colostrum, 2 L (2.1 qt) or 4 L (4.3 qt), provided to calves at birth significantly increased pre-pubertal growth rate under similar nutritional and management conditions.

To extend this data, Soberon and Van Amburgh (2011) examined the effect of colostrum status on pre-weaning ADG and also examined the effects of varying milk replacer intake after colostrum ingestion. Calves were fed either high levels (4 L (4.3 qt)) or low levels (2 L (2.1 qt)) of colostrum, and then calves from these two groups were subdivided into two groups that were fed milk-replacer in limited amounts or ad-libitum. Calves fed 4 L of colostrum had significantly greater average daily gains pre-weaning and post-weaning and greater post-weaning feed intake, consistent with the data from Faber et al. (2005) and Jones et al. (2004). The observations from these experiments reinforce the need to ensure that calves receive as much colostrum as possible over the first 24 hr and possibly over the first 4 days as described by Steinhoff-Wagner et al. (2011) to ensure greater nutrient availability and absorption for the calf. The non-nutritive factors in colostrum, other than Ig's, appear to be important for helping the calf establish a stronger anabolic state and develop a more functional GIT barrier and surface area for absorption.

Also, colostrum is the first meal and accordingly is very important in establishing the nutrient supply needed to maintain the calf over the first day of life. The amount of colostrum is always focused on the idea we are delivering a specific amount of immunoglobulins (Ig's) to the calf, and many times we underestimate the nutrient contribution of colostrum. Further, many times of year, we tend to underestimate the nutrient requirements of the calf, especially for maintenance. For example, a newborn Holstein calf at 85 lbs birth weight has a maintenance requirement of approximately 1.55 Mcals ME at 72 °F. Colostrum contains approximately 2.51 Mcals metabolizable energy (ME)/lb, and a standard feeding rate of 2 quarts of colostrum from a bottle contains about 1.5 Mcals ME. Thus, at thermoneutral conditions, the calf is fed just at or slightly below maintenance requirements at its first feeding. For comparison, if the ambient temperature is 32 °F the ME requirement for maintenance is 2.4 Mcals, which can only be met if the calf is fed approximately 1 lb of DM or about 3.5 quarts of colostrum. This simple example illustrates one of the recurring issues with diagnosing growth and health problems with calves and that is the use of volume measurements to describe nutrient supply instead of discussing energy and nutrient values. Two quarts of colostrum sounds good because that is what the bottle might hold, but it has little to do with the nutrient requirements of the calf.

Managing the calf for greater intake over the first 24 hours of life is important if we want to ensure positive energy balance and provide adequate Ig's and other components from colostrum for proper development. For the first day, at least 3 Mcals ME (approximately 4 quarts of colostrum) would be necessary to meet the maintenance requirements and also provide some nutrients for growth. On many dairies this is done via an esophageal feeder and the amount dictated by the desire to get adequate passive transfer. Those dairies not tube feeding should be encouraging up to 4 quarts by 10 to 12 hours of life to ensure colostrum is fed not only to meet the Ig needs of the calf, but also to ensure that the nutrient requirements are met for the first day of life.

Table 2. Effect of high (4+2 L) or low (2L) colostrum and ad-lib (H) or restricted (L) milk replacer intake on feed efficiency and feed intake in pre and post-weaned calves (Soberon and Van Amburgh, 2011).

Treatment[1]	HH	HL	LH	LL	Std dev
N	34	38	26	27	
Birth wt, lb	97	95.7	92.1	95.4	2.1
Birth hip height, in	31.7	31.6	31.5	31.9	0.2
IgG concentration, mg/dl*	2,746[a]	2,480[b]	1,466[c]	1,417[c]	98
Weaning wt, lb	172.4[a]	140[b]	159.1	137.5[b]	4.2
Weaning hip height, in	36.6[a]	34.9[b]	36[c]	35.3[b]	0.2
ADG pre-weaning, lb	1.7[a]	0.9[b]	1.5[c]	0.9[b]	0.1
Hip height gain, pre-weaning, in/d	0.1[a]	0.06[c]	0.09[b]	0.06[c]	0
ADG birth to 80 d, lb	1.7[a]	1.3[b]	1.5[b]	1.2[c]	0.1
Hip height gain, birth to 80 d, in/d	0.08[a]	0.06[b]	0.07[c]	0.06[b]	0
Total milk replacer intake, lb DM	97.9[a]	45.2[b]	90.1[c]	44.1[b]	2.6
Grain intake pre-weaning, lb	5.5[a]	26.4[b]	4.6[a]	21.4[b]	3.3
ADG/DMI, pre-weaning	0.6	0.61	0.67	0.61	0.04
ADG post-weaning, lb	2.4[a]	2.1[b]	1.9[b]	2.0[b]	0.1
DMI post-weaning, lb/d	6.4[a]	6.4[a]	5.7[c]	5.9[b]	0.2
ADG/DMI post-weaning	0.36	0.35	0.34	0.36	0.02

[1]HH = high colostrum, high feeding level, HL = High colostrum, low feeding level, LH = Low colostrum, high feeding level, LL = Low colostrum, low feeding level. Rows with different superscripts differ $P < 0.05$.

Given the data on effects of colostrum on metabolism, a management suggestion to make best use of the factors the dam is trying to supply the calf would be to feed first milking colostrum to the calf immediately, then feed colostrum from milkings 2 through 4 (day one and two of lactation) to the calves over the first 4 days. This would ensure the non-nutritive factors are supplied to the calf during the period the calf is responsive to them in an effort to enhance intestinal development and function along with enhancing glucose absorption during a period when energy status is extremely important to the calf.

Nutrient status and long-term productivity

There are many studies in various animal species that demonstrate early life nutrient status has long-term developmental effects. Aside from the improvement in potential immune competency, there appear to be other factors that are impacted by early life nutrient status. There are many published studies and studies in progress that have both directly and indirectly allowed for an evaluation of first lactation milk yield from cattle that were allowed more nutrients up to eight weeks of age. In the majority of these studies, increased nutrient intake prior to 56 days of life resulted in increased milk yield during the first lactation that ranged from 0 to 3,000 additional pounds compared to more restricted fed calves during the same period (Table 3).

Table 3. Milk production differences among treatments where calves were allowed to consume more nutrients than the standard feeding rate prior to weaning from milk or milk replacer. The milk yield values are the difference between the control and treatment animals.

Study	Milk yield, lb
Foldager and Krohn, 1991	3,092[s]
Bar-Peled et al., 1998	998[ns]
Foldager et al., 1997	1,143[t]
Ballard et al., 2005 (@ 200 DIM)	1,543[s]
Shamay et al., 2005 (post-weaning protein)	2,162[ns]
Rincker et al., 2006 (proj. 305@ 150 DIM)	1,100[ns]
Drackley et al., 2007	1,841[s]
Raith-Knight et al., 2009	1,582[t]
Terre et al., 2009	1,375[t]
Morrison et al., 2009 (no diff. calf growth)	0
Moallem et al., 2010	1,600[s]
Soberon et al., 2012	1,217[s]
Margerison et al., 2013	1,311[s]
Kiezebrink et al. 2015 (little diff. calf growth through entire phase)	0

The papers and data described in Table 3 were analyzed in a meta-analyses to further investigate the impact of nutrient intake and growth rate prior to weaning (Soberon and Van Amburgh, 2013). The analysis excluded Foldager and Krohn, (1991) due to inadequate data to fully describe the treatments and Davis-Rincker et al. (2011) because they did not measure full lactations. The Morrison et al. (2009) study was included in the analysis and the data of Margerison and Kiezebrink were not available at the time of the analysis. The software used was Comprehensive Meta Analyses software (www.Meta-Analysis.com) (Borenstein et al. 2005) and the data included were study, treatment size (number of calves), mean milk yield, standard error or deviation, P value and effect direction. The data of Soberon et al. (2012) was initially excluded and then included to test for weighting effects since Soberon et al. contains many hundreds of animals. Inclusion of Soberon et al. did not change the outcome and the data were included in the analyses. The analysis indicated that feeding higher levels of nutrients from milk or milk replacer prior to weaning significantly increased milk yield by 959 ± 258 lb, $P < 0.001$, with a confidence range of 452 to 1,463 lb of milk. Further, when ADG was included as a continuous variable among the data set, the outcome was similar to that of Soberon et al. (2012) where for every pound of pre-weaning ADG, milk yield in the mature animal increased by 1,540 lb ($P = 0.001$). This is a significant amount of milk and demonstrates the sensitivity of the calf to pre-weaning nutrition, health and growth. Maintaining health to ensure high levels of feed intake reinforces the objectives of the dam to provide more nutrients to the heifer as described in the study by Hinde et al. (2013).

An analysis of all the lactation data and the pre-weaning growth rates, when controlled for study, suggests that to achieve these milk yield responses from early life nutrition, calves must at least double their birth weight or grow at a rate that would allow them to double their birth weight by weaning (56 days). This further suggests that milk or milk replacer intake must be greater than traditional programs for the first 3 to 5 weeks of life in order to achieve this response.

An analysis of 1,244 heifers with completed lactations from the Cornell herd was conducted and used a statistical approach similar to a sire evaluation to determine the effect of pre-weaning nutrition on lifetime productivity (Soberon et al., 2012). These data demonstrated there are programming or developmental events being affected in early life that have a lifetime impact on productivity (Table 4). Two aspects of the data that are worth noting were the effect on milk yield over multiple lactations and some effects of immune stress during the pre-weaning period. Within the data set, we were able to evaluate a portion of the cattle that completed up to 3 lactations. When we evaluated the 450 animals that had completed a third lactation, we found a lifetime milk effect of pre-weaning average daily gain of over 6,000 lb of milk depending on pre-weaning growth rates.

Table 4. Predicted differences by TDM residual milk (lb) for 1st, 2nd, and 3rd lactation as well as cumulative milk from 1st through 3rd lactation as a function of pre-weaning average daily gain and energy intake over predicted maintenance for the Cornell herd. (Soberon et al. 2012)

Lactation	*n*	*Predicted difference in milk per lb of pre-weaning ADG*	*P value*	*Predicted difference in milk (lb) for each additional Mcal intake energy above maintenance*	*P value*
1st	1244	850	< 0.01	519	< 0.01
2nd	826	888	< 0.01	239	0.26
3rd	450	48	0.91	775	< 0.01
1st – 3rd	450	2,280	0.01	1,991	< 0.01

The other observation worth noting was the effect of diarrhea or antibiotic treatment on growth and productivity. For calves with either diarrhea or antibiotic treatment, ADG was not significant and ADG differed by approximately 30 g/d for calves that had either event in their records ($P > 0.1$). However, for calves that had both events recorded, ADG was lower by approximately 50 g/d ($P < 0.01$). Over the eight year period, approximately 59% of all of the calves had at least one of the recorded events. First lactation milk yield was not significantly affected by reported cases of diarrhea. However, antibiotic treatment along with diarrhea had a significant effect on TDM residual milk and calves that were treated with antibiotics produced 1,086 lb less milk in the first lactation ($P > 0.01$) than calves with no record of being treated. Regardless of antibiotic treatment, the effect of ADG on first lactation milk yield was significant in all calves ($P < 0.05$). Calves that were treated with antibiotics produced 1,373 lb more milk per kg of pre-weaning ADG while calves that did not receive antibiotics produced 3,101 lb more milk per kg of pre-weaning ADG. The effect of increased nutrient intake from milk replacer was still apparent in the calves that were treated, but the lactation milk response was most likely attenuated due to factors associated with sickness responses and nutrient partitioning away from growth functions (Johnson, 1998; Dantzer, 2006).

Practical considerations to ensure adequate pre-weaning growth

To meet the requirements, there are several options and each option requires an economic and management process for each farm. For example, standard calf feeding programs over the last 30 years took the approach of feeding modest amounts of milk or milk replacer, generally at a level that would meet the maintenance energy requirements, and the overall objective was to encourage dry feed intake (Kertz et al. 1979; Otterby and Linn, 1980). This practice was developed to overcome certain health issues in addition to being low cost. Weaning as early as possible does offer the benefits of lower feed costs and reduced labor, however, the approach only works effectively when the calf is always in a thermo-neutral situation. For example, using the calf model within the 2001 Dairy NRC (NRC, 2001) a 110 lb calf consuming 1.25 lb of a 20:20 milk replacer has a metabolizable energy (ME) allowable gain of 0.68 lb/d at 68°F, which is within the thermo-neutral zone for this calf. However if the temperature is 32°F, the ME allowable gain is 0 lb/d and energy balance is actually negative, thus the calf must rely solely on dry grain to meet its nutrient requirements and a 110 lb calf is generally less than 2 weeks of age, so this is somewhat unrealistic for adequate nutrient intake above maintenance and acceptable growth and health performance.

Other considerations for nutrient source relates to the feeds available. For example, nonsaleable milk is an excellent source of nutrients for the calf assuming the solids and bacteria content are managed appropriately to provide a consistent and healthy diet. The energy content of milk is greater than most milk replacers due to the higher fat content of milk so meeting the nutrient requirements of calves fed nonsaleable milk is easier, especially in regions where the temperatures drop far below the critical temperature. It is important when feeding nonsaleable milk that the solids content be measured and standardized. Variability in nonsaleable milk solids content can be significant and affect the delivery of nutrients to the calf as described by Moore et al (2009) where the measured range over 12 samples from individual dairies was 5.1 to 13.4%. A Brix refractometer can be used to monitor the solids level to provide consistent delivery of nutrients to calves, and aid in developing management protocols using milk extenders, milk replacer or other sources of digestible nutrients (Bielmann et al., 2010).

Similarly, ensuring the reconstituted solids level of milk replacers is in an acceptable range is also important for a consistent and digestible nutrient supply. The directions supplied by the manufacturer should be followed for temperature of the mixing water to ensure appropriate mixing and stability within the water and also that the powder be weighed and not measured volumetrically to ensure proper weight to volume relationships. Due to manufacturing differences among milk replacers, the weight to volume relationship can vary greatly, and if similar vessels are used to measure the volume, then error in the solids content of the total solution can occur and this can cause osmotic issues in the calf, which in turn can lead to scours and reduced nutrient absorption. Acceptable ranges in the solids content of reconstituted milk replacers are 12.3% to about 18%, however at concentrations greater than 13.5%, free-choice water availability, times fed per day (>2x feeding) and water quality all become critical factors to ensure successful implementation of such a diet.

Water quality is also important for adequate mixing and feeding of milk replacers and general calf health. The total dissolved solids (TDS) content of water, along with the mineral content and concentration can greatly affect the osmolarity and osmolality of the final solution and can be a source of frustration when diagnosing scours, inconsistent feed intakes and abnormal feeding behavior. Kertz et al. (1984) demonstrated the need and effect of supplying adequate water for ensuring feeding intake and overall animal performance, however, quality of water is important in facilitating that outcome. Calves fed milk replacer are potentially more sensitive to poor water conditions because if water is high in TDS and other elements or compounds that affect water holding capacity, then when combined with milk replacers the high osmolarity can cause scours and this is not the fault of the milk replacer, but the combination of the two factors. Beede (2006) has summarized much of the literature on water and provided guidelines for evaluating water quality for dairy cattle. Recommendations for TDS for calves is less than 2,000 ppm (mg/L) however, for calves fed milk replacer the TDS in water should be less than 1,000 ppm to ensure salt toxicity and other osmotic problems do not occur. Sodium concentration in milk is typically in the range of 20-35 mmol/L and total solids are 11.2% to 13.7% depending on the nonsaleable milk source, handling and management. Thus, any concentration above those levels can have an effect on the osmolality of the solution and potentially cause digestive upsets and diarrhea. Recommended levels of sodium for water are <100 ppm and for chloride are <250 ppm (NRC, 2001). Other concerns with water would be pH and high levels of iron, magnesium, manganese and sulfur that can cause high osmotic pressure in the gut or a laxative effect and lead to diarrhea or other undesired outcomes.

Post-weaning Growth Benchmarks to Optimize Milk Yield

The other management objective is to encourage dry feed intake to develop the rumen and supply nutrients. It is essential that the calf learn to consume starter and develop a functional rumen by the time the weaning process is completed. Basic requirements for starter intake prior to complete weaning are that calves be consuming at least 2-2.5 lb of starter by the time liquid feed is removed. However, the amount of starter intake prior to weaning is confounded by the level of milk fed, so an absolute value is not really appropriate. It is most important that the calf consume enough to develop the rumen and establish a robust microbial population to ensure good digestion and rumen function. Under most of the conditions that dairy calves are managed, there are barriers to learning that affect how the calf views and accepts starter grain as a food source. Our way of managing that learning has been to limit the nutrients from milk or milk replacer in an effort to enhance hunger so they are encouraged to consume nutrients from other sources. Having calves of somewhat varying ages in housing conditions that allow for interaction or at least visual observation helps with the learning process because the older calves provide lessons in eating behavior for the calves not yet experienced enough to understand where and what the starter grain might be. Creating an environment that allows calves to teach each other about starter grain intake is essential to enhance nutrient delivery and weaning efficiency in dairy calves and help avoid post-weaning nutrient balance problems (de Paula Viera et al., 2012).

This all implies there are some benchmarks for growth post-weaning and those benchmarks are a function of the desired age at first calving (AFC) and the mature size of the herd you are working with (Table 5). These benchmarks have been described in the 2001 Dairy NRC but are difficult to implement due to the lack of data on BW and ADG that exists on most herds. This lack of data puts the nutritionist and heifer manager in a situation where they are attempting to make change in the absence of any real quantifiable data. The most important input in any ration balancing software is body weight and this also happens to be the most important information for managing heifer growth and AFC. It is important that if we are going to invest so much effort into the pre-weaned calf, that post-weaning, a similar amount of effort be applied to ensure that the benchmarks are met in order to achieve a BW at calving that allows the potential increase in milk yield to be realized.

Table 5. Example target weights for breeding weight, first, second and third calving weights based percent of mature body weight. Percent of mature body weight for breeding is based on physiologic maturity and the percent mature weight at first calf is a post-calving weight where milk yield is optimized in the first lactation (Hoffman, 1997; Van Amburgh et al., 1998; NRC, 2001).

		Mature weight, lb		
	Percent of mature weight	900	1,300	1,760
Pregnancy wt., lb	55%	494	716	967
1st Post calving wt., lb	85%	765	1,106	1,494
2nd Post calving wt., lb	92%	828	1,197	1,617
3rd Post calving wt., lb	96%	864	1,248	1,688

Farm data from the Northeast U.S. suggests that the benchmarks for first calving BW are not being met and milk yield is significantly lower due to the partitioning of nutrients to growth during that lactation. This can have a negative impact on income over feed costs in many herds, especially when heifer inventories are high and heifers make up a larger percent of the lactating herd. A typical scenario in the Northeast revolves around milk price and cull cow prices over the last 3 to 5 years and a lack of monitoring of heifer growth post-weaning or once pregnant. Milk price was high for most of 2014 and 2015 and cull cow prices were also high for same period. In many cases, cull value was almost equal to heifer rearing costs and this lead to higher than average culling in many herds especially if the herd had a strong heifer inventory. Accordingly, many herds now have more than 35-38% first lactation animals – upwards of 50% first lactation cattle in some herds; however there was little to no monitoring for adequate growth of the heifers after they were confirmed pregnant. The benchmark of weight at pregnancy (55-60% mature BW) was successfully achieved, however, heifers were calving at weights below the benchmark of 82% mature BW.

The value of calving at a BW less than the benchmark involves unrealized milk income due to the partitioning of nutrients to growth by the heifer during the first lactation. The heifer is always going to prioritize growth and attempt to achieve 90-92% of mature size by the second lactation, so this happens at the expense of milk yield. In one herd scenario, the heifers were calving at 72% of the mature BW of the herd (10 units or 13% below the target (82%) for optimizing milk yield) and the heifers were peaking at 80 lb, whereas they should have been peaking at 90-92 lb (heifers should be approximately 80-82% of mature cow milk when calving at the proper weight). Assuming 225 pounds milk per pound of peak, which means the unrealized milk for this group of heifers was approximately 2,500 lb due to not meeting the mature size benchmark. If the net milk price was $16.80/CWT and the income over feed cost (IOFC) margin was $8.33, then the reduced IOFC was ($8.33*25 CWT) $208.25 per heifer and for an 800 cow herd with 40% first lactation heifers, the value was $66,640 IOFC. At a milk price of $20/CWT the value is closer to $100,000 IOFC for the same herd and scenario.

Thus, it is important to make sure that the benchmarks for growth are achieved, especially if the objective is to realize not only the milk due to the growth objective, but also due to the management and investment that was made during the pre-weaning period.

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Breeding for Feed Efficiency: Yes We Can!

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Take-home point

Efficiency of cows can be improved further by continuing to select for more milk per cow along with modest decreases in cow size and by using genomic technologies to select for animals that eat less than expected to achieve their production.

Introduction

Feed efficiency in North America has more than doubled in the past 70 years, largely as a byproduct of selecting and managing cows for increased milk production (VandeHaar et al., 2016; Capper et al., 2009). Continued gains in feed efficiency are likely and possible as we adopt new technologies and make better use of existing ones Many factors influence feed efficiency on farms. For example, feed efficiency is decreased directly by losses of feed or products on the farm. Feed efficiency is altered indirectly by diet composition, management of cows, and genetics through effects on feed intake, milk production, maintenance requirements, digestion, nutrient partitioning, and metabolic efficiency. These topics have been reviewed recently by the authors and colleagues in an open source publication of the Journal of Dairy Science (VandeHaar et al., 2016), and we direct readers to that publication <journalofdairyscience.org/article/S0022-0302(16)30165-5/abstract> as well as to papers in the Large Dairy Herd Management Handbook soon to be published in 2017 (VandeHaar and Tempelman, 2017; Cole and Spurlock, 2017; and other chapters in the section on breeding strategies, edited by Weigel). We also recommend other recent reviews of dairy feed efficiency (Berry and Crowley, 2013; Connor, 2015; Pryce et al., 2014). In this paper, we briefly discuss the role of genomics and traditional genetics in selecting animals that are more efficient. We will focus on two areas for future improvements in feed efficiency: 1) continued increases in milk production per cow on a per unit of metabolic body weight basis, and 2) adoption of new genomic methods to select for cows that eat less than expected based on production.

Defining feed efficiency

Feed efficiency is a complex trait for which no single definition is adequate. Feed efficiency should be considered over the lifetime of a cow and include all feed used as a calf, growing heifer, dry cow, and lactating cow and all products including milk, meat, and calves. Feed efficiency could also account for whether the feeds eaten by cattle could be consumed directly by humans, how much land is required to grow feed, whether wastes are captured, and how much the cows contribute to climate change and pollution. Developing a metric that includes all relevant factors for feed efficiency would be difficult. Whereas protein could be considered the most important component of milk, energy intake generally limits milk production, and feed energy includes the energy of protein. Thus, this paper focuses on energetic efficiency.

Gross energy (**GE)** is the total chemical energy of a feed but some of it is lost as the chemical energy in feces, gasses, and urine, and some is lost as the heat associated with the metabolic work of fermenting, digesting, and processing nutrients. The remaining chemical energy is known as net energy (**NE**). Some NE is used to support maintenance functions and is subsequently lost as heat. Some NE is the chemical energy of secreted milk or accreted body tissue and conceptus. For this paper, feed efficiency is defined as the energy captured in milk and body tissue divided by the GE consumed by a cow in her lifetime, and it is highly correlated to milk energy output per unit body weight (**BW**). The major components affecting feed efficiency can be divided into 1) those that alter maintenance and the dilution of maintenance, or the portion of NE that is captured in milk or body tissues instead of used for maintenance, and 2) those that alter the conversion of GE to NE, which include diet and cow effects. To breed for improved feed efficiency, we can focus on these independently. To enhance the portion of NE that is captured in products, we can breed for continued increases in milk production per cow on a per unit of metabolic body weight basis. In the past, we have not been able to select for improved conversion of GE to NE; however, new genomic methods are becoming available.

Selecting for cows that capture NE more efficiently.

The typical Holstein cow has a maintenance requirement of ~10 Mcal of NE/day (equivalent to ~25 Mcal of GE and ~6 kg of feed; the requirement is ~8 Mcal for Jerseys). This feed is used for basal life-sustaining functions even if animal is not producing milk, growing, working, or pregnant. Any extra feed consumed above that needed for maintenance can be converted to milk or body tissues. As a cow eats and produces more, the portion used for maintenance becomes a smaller fraction of total feed intake. This "dilution of maintenance" increases feed efficiency and has been known for a long time (Freeman, 1975; VandeHaar et al., 2016).

Production relative to maintenance can be increased by increasing production or by decreasing maintenance. Maintenance is correlated to a cow's body weight, and, over the past 50 years, the body size of dairy cattle has increased. Because of this, the US genetic base for body size traits in all dairy breeds is continually being adjusted up. However, our latest analysis on 5000 Holsteins in mid-lactation (using the dataset of Tempelman et al., 2015) demonstrated no genetic correlation between BW and milk energy output (VandeHaar et al., 2014); moreover, BW was genetically correlated negatively with overall feed efficiency. In a smaller subset of that data, Manzanilla-Pech et al. (2016) showed that milk energy output had zero or negative genetic correlations with BW and that stature was genetically correlated negatively with feed efficency. Lifetime feed efficiency of dairy cows had more doubled in the past 70 years because of increased milk production per cow; however, the fact that cows have gotten larger at the same time is counter to the goal of increasing efficiency. If cows had simply gotten larger as we bred for greater milk production, this might be acceptable; however, it seems we have bred for larger cows simply because we like larger cows and think they should produce more milk. If we want more milk, we should breed for more milk. If we want more efficient cows, we use a linear index that favors more milk protein and fat and smaller, or at least not larger, body size.

At present, we don't know exactly the optimal level of milk production and body weight to maximize feed efficiency of dairy cows. We do know the following.

1. As cows eat more and produce more milk, the improvement in overall feed efficiency per lb of extra milk produced or feed consumed diminishes. This is due to simple math. If a 1400-lb cow

requires 10 Mcal of NEL per day for maintenance and eats 10 Mcal, then 100% goes toward maintenance. If she eats 20 Mcal per day and puts the extra 10 Mcal into milk (about 30 lb of milk/day), 50% goes toward maintenance. At 30 Mcal per day (almost 70 lb of milk), 33% is for maintenance; at 40 Mcal (100 lb of milk), 25% is for maintenance; and so on. With each extra 10 Mcal of feed and milk, the advantage in milk/feed from diluting maintenance decreases.

2. Breeding for smaller cows provides the same result for feed efficiency as does breeding for more milk. What matters is how much milk energy a cow produces relative to her BW. More specifically, what really matters is her BW to the 0.75 power, or metabolic BW (MBW) because maintenance requirements are directly related to $BW^{0.75}$. As a percentage, the difference in MBW is less than the difference in BW, so while a 1500-lb cow weighs 50% more than a 1000-lb cow, on a MBW basis, she is only 36% heavier.
3. Previous estimates of the maintenance requirement of cows is likely too small for today's cows. Based on a recent publication (Moraes et al., 2015), cows probably require 25% more energy for maintenance than predicted by the last NRC (2001). In addition, maintenance per unit MBW is higher for thin cows than fat cows (Birnie et al., 2000), indicating that maintenance is more related to the frame size of a cow than her actual BW.
4. We don't have measures of BW for cows that can be used to predict feed costs for maintenance in a breeding index. Instead we have estimates of BW based on classification scores. These are imperfect but are improving as new data becomes available. In the past year, the TPI was updated with new estimates for BW, and the Net Merit Index will likely be changed in August 2017.
5. To complicate this further, as cows eat more per day relative to their size, they digest feed less efficiently because it passes through the tract faster (NRC, 2001). The magnitude of this digestibility depression is not clear.
6. Efficiency on a lifetime basis is what matters. To that end, we must consider the amount of milk produced per unit of feed over the cow's lifetime, not just during lactation. Larger animals eat more feed while heifers and dry cows, but they also give more salvage value.
7. Lifetime feed efficiency likely is close to its maximum at 40,000 lb of milk/year for a cow with 1700 lb mature BW (VandeHaar, 1998).
8. We do not know with certainty whether feed efficiency for Holsteins and Jerseys is different. Jerseys might be more efficient for producing cheese, due to the higher protein and fat content of their milk (Capper and Cady, 2012). However, studies with actual measures of feed intake and production on lots of animals are needed to many any conclusions regarding breed differences.
9. If the milk and body tissues are not harvested, they are of no value. Cow deaths and unsaleable milk are major losses for feed efficiency. Both are both influenced by heritable traits (such as productive life and somatic cell score) and are not considered in the traits we use to breed for milk production and body weight.

Thus, based on all available data, we suggest that substantial gains can still be made in lifetime feed efficiency from increasing production relative to body size and that a linear index should be used to select cows for greater milk production and smaller BW together. However, top North American herds are at a point where the return in efficiency from further gains in productivity or from smaller cows certainly will be smaller than they have been in the past. Thus, along with continuing to breed for more milk per unit BW, we should also develop new methods to select for cows that convert GE to NE more efficiently.

Selecting for cows that convert GE to NE more efficiently

During the 20th century, we selected for superior genetics based on measuring phenotypes (traits like milk production) in daughters of young sires; sires with outstanding daughters were deemed genetically superior. Because DMI cannot be measured easily and routinely on individual cows in commercial farms, direct selection for feed efficiency was impossible. However, the advent of genomic selection is revolutionizing the dairy industry. Genomics enables selection for traits like feed efficiency for which daughter phenotypes are unknown.

Excellent reviews on the general methodology of genomic selection are Eggen (2012) and Hayes et al. (2010). In short, the genome (all of the DNA) of a cow consists of 30 pairs of chromosomes and 3 billion base pairs. There are 4 options for each base pair in the genome, and for most of these 3 billion base pairs, the base of the coding strand is the same for all cows. A single nucleotide polymorphism (SNP) is any place in the DNA where more than one base is found. When we genotype cows, we typically examine from 6,000 to 90,000 of these SNP across the genome, but even 800,000 SNP can be examined. An individual SNP may have no biological function, but it is linked to the DNA around it, so the SNP serves as a marker for the variation in the DNA at surrounding genes. When the small effects of 50,000 or more SNP are added together, they can help identify animals that are expected to be superior for heritable traits like milk production.

One trait of particular interest in selecting animals for feed efficiency, independently of production level, is **Residual Feed Intake** (**RFI).** RFI is a measure of actual versus predicted intake for an individual and is essentially "unjustified feed intake" (VandeHaar et al., 2016, which provides references for other great reviews on the subject). Cows that eat less than expected have negative RFI, and thus are desirable when comparing animals for selection purposes as long as RFI is only seen as one factor to use in selecting for efficiency. Selecting for high milk production relative to BW also remains an important selection objective.

Based on our data examining the feed efficiency of cows compared to their level of production (see figures in VandeHaar et al., 2016), efficiency varies considerably among cows within a production level. This variation can also be examined in intake units, or RFI. Whereas part of the variation in RFI is error in measurements, some RFI is biological. We found the pedigree-based heritability of RFI to be 0.17 based on measures in 4900 cows from across the US, Canada, Scotland, and the Netherlands (Tempelman et al., 2015). We also found that RFI was heritable at the genomc level. Based on the first 2900 cows of our study, the proportion of RFI variance accounted for by about 50,000 SNP markers was 14% (Spurlock et al., 2014), and this has been confirmed when examing 5000 cows by separate analyses at Iowa State, Michigan State, and the University of Wisconsin. However, in all of our analyses, very few SNP had major effects; instead, the additive effects of many SNP were important in identifying the efficient vs inefficient cows. Publications from those papers are forthcoming.

New breeding value equations based on the cows in our current database (7,600 cows with feed efficiency phenotypes, of which about 5,300 have genotypes) can be applied to bulls currently available in the US and used to predict which bulls will sire the most efficient daughters. We have already computed preliminary breeding values for "Feed Saved", similar to Pryce et al. (2015). The Feed Saved trait is based on the sum of RFI and the extra feed consumed for maintenance due to larger-than-average body size with Feed Saved equal to -1 x (RFI + extra feed for maintenance).

Based on our preliminary analyses, sires with superior genetics for Feed Saved would have a predicted transmitting ability of about 1000 lb of feed saved per lactation compared to the breed average. About half of the total feed saved is from RFI and half from maintenance savings. Furthermore, based on current data, we expect that the Feed Saved trait is not correlated (positively or negatively) with health or fertility traits.

Evidence that genomic selection for RFI can work in the dairy industry has been nicely demonstrated by Davis et al. (2014). In their study, genomic predictions for RFI were developed for growing heifers, and then 3,400 mature cows were genotyped and ranked based on the RFI genotypes for growth. Actual feed intake and production were then measured in the top 100 and bottom 100 at a common location during lactation. Cows from the top 10%, compared to the bottom 10%, for RFI genotype during growth needed 1.4 lb less feed per day to produce the same amount of milk. This is similar to the expected savings in feed for maintenance in a cow weighing 180 lb less. The use of genomics in selection against RFI or DMI is already beginning in Australia (Pryce et al., 2015) and the Netherlands (Veerkamp et al., 2014) and will likely occur in North America in the near future.

If selection for RFI is to be effective, it should be repeatable across diets, climate conditions, lactations, stages within a lactation, and even stages of life. Data to date suggest that it is (Tempelman et al., 2015; Potts et al., 2015; Connor et al., 2013; MacDonald et al., 2014). In addition, if genomic selection for RFI is to be used in making breeding decisions in the future, we must continue to update our database of feed efficiency. We believe this will happen and encourage producers to consider using the new genomic tools as they become available.

It is important to note that RFI is only part of feed efficiency. Selection for efficiency must also consider the optimal levels of milk production relative to body weight. The “feed saved” approach used by Pryce et al. (2015) seems reasonable, with an index to select for smaller body size and lower RFI, while continuing to select for high milk yield and desirable milk composition. Improvements in feed efficiency must not occur at the expense of health and fertility of dairy cows. Many traits must be optimized as we consider the ideal cow of the future to promote efficiency and profitability of farms and sustainability of the dairy industry (Table 1). Genomics will help us achieve these goals.

Conclusion

We have made major gains in feed efficiency in the past as a byproduct of selecting, feeding, and managing cows for increased productivity, which dilutes maintenance. To enhance efficiency further, we should take advantage of new genomic tools that will enable us to select for cows that require less feed per unit of milk by using a selection index that favors greater milk production and components, smaller cow size, and negative RFI.

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Table 1. Breeding goals for the cow of the future to enhance efficiency and sustainability. (from VandeHaar et al., 2016).

Efficiency goals	Efficiently captures (partitions) lifetime NE to product because maintenance represents a small portion of required feed NE
	Has a negative RFI, indicating greater efficiency at converting GE to NE or lower maintenance than expected based on BW
	Is profitable (high production dilutes out farm fixed costs)
	Has minimal negative environmental impacts
	Can efficiently use human-inedible foods, pasture, and high fiber feeds
	Requires less protein and phosphorus per unit of milk
	Produces milk and meat of high quality and salability
Other goals	Is healthy, long-lived, and thrives through the transition period
	Is fertile and produces high-value offspring
	Is adaptable to different climates and diets
	Has a good disposition

Notes:

Environmental Impacts on Forage Quality

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Farmers spend considerable time on crop variety selection in search for high yields but also for high forage quality. And for good reason since genetic advances including brown midrib (BMR) corn hybrids, other BMR summer annuals and, more recently, reduced-lignin alfalfa offer the potential for improved quality. Additionally, the tremendous growth in the availability and range of genetically engineered traits—Bt corn hybrids, glyphosate resistant corn and alfalfa—has greatly increased farmers' pest control alternatives. However, the influence of plant genetics on crop yield and quality is modest when compared to the combined effect of genetics plus environment. For instance, selecting corn hybrids for high silage yield can result in about a 10% yield improvement. But when hybrid selection is combined with the impact of environment—primarily but not exclusively weather conditions—the yield impact triples. Similarly, the combined impact of hybrid plus environment results in much greater differences in corn silage quality (including starch content and digestibility) than does hybrid selection alone.

Plants have several defenses against adverse weather conditions, not all of which promote higher forage quality. Plants accumulate nutrients in various organs to help them survive adverse weather conditions including defoliation from hail or frost, and in the case of alfalfa and other perennial legumes, from the depletion of nutrients following harvest. Plant stress can increase some aspects of forage quality: for example, when subjected to drought stress, corn yields less grain per acre but the stover is usually more digestible. The result is whole-plant silage quality which is often similar to that of corn grown under adequate moisture. Alfalfa grown under limited moisture will be lower in yield but the leaf-to-stem ratio may be higher than when the crop is grown with adequate soil moisture. Another way that plants protect themselves against environmental challenges is by the formation of compounds such as lignin and alkaloids. Increased lignin content in forage crops can decrease dry matter intake by ruminants, while alkaloids are nitrogen-containing compounds that are usually bitter in taste, resulting in decreased palatability. Examples of this include two older varieties of reed canarygrass, "Rise" and "Vantage", which contain significant amounts of the alkaloid indole. Dairy cattle are particularly affected by these alkaloids; realizing this, in 1985 plant breeders developed and released two reed canarygrass varieties, "Palaton" and "Venture", that contain about 20% less alkaloid than do the older varieties and are therefore more readily consumed by ruminants.

It ain't the heat…

The two major environmental impacts on forage quality are heat and moisture. High temperatures reduce plant digestibility in several ways: by increased lignification of plant cell walls, higher neutral detergent fiber (NDF), and by decreased metabolic activity resulting in lower protein and soluble carbohydrates. The corn plant will tolerate a wide range in air temperatures, from about 30°F to 110°F. While temperatures above 95°F can negatively affect pollination, this seldom is a problem provided there's adequate soil moisture. Also, pollen shed usually occurs in the morning before temperatures exceed 95°F. What really affects corn silage quality is the combination of high temperatures and excess soil moisture. Excess heat is harmful; excess soil moisture is harmful; hot and wet is *terrible* for NDF digestibility. To make matters worse, during periods of high precipitation there's often a lot of cloud cover and therefore less sunlight. Cornell University's Peter Van Soest noted that under these conditions the forage quality (primarily of corn silage but of other forages as well) may be even worse than would be predicted by laboratory analyses.

Alfalfa is a cool-season crop but can tolerate temperatures of up to 100°F *if the air is dry*. That's why irrigated alfalfa does much better in Arizona and the arid Southwest than in the Southeastern U.S. "It ain't the heat, it's the humidity."—this is true for alfalfa as well as for humans. What's referred to as the "summer slump" of alfalfa grown in the Southwest usually occurs in July when the dew point peaks for the summer. High temperatures increase the rate of maturity and stem lignin content while plant height and leaf-to-stem ratio decrease. The cumulative effect is lower fiber digestibility. Hot weather can have a long-lasting impact on yield and plant health because when the alfalfa plant is heat-stressed—especially during the "summer slump"—it stores less carbohydrate because of increased respiration.

Summer slump of alfalfa is different than "summer scald", also common in the arid Southwest. Summer scald occurs when the air temperature is over 90°F and water stands for several hours following surface irrigation. The alfalfa roots suffer from lack of oxygen, resulting in reduced growth which in turn leads to lower yield and lower forage quality. Summer scald can also affect bermudagrass and sudangrass, but is most common in irrigated alfalfa.

When managing alfalfa in hot climates, "Fear the night." Hot nights can reduce alfalfa quality, but hot nights preceded by 100°F days are worse. The result is higher crude protein but also higher fiber levels, particularly lignin. Mowing heat-stressed alfalfa at the late bud stage may be too early under these conditions because the alfalfa needs additional time to rebuild root carbohydrates. Although too soon to know for sure, this probably is the case even with reduced-lignin alfalfa varieties.

Summer slump aside, alfalfa is a very good crop for hot environments as long as there's adequate rainfall or irrigation. Alfalfa leaflets have no structural function, so there's almost no change in leaf quality as the plant matures—or as temperatures rise. Stem lignification is at least partly offset by the unchanged leaf quality. The result is a widening of the quality difference between the more and less digestible parts of the alfalfa plant. Therefore, leaf retention during harvest—from mowing through ensiling—is critical for maintaining high alfalfa digestibility. This places additional importance on harvest management—impellers vs. roller conditioners, and no conditioning vs. conditioning. Conditioning may be necessary for dry hay production, but perhaps not for hay crop silage (assuming the use of wide windrows).

If life gives you lemons…

Farmers can't control the weather, but with corn harvested for silage they have some influence over the degree to which the weather impacts forage quality, and hybrid selection is a key. "Hot and wet" reduces fiber digestibility and perhaps grain *yield* but has much less impact on grain *quality*. That's because while corn stalks contain about 65% NDF, corn kernels have only about 8% NDF.

Therefore, kernels are Mother Nature's crop insurance against the impacts of a hot, wet growing season.

Adverse weather conditions can have a large impact on high-fiber, low starch corn hybrids. Over the years there have been a small number of leafy gene hybrids with high forage yield but low grain content, in some cases five or more percentage points lower in starch than normal. (This isn't a general characteristic of leafy hybrids, many of which have normal leaf-to-grain ratios.) When weather conditions are favorable for NDF digestibility a high fiber, low starch hybrid may do well both in the field and in the feedbunk. But during a hot, wet summer the low grain content of these hybrids provides little defense against the impact of adverse weather conditions.

As noted this is not an indictment of leafy hybrids, some of which have performed very well for both yield and quality in university hybrid trials when harvested as whole-plant silage. Some leafy hybrids have a slightly longer "harvest window" since once they reach the generally recommended harvest moisture content there's a slower rate of moisture loss. Leafy hybrids are recommended almost exclusively for silage harvest and have more leaves above the ear. University trials haven't found any consistent differences in yield or forage quality between leafy and conventional hybrids, but there's been little of this testing in weather-stressed environments. The additional leaves in leafy hybrids are all above the ear, where they're most visible—even from the seat of the farmer's pickup truck. But appearances can be deceiving: in one Penn State trial comparing leafy and conventional hybrids, conventional hybrids had 12% leaf content while leafy hybrids were only slightly higher at 13-16% leaf content. Looking at side-by side rows of leafy and conventional hybrids, most farmers would be very surprised at this small difference. However, there are meaningful differences in starch content within the leafy genotype. In regions where temperatures often exceed 100°F, particularly with surface irrigation that can challenge plant digestibility, farmers should choose corn hybrids (including both leafy and conventional) with a proven record of high grain-to-stover ratio.

Irrigation impacts on forage quality

Most farmers don't have a choice of irrigation method, but it's useful to understand the quality challenges that can be posed by surface (vs. sprinkler) irrigation, both for alfalfa and for corn. Montana research with surface-irrigated alfalfa evaluated the relationship of temperature and how long the field was irrigated. Three weeks after alfalfa was surface irrigated, alfalfa yield was 50% lower when the crop had been flooded for four days at 70°F, but yield was 50% lower when alfalfa had been surface-irrigated for only *two* days when temperatures were 90°F. There was no alfalfa root growth during the time the field was flooded.

The impact of irrigation method on the quality of corn harvested as whole-plant silage can be considerable. Italian researchers, using three U.S. corn hybrids, applied two rates each of sprinkler and surface irrigation to growing corn. When the corn was harvested for silage at 30-32% DM, compared to sprinkler irrigation both high and low rates of surface irrigation resulted in much higher NDF and lignin content, and lower protein, NDF digestibility and rates of digestion. There was much more difference between surface and sprinkler irrigation than between the high and low irrigation rates. Farmers using surface irrigation should pay particular attention to the starch content of the corn they plant for silage, using management strategies (hybrid selection, plant population, fertilization, etc.) that promote high grain content. Over a generation ago Cornell University dairy scientists stated that "The best grain hybrid is the best silage hybrid." With the notable exception of

BMR corn, and particularly in environments where heat and excess soil moisture are frequent challenges, forty years later this statement remains mostly true.

Ash

When deposited in the form of dust or other external contaminants, ash is another environmental factor that can affect forage quality. The ash levels in Western U.S. corn silage are generally higher than in other regions of the U.S. For instance, California corn silage averages about 6% ash while New York and Wisconsin corn silages both average about 3.5% ash. Surface-irrigated corn doesn't get the frequent "wash/rinse" cycles that corn receives from rain or center-pivot irrigation, and additional dust is often deposited by choppers and trucks during harvest, so ash levels in surface-irrigated corn may be even higher than the overall California state average of 6%. (Similar results would be expected in corn silage on farms in other states using surface irrigation.) It should be noted that California corn silage has a slightly higher mineral content than Wisconsin or New York corn silage, some of which is "internal" ash—plant potassium, calcium, etc. But even accounting for differences in the plant's mineral content there's somewhat more "external" ash in Western U.S. corn silage.

Sunlight, light intensity, and when to mow alfalfa—dawn or dusk?

We often underestimate the importance of daylight in discussions of forage quality, mostly because there's so little we can do to change it. Light is the main energy source for forages, influenced by both light intensity and day length. The end process of photosynthesis is glucose, so sunlight promotes the formation of sugars. At the same time there's a decrease in fiber concentration, though much of this is the result of dilution by the increased level of nonstructural carbohydrates and amino acids. Cloud cover reduces the amount of light that plants receive, which decreases forage quality. Fog would be expected to have a similar effect as cloud cover, something that may affect the quality of forage crops grown in California's Central Valley (where ground fog is common) vs. those grown in higher elevation areas.

Plants gain dry matter primarily in the form of sugars during a sunny day and lose these sugars overnight through transpiration. This occurs regardless of whether a forage crop is standing in the field or has just been mowed. Plant sugar content is highest in the late afternoon and lowest right after sunrise. Arizona researchers found 4% higher alfalfa yield when it was harvested at dusk vs. when the same crop was harvested just after dawn. Other research in the Southwestern U.S. found that alfalfa harvested in the late afternoon and preserved as dry hay was higher in digestibility, more palatable to dairy cattle, and resulted in higher milk production.

A challenge in making the diurnal pattern of plant sugar accumulation work for farmers is that much of the sugar accumulated during a sunny day is lost during the night through respiration. Alfalfa mowed in the morning has low sugar content, but when managed in wide windrows can often be mowed and chopped for silage in the same day, thereby avoiding overnight respiration losses. However, alfalfa mowed late in the day (after sugars have accumulated) can seldom be chopped until the following morning so much of the day's gain in sugars is lost overnight. Two years of research at Miner Institute (Chazy, NY) involved mowing replicated blocks of alfalfa between 7:00 and 8:00 AM vs. between 3:00 and 4:00 PM. By the time the alfalfa was chopped for silage—the same day for that mowed in the AM, the next morning for that mowed in the PM—there was no significant difference in plant sugar content.

So, what should farmers do? For dry hay production mowing in the afternoon may have an advantage since the alfalfa would have to remain in the windrow for at least one night regardless of the time of day that it's mowed. For hay crop silage, the highest quality silage will be that mowed as late in the morning as possible *while still able to be chopped the same day.* However, it's important to keep in mind that harvesting alfalfa at the proper stage of maturity is more important than AM vs. PM decisions.

While we can't change the amount of sunlight, we can manage crops to maximize its impact. Sunlight will penetrate deeper into a canopy of corn when the rows are planted in a north-south direction. More sunlight results in higher yield potential. In a Dupont-Pioneer trial, compared to corn planted in an east-west direction, corn planted north-south and harvested as silage averaged 13% more yield and 11% more milk per acre. There were similar results—12% higher corn grain yield with north-south rows—in an irrigated South Carolina trial. However, not all crops respond similarly to row orientation. In shorter-statured crops including cereal grains, more sunlight penetrating the crop canopy and reaching the soil surface can result in increased weed growth. Researchers in Australia found 44% fewer weeds and 25% higher crop yield with a cereal crop planted in an east-west row orientation.

Soil factors influencing forage quality

Soil is part of the crop's environment, and not just from a soil moisture standpoint. Both total plant-available nutrients as well as the relationship between nutrients impact crop yield, and some of these relationships also affect forage quality. For instance, alfalfa plants need adequate potassium for normal protein production. The higher protein content in alfalfa when soil potassium levels are increased from deficiency to sufficiency is the result of at least two factors: An increased leaf-to-stem ratio and increased nodulation. There are a number of interrelated factors, but the protein content of alfalfa may be reduced when whole plant potassium levels fall below 2.0%.

ABSTRACTS

INVITED PRESENTATIONS

Milk fat depression: A nutri-genomic view of how rumen fermentation products regulate dairy cow metabolism

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Milk fat comprises many differ fatty acids (FA) and the most variable component of milk. Nutrition can have a major effect on milk fat output, the most striking example being the low-milk fat syndrome, more commonly referred to as diet-induced milk fat depression (MFD). Recognized for over a century, certain diets and dietary conditions cause a reduction in milk fat whereas yield of milk and other milk components are unaffected. It was clear that MFD involved a metabolic interaction between fermentation in the rumen and the metabolism of body tissues, but the cause remained elusive until it was recognized that it was associated with rumen biohydrogenation of dietary polyunsaturated FA. The biohydrogenation theory established that diet-induced MFD occurred when typical pathways of rumen biohydrogenation were altered to produce unique FA intermediates that inhibited milk fat synthesis. Through advances in analytical and chemical synthesis methods, *trans*-10,*cis*-12 conjugated linoleic acid (CLA) was the first of these unique intermediates identified. During MFD, mammary lipogenic capacity is reduced and the transcription of key mammary lipogenic enzymes is coordinately down regulated. Dose-response studies established *trans*-10,*cis*-12 CLA is a very potent inhibitor of FA synthesis, but the mechanism by which it causes this coordinated downregulation is not known, but evidence supports roles for sterol response element binding protein-1 (SREBP1) and Spot 14 as components in the mammary signaling pathway. Overall, the MFD story in dairy cows represents an elegant example of nutrigenomics, and investigations have provided novel mechanistic insight in the regulation of FA synthesis with potential applications in agriculture and human biology.

Key Words: rumen, milk fat, conjugated linoleic acid, milk fat depression, nutrigenomics

Host-gut microbial metabolic interactions: Linking gut microbial ecology to metabolic health

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Gut microbiota are now recognized as fundamental partners of the host’s health. As the environment changes, our overall metabolism adapts to maintain homeostasis within an optimal metabolic space, and so do our microbiota. Normally, the host-microbiota symbiosis triggers a healthy metabolic phenotype. But how does this interplay result in an optimal metabolic state? And how can this be measured? Nutrimetabonomics is a useful tool to assess the metabolic state of the host in response to a gut microbial modulation. This method was successfully applied in mouse models to examine how the progressive colonization of the gut affects the host metabolism. In particular, it was revealed that gut bacteria triggered a specific hepatic response to modulate energy metabolism during the early colonization process. In humans, we applied a similar nutrimetabonomics approach to investigate the effects of an inulin-type fructans prebiotic on obese patients. The prebiotic treatment resulted in specific modulations of the gut microbiota, such as increased levels of *Collinsella* that were positively correlated with urinary hippuric acid, a marker of gut microbial degradation of polyphenols. In addition, the prebiotic treatment induced a decrease level of *Propionibacterium,* which were found positively correlated with circulating levels of VLDL, lactate and phosphatidylcholine, suggesting a potential positive effect of the treatment on energy metabolism. Finally, we also applied such approach in a clinical setting to decipher the metabolic perturbations associated with the degree of disease severity in patients suffering from ulcerative colitis. Altogether, these data indicate that nutrimetabonomics can be a powerful approach to study host-gut microbial interactions in a clinical context where patient stratification is key to further develop personalized medicine.

Key Words: gut microbiota, nutrimetabonomics, metabolic profiling

Bacterial degradation of host and dietary polysaccharides in the human gut during health and disease

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The trillions of symbiotic microorganisms in the human gut expand our digestive physiology by providing an armament of polysaccharide-degrading enzymes that are absent in the human genome. Dietary polysaccharides, mixed with endogenous mucosal secretions, present a diverse menu of complex carbohydrates that our gut symbionts have adapted strategies to sense, triage and degrade. Understanding which species consume each nutrient, how abilities vary among taxa and what the molecular mechanisms involved are, represent central problems in defining the relationship between diet, microbiota and health.

We are taking microbiological, genomic, genetic and biochemical approaches to address these problems. Our results have revealed that members of the phylum Bacteroidetes are major contributors to carbohydrate digestion and rely on expression of discrete gene clusters that each encodes the requisite proteins to catabolize a particular polysaccharide. Expression of each gene cluster is activated by a locally encoded transcription factor that participates in carbohydrate sensing and metabolism until its supply is exhausted. In the context of a single bacterium, many dozen individual gene clusters may simultaneously be triggered to respond to available nutrients. Yet, in experimental conditions in which such complex nutrient environments are modeled, there is an ordered progression of carbohydrate utilization that is reminiscent of catabolite repression.

Of central focus in our studies is the interplay between dietary fiber polysaccharides and mucosal glycans. Some bacteria possess mechanisms to suppress utilization of mucosal glycans when dietary alternatives are present, while

others exhibit opposite behavior. Our results reveal that sensing and triaging of glycans is a complex process that varies among species, underscoring the idea that these phenomena are likely to be hidden drivers of microbiota community dynamics and may dictate which microorganisms commit to various niches in a constantly changing nutritional environment.

Bile Acid Modifications at the Microbe-Host Interface: Implications for the Rational Selection of Probiotics

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Bile acids act as key signalling molecules that have the capacity to alter systemic endocrine functions in the host. Individual bile acids are capable of interacting with host cell receptors (including FXR and TGR5 receptors) to induce cellular responses in the intestine and other tissues (including the liver and adipose tissue). As gut microorganisms have the capacity to significantly alter the signalling properties of bile acids we, and others, have investigated the impact of altered microbial bile acid signatures upon host physiological processes. In particular we have focused upon microbial bile salt hydrolase (BSH) activity as a gut microbial activity that has the capacity to profoundly alter both local (gastrointestinal) and systemic (hepatic) host functions. Using a functional metagenomics approach we demonstrated that BSH activity is widely distributed amongst gut bacteria and may contribute to microbial colonisation in the gut. Using both germ free and conventionally-raised mouse models we showed that gastrointestinal expression of BSH results in local bile acid deconjugation with concomitant alterations in lipid and cholesterol metabolism, signalling functions and weight gain. Key mediators of cholesterol homeostasis (*Abcg5/8*), gut homeostasis (*RegIII*□) and circadian rhythm (*Dbp*) were influenced by elevated BSH in our study. The implications of this work for the rational development of probiotics with the potential to modulate host weight gain will be discussed.

Can we transform *Faecalibacterium prausnitzii* from a friend in need, to a friend in deed, for IBD patients?

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Faecalibacterium prausnitzii is a Gram-positive “commensal” bacterium that produces anti-inflammatory factors and also enhances intestinal barrier function in murine models of chemically induced colitis. Langella and colleagues have shown that peptides, as well as other fermentation products arising during *F. prausnitzii* growth *in vivo*, possess anti-inflammatory effects. These findings have prompted widespread interest and optimism that *F. prausnitzii* can be used therapeutically to attenuate inflammation and/or promote gut homeostasis. However, microbiota profiling studies commonly show that *F. prausnitzii* is present in high abundance in healthy subjects, but depleted in most patients suffering from Crohn's disease, ulcerative colitis, or other gastrointestinal disorders with associated inflammation. Furthermore, two longitudinal studies of CD patients suggest that the restoration of *F. prausnitzii* populations is variable across patients after disease episodes, and their sustained low numbers are predictive of poor health outcomes, including recurrent disease. This poses the question as to whether depletion of *F. prausnitzii* is a cause, or consequence, of inflammation. In this context, the host- and environmental cues affecting *F. prausnitzii* colonisation, persistence and adaptive capacity in the human gut remain poorly defined, as does the degree of genome variation across strains and its effects on their ecological fitness. In collaboration with French colleagues we have so far examined the genomes of five *F. prausnitzii* strains, and found some key differences between the phylogroups in terms of their glycoside hydrolase and glycosyltransferase profiles, suggesting possible differences in carbohydrate utilization and bacterial surface decoration relevant to host-microbe interactions. Interestingly, all five genomes appear to lack the common pathway for tryptophan biosynthesis, and a candidate tryptophan uptake system was assigned to the core genome. Even at this early stage, our comparative genomic analyses have provided new opportunities for interventions that can be evaluated to enhance the restoration and/or persistence of *F. prausnitzii* in the human gut, which may be critical for translating this bacterium from a "friend in need" to a "friend in deed", that counteracts dysbiosis with clinical benefits.

Keywords: IBD, *Faecalibacterium prausnitzii,* genomics, carbohydrate active enzymes, ecological fitness

Towards understanding and predicting dietary responsiveness of the gut microbiota and the host

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There is growing interest to understand how diet affects the intestinal microbiota and how this translates to host health. One of the major challenges in the field is the high individuality of the microbiota composition and its individual-specific dietary responses. Similarly, the high variation of host responses is a challenge especially in human nutritional research and practise. We have started to study the microbiological basis of the individual dietary responses by using a deep community-wide microbiota analysis before and after dietary interventions. We and others have shown that categorization of the study subjects to dietary responders and non-responders allows identification of baseline microbiota features that are specific to responders, both in terms of the microbiota and most importantly, of the anticipated host parameters, such as metabolic health markers or gastrointestinal symptoms. If such predictive microbiota signatures can be validated in further studies, they will provide a radically new way to understand diet-microbiota-health trialogue and further use this knowledge as a basis for tailored nutrition.