Nutrition Influences the Health of Dairy Calves

Michael A. Ballou, Ph.D.[1]
Associate Dean for Research and
Associate Professor of Nutritional Immunology
Texas Tech University
College of Agricultural Sciences and Natural Resources
Department of Animal and Food Sciences
[1]Contact at: Goddard Building, Suite 108, MS 42123, Lubbock, Texas 79409
P: 806.834.6513, F: 806.742.2836, Email: michael.ballou@ttu.edu

Take home messages

- Dairy calves are highly susceptible to enteric disease during the first few weeks of life as the gastrointestinal tract matures.
- Probiotics, prebiotics, and protein from either hyper-immunized egg or plasma can improve enteric health during the first few weeks of life.
- Calves can digest, absorb, and utilize the additional protein and energy early in life when fed greater quantities of milk replacer.
- The risk for some enteric diseases may be greater among calves fed greater quantities of milk replacer early in life.
- In contrast to early life, feeding greater quantities of milk replacer could improve post-weaning health.

Abstract

Dairy calves are extremely susceptible to gastro-intestinal disease during the pre-weaned period. The risk for enteric disease decreases as the calf ages; therefore, it is important to break the pre-weaned period up into at least two distinct phases that likely need to be managed differently, early life (first couple weeks of life) and the remaining time the calf is fed milk or milk replacer. When a calf is born they have been exposed to very few if any microorganisms and some aspects of their gastrointestinal immune system are not fully developed. After birth, the calf is now in a microbial world and exposed to a greater quantity and diversity of microorganisms. This adaptation is abrupt and dramatic and is a major stressor to a newborn calf. The gastrointestinal tract of the calf is naïve and develops rapidly during the first few days to weeks of life. The cells that make up the gastro-intestinal tract are the first line of defense of the immune system; therefore, until the cells are more adult-like the calf maybe at an increased risk for developing gastro-intestinal diseases. My laboratory recently tested the hypothesis that feeding greater quantities of milk solids during the first week of life would increase the percentage of dietary nutrients that were neither digested nor absorbed by the calf, which would increase the risk of scours. The data indicated that dairy calves during the first few weeks of life digest and absorb nutrients well, and when fed a greater plane of nutrition the

additional nutrients were incorporated into tissue growth. However, the increased absorption of nutrients among calves fed greater quantities of milk replacer may increase the risk for enteric disease (Liang et al., unpublished). A group of calves were challenged with an opportunistic enteric pathogen, *Citrobacter freundii*, at 10 days of life and the calves fed the greater plane of milk solids had greater rectal temperatures (P = 0.021) and numerically greater peak concentrations of plasma haptoglobin after the challenge (511 versus 266 ± 107.9 μg/mL; P = 0.118). The greater clinical response among the calves fed the greater plane of nutrition could be due to the numerically greater ileal mucosal height (921 versus 752 ± 59.1 μm; P=0.059). Our data also indicated that calves fed greater planes of nutrition had increased fecal scores, but when the dry matter percentage was determined there were no differences. This suggests that fecal scores alone are inadequate as a measure of enteric health, especially when evaluating various planes of nutrition. Others have reported that calves fed greater quantities of milk and challenged with *Cryptospporidium parvum* had reduced duration of scours and improved hydration (Ollivett et al., 2012). More data are needed to further investigate the mechanisms underlying this altered response to infectious diseases and understand how early life plane of nutrition influences gastro-intestinal disease during that early life period. In addition, an interesting area of research is that the plane of nutrition of calves during the pre-weaned period improved future lactational performance, and emerging data is suggesting that it may also improve the resistance to some diseases that persists past the pre-weaned period (Ballou et al., JDS *In Press*; Sharon and Ballou, unpublished). Calves that were previously fed a greater plane of milk replacer nutrition had greater leukocyte responses after they were challenged orally with *Salmonella enterica* Serotype Typhimurium and subsequently had reduced measures of disease (Ballou et al., JDS *In Press*). Similarly, another group of calves that were previously fed a greater plane of milk replacer nutrition had reduced mortality and less clinical disease after they were challenged approximately a month after weaning with both bovine herpes virus-1 and *Mannheimia haemolytica* (Sharon and Ballou, unpublished). More research is needed in this area before any conclusions should be made. In addition to plane of nutrition, the primary strategy to improve the resistance to gastro-intestinal diseases during early life is focused on decreasing the interaction of potential pathogens with the cells of the calf's gastro-intestinal tract. The uses of prebiotics, probiotics, hyper-immunized egg protein, and spray-dried plasma proteins were in many cases shown to decrease the incidence of gastro-intestinal diseases and improve the growth of pre-weaned calves. In summary, nutrition influences leukocyte responses and disease resistance of calves in many ways, both directly by supplying specific nutrients and indirectly by influencing the exposure to microorganisms. Again, I think it is important that we think about the pre-weaning period as two distinct phases that need to be managed differently, the first couple weeks while the gastrointestinal tract is maturing, and the remaining of time the calf is fed fluid.
Keywords: Calf, Health, Housing, Immune, and Nutrition

Introduction

It is well documented that dairy calves are extremely susceptible to enteric diseases and mortality during the first few weeks of life. The latest reports from the USDA's National Animal Health and Monitoring System (NAHMS, 1993; 1996; 2007) report that the national mortality rate of heifer calves from 48 hours of life to weaning is approximately 7.8 to 10.8%. Producer perceived records indicate that scours account for 56.5 to 60.5% of all pre-weaned deaths. Approximately one-fourth of all pre-weaned calves are therapeutically treated for scours, and the major causes of death from scours are either dehydration or the pathogen gains access to the blood and causes septicemia. The high incidences of disease indicate we have much to learn about improving gastro-intestinal disease resistance among pre-weaned calves. Colostrum management, how much and the composition of fluid fed, the use of various additives such as prebiotics, probiotics, and proteins from hyper-immunized egg or plasma proteins, and housing can all influence the health of pre-weaned dairy calves. In addition, there are a few data that indicate that early life nutrition can have long-term impacts on leukocyte responses and disease resistance (Ballou, 2012; Ballou et al., JDS *In Press*; Sharon and Ballou, unpublished). There is a high incidence of respiratory disease among dairy calves and it is the main contributor to the high death losses, 1.8%, after weaning (NAHMS, 2007). This is an exciting area of research that needs to be addressed further.

Why are calves so susceptible to gastro-intestinal disease?

The calf is in a bit of a 'catch-22' situation early in life because it requires the passive absorption of many macromolecules from colostrum and milk, but this also increases the risk of translocation of pathogenic microorganisms. The gastrointestinal tract of many neonates undergoes a rapid maturation after parturition, and the timing of this depends largely on the species of interest. There are large gaps in our knowledge regarding how the gastrointestinal tract of a calf changes early in life; however, using gastrointestinal morbidity/mortality risk as an indirect measurement, the maturation occurs quite rapidly over the first few weeks of life. There are many components to the gastrointestinal immune system (Figure 1). Most of my discussion in this section was derived from animal models other than the calf, but the general principles can still be applied to the calf.

The epithelial cells that make up the mucosal surface and the tight junctions between those cells form a **physical barrier** that prevents luminal contents from flowing directly into systemic circulation. A breakdown in the tight junctions increases the likelihood of infectious disease because of increased bacterial translocation. Goblet cells are one of the types of epithelial cells found in the gastrointestinal tract, and they produce mucus that creates a layer that covers most of the intestinal epithelium. This mucus layer forms an additional physical barrier against potential enteric pathogens. Additionally, the mucus layer contains many antimicrobial factors that were secreted from immune cells in the intestinal mucosa. These antimicrobial factors include: defensins, lysozyme, and sIgA, and their function is to limit the interactions of live microorganisms with epithelial cells by creating a **chemical barrier**. Many leukocytes are found in the mucosa of the gastrointestinal tract as well as large lymphoid aggregates are localized in the submucosa of the distal region of the small intestines. These leukocytes contribute to the **immunological barrier** of the gastrointestinal tract. The majority of leukocytes found in the gastrointestinal (sub)mucosa contribute to adaptive immune responses and create memory that will help to prevent subsequent infections. Macrophages are found in the mucosa and could be involved in the clearance of some microorganisms, but neutrophils are rarely found in the mucosa and are only present in a pathologic state. Trillions of commensal microorganisms live in the gastrointestinal tract and they have a symbiotic relationship with the calf. These commensal microorganisms are part of a **microbial barrier** that limits the colonization of the gastrointestinal epithelium with more potentially pathogenic microorganisms. These commensal microorganisms compete directly for substrates and space with the potentially pathogenic microorganisms and many of them produce antimicrobial factors and stimulate mucus production that further restrict potential pathogens from infecting the calf. These barriers work together to create a competent **Immune System** of the gastrointestinal tract. A defect in any of these components can increase the risk for infectious disease.

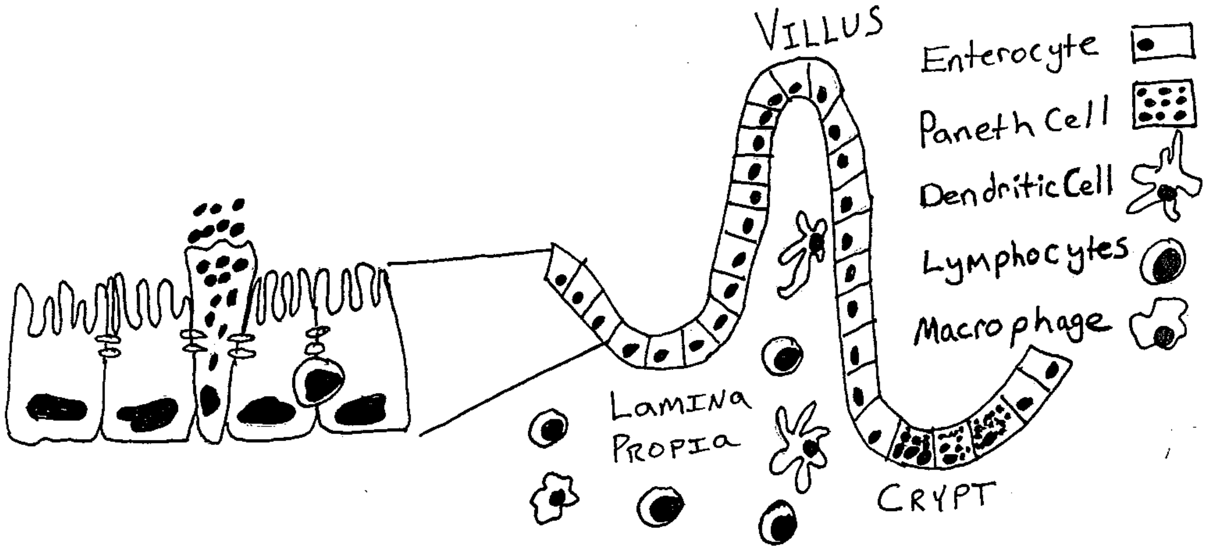


Figure 1. Schematic drawing of the small intestinal mucosa. The crypt-villus axis and common leukocytes found in the mucosa are shown on the right. The insert on the left is a magnification of the epithelial layer, depicting microvilli, tight junctions between epithelial cells, a goblet cell secreting mucus, and an intraepithelial lymphocyte.

Many of the components of the gastrointestinal immune system begin to develop as early as the first trimester of gestation; however, further maturation of many of these barriers occurs only after birth (Guilloteau et al., 2009). This process of rapid intestinal maturation is known as “gut closure” and contributes to the **physical barrier**. The enterocytes, the nutrient absorptive cells that make up the majority of cells in the intestinal epithelium, are considered fetal-type at birth because they are largely vacuolated and can absorb intact macronutrients through pinocytosis. These fetal-type enterocytes are quickly replaced by more adult-like enterocytes. This process occurs from the proximal to distal intestines and from the crypt to the villus tip; therefore, even though the majority of the gastrointestinal tract may have undergone “gut closure” in the day and a half after birth there likely persist vacuolated, fetal-type enterocytes toward the villus tip of the lower regions of the intestines for a longer period of time. In addition to transcellular absorption of macromolecules, the gastrointestinal epithelium may also be more prone to paracellular absorption because of reduced tight junctions between the enterocytes. The mucus layer that covers the intestinal epithelium is dynamic and cannot be studied with traditional histological methods; therefore, very little is known regarding the postnatal changes in the mucus layer. Goblet cells respond to microbial exposure by increasing mucus secretion; therefore, it is conceivable that the mucus layer develops further during the post-natal period. Intestinal motility and the movement of digesta through the gastrointestinal tract can also reduce colonization of potentially pathogenic microorgansims, so a reduced intestinal motility can also contribute to the high incidence of enteric disease. Therefore, the **physical barrier** of the intestines is compromised during the early post-natal period and likely contributes to the high incidence of enteric disease and bacterial translocation.

The **chemical and immunological barriers** are also compromised during the early post-natal period. Paneth cells begin to develop during gestation; however, the number of Paneth cells and the antimicrobial secretions increase throughout life. Additionally, the adaptive arm of the immune system is naïve at birth and develops over the life of the animal as the calf is exposed and re-exposed to antigens. Therefore, sIgA concentrations and diversity are low and will remain low until the calf begins to develop its own active immunity. Antibodies from colostrum are known to recirculate back to the mucosa of the intestines, and can offer some immediate protection from enteric pathogens; however, the half-life of many passively derived antibodies is one to two weeks. Therefore, the gastrointestinal tract will become more susceptible to those specific microorganisms again until they develop their own active immunity against them. This is probably why many calves start developing localized enteric disease and scours during the 2nd or 3rd week of life. The fact is young animals will always be at an increased risk for infectious diseases until they develop their own active immunity. It's one of the benefits of getting older, the adaptive arm of the immune system becomes 'wiser' because of what it has been exposed to and experienced.

The calf *in utero* is developing in a relatively sterile environment and upon parturition and during the post-natal life they are exposed to a greater number and diversity of microorganisms. There is a progression in the microbial colonization of the gastrointestinal tract, with facultative anaerobes from the environment (ie: *Enterobacteriaceae*, *Streptococcus*, and *Staphylococcus)* dominating during the early post-natal period. There will be a switch to where strict anaerobes (ie: *Bifidobacterium*, *Bacteroides*, *Lactobacilli*, and *Clostridia*) will dominate and account for greater than 99% of the bacteria in the intestines for the rest of the animal's life. Therefore, the **microbial barrier** of the gastrointestinal tract is also compromised during early life and likely contributes to the greater incidence of enteric disease.

Therefore, from a systematic perspective, there are many holes in the gastrointestinal immune system defense during the early post-natal life. This greatly increases the relative risk for enteric disease. It is well known that what an animal is fed during the neonatal period will influence the development of the gastrointestinal immune system and enteric disease resistance. It should be noted that a lot more basic research on the development of the post-natal gastrointestinal immune system in calves is needed and should be a research priority.

Maturation of the gastrointestinal immune system and preventing pathogen-host interactions

A common management strategy in the dairy industry is to feed approximately 4L of colostrum within the first 6-12 hours of birth. Then calves are switched to either milk or milk replacer. It is well known that bioactive compounds in colostrum and transition milk directly influence the maturation of the gastrointestinal immune system. Our current colostrum management protocols are designed to ensure as many calves as possible get adequate passively derived immunoglobulins as possible. I don't want to down play the importance of passive transfer of immunoglobulins because it is essential in preventing systemic and local enteric diseases while the gastrointestinal tract matures; however, current colostrum management programs completely ignore the role that colostrum and transition milk play in the maturation of the intestinal immune system. Enteric disease would likely be reduced if we fed calves to hasten the maturation of the gastrointestinal immune system. Most of our management decisions after feeding colostrum are aimed at reducing the interaction of potentially pathogenic microorganisms with the intestinal epithelial cells.

Prebiotics, probiotics, and proteins from hyper-immunized egg or spray-dried plasma all have shown some merit in improving the resistance to enteric disease. Prebiotics are dietary components that are not easily digested by the calf, but are used by bacteria in the lower intestines to improve their growth. Probiotics are a vague term, but generally are live microorganisms that provide ‘some’ health benefit. At first glance this may seem bad, why would we want to improve the growth of bacteria in the lower intestines? As mentioned before, the intestinal tract is not sterile. Soon after birth, a wide range of bacterial species colonizes the gastro-intestinal tract of calves. Most of these bacterial species do not pose any immediate threat to the survival of the calf and in the past were called “good bacteria” and, of which, many of the common probiotic species are routinely classified as, including: *lactobaccilus* species, *bifidobacteria*, *Enterocooccus faecium*, and *Bacillus* species. Remember that the microbial barrier of the intestinal tract soon after birth is colonized primarily by facultative anaerobes and subsequently becomes inhabited largely by strict anaerobes. Most of the probiotic microorganisms are strict anaerobes. Many of the probiotic species also have a direct bactericidal activity or compete with the more pathogenic microorganisms for limited resources. In addition, probiotics are themselves bacteria and they may “prime” the immune system of the calf by staying alert, as even the immune system recognizes the “good” bacteria as foreign. The common, commercially-available prebiotics available are the fructooligosaccharides (FOS), mannanoligosaccharides (MOS), lactulose, and inulin.

Data on the influence of prebiotics and probiotics alone on the health of dairy calves is equivocal. There are data that show improvements in reducing scouring and improving growth (Abe et al., 1995), whereas equally as many studies show no benefits to including either prebiotics or probiotics in milk (Morrill et al., 1995). The lack of a clear effect in calves is likely due to many environmental factors. Research does however support that many prebiotics and probiotics are generally safe and do not have any adverse effects on calf health of performance. In fact, most regulatory agencies around the world classify most prebiotics and probiotics as Generally Regarded As Safe (GRAS). Lastly, it is important to note that not all probiotic species and further, not all strains of a specific species, ie: not all *Lactobaccilus acidophilus* strains, behave similarly. Therefore, I would recommend only using probiotic species and strains that have been reported, through 3rd party research, to improve health and performance of calves. Additionally, viability/stability of the product should be confirmed as many of the probiotic species can become nonviable during processing and storage.

Another strategy to reduce the interaction of pathogenic microorganisms is to feed egg protein from laying hens that were vaccinated against the very microorganisms that cause gastro-intestinal diseases in calves. The laying hens will produce immunoglobulins (IgY) and concentrate those proteins in their eggs, which can recognize the pathogen, bind to it, and prevent its interaction with a calf’s gastro-intestinal tract. Inclusion of whole dried egg from these decreased the morbidity due to various bacteria and viruses. In addition to the use of hyper-immunized egg protein, spray-dried plasma proteins can improve gastro-intestinal health of calves. Spray-dried plasma is exactly like it sounds, plasma that is spray-dried to preserve the functional characteristics of the diverse group of proteins in plasma. The use of spray-dried plasma has been used for many years in the swine industry to improve the performance and health during the post-weaned period. The addition of spray-dried plasma proteins in milk replacer reduced enteric disease in calves (Quigley et al., 2002).

In 2010, my lab evaluated the effects of supplementing a blend of prebiotics, probiotics, and hyper-immunized egg proteins to Holstein calves from immediately after birth through the first three weeks of life (Ballou, 2011). Calves given the prophylactic treatment (n=45) were administered directly into the milk 5×10^9 colony forming units per day (from a combination of *Lactobacillus acidophilus*, *Bacillus subtilis, Bifidobacterium thermophilum, Enterococcus faecium,* and *Bifidobacterium longum*), 2 grams per day of a blend of MOS, FOS and charcoal, and 3.2 grams per day of dried egg protein from laying hens vaccinated against K99+ *Escherichia coli* antigen, *Salmonella typhimurium*, *Salmonella Dublin*, coronavirus, and rotavirus. Control calves (n=44) were not given any prebiotics, probiotics, or dried egg protein. All calves were fed 2 Liters of a 20% protein / 20% fat, non-medicated milk replacer twice daily. Prior to each feeding fecal scores were determined by 2 independent trained observers according to Larson et al. (1977). Briefly 1 = firm, well-formed; 2 = soft, pudding-like; 3 = runny, pancake batter; and 4 = liquid splatters, pulpy orange juice. The prophylactic calves refused less milk (P<0.01) during the first 4 days of life (57 vs 149 grams of milk powder). There were no differences in starter intake or average daily gain due to treatments. However, calves that received the prophylactic treatment had decreased incidence of scours (P<0.01) during the first 21 days of life (25.0 vs 51.1%). Scours were classified as a calf having consecutive fecal scores ≥ 3. The intensity of disease in this study was low and only 1 out of 90 calves died during the experiment. These data support the hypothesis that a combination of prebiotics, probiotics, and hyper-immunized egg protein can improve gastro-intestinal health and could be an alternative to metaphylactic antibiotic use. Future research should determine the efficacy of that prophylactic treatment in calves that are at a higher risk of developing severe gastro-intestinal disease and subsequently death as well as investigate the mechanism(s) of action within the gastrointestinal immune system.

Plane of nutrition

The interest in the plane of nutrition that calves are fed during the pre-weaned period has increased primarily because data indicate that calves fed a greater plane of nutrition have decreased age at first calving and they may have improved future lactation performance (Soberon et al., 2012). More large prospective studies in various commercial settings should confirm that calves fed greater planes of nutrition during the pre-weaned period have improved future lactation performance. Most data on how plane of nutrition influences the health of calves during the first few weeks of life is limited to small, controlled experiments with fecal scores as the primary outcome variable (Nonnecke et al., 2003; Ballou, 2012). Many studies observed that the calves fed the greater plane of nutrition had more loose feces or greater fecal scores (Nonecke et al., 2003; Bartlett et al., 2006; Ballou et al., In Press JDS), while others reported no differences in fecal scores (Ballou, 2012; Obeidat et al., 2013). It is important to note, that no study has reported greater fecal scores among calves fed a lower plane of nutrition when compared to calves fed a greater plane of nutrition. It has been suggested that the greater fecal scores were not due to a higher incidence of infection or disease, but may be associated with the additional nutrients consumed. A couple of recent studies from my lab are confirming that calves fed greater quantities of milk solids early in life have greater fecal scores; however, when the dry matter percentage of the calves feces were determined there were no differences between calves fed differing quantities of milk solids (Liang and Ballou, unpublished).

It was unknown whether the digestibility of nutrients of calves fed varying planes of nutrition would differ during the first week of life. Decreased nutrient digestibility would likely increase the risk of enteric disease because the increased supply of nutrients to the lower gastro-intestinal tract could provide a more favorable environment for pathogenic microorganisms to thrive. My lab recently tested the hypothesis that feeding a higher plane of nutrition during the first week of life would decrease the percentages of dietary nutrients that were digested and absorbed (Liang and Ballou, unpublished). Our justification for this hypothesis was that the reduced plane of nutrition during the first week of life would allow the gastro-intestinal tract time to adapt to enteric nutrition, without overwhelming the system. However, after conducting a digestibility trial with Jersey calves during the first week of life we had to reject that hypothesis. In fact, there was no difference in the percentage of intake energy that was captured as metabolizable energy, averaging 88% across treatments for the first week of life. We separated the first week of life up into 2 three-day periods and observed a tendency (P=0.058) for more of the intake energy to be captured as metabolizable energy during the 2nd period (85.9 versus 91.2 ± 2.0; 1st and 2nd period, respectively); however, the first period was likely underestimated because residual meconium feces would decrease the apparent digestibility. There was a treatment x period interaction (P=0.038) on the percentage of dietary nitrogen that was retained. The calves fed the greater plane of nutrition had improved nitrogen retention during the first period (88.0 versus 78.7 ± 1.20; P=0.004), but was not different from calves fed the reduced plane of nutrition during the second period (85.3 versus 85.0 ± 1.20; P=0.904). Most of the difference in nitrogen retention during the first period could be explained by differences in apparent nitrogen digestibility. It should be noted that apparent digestibility was likely more underestimated among the calves fed the restricted milk replacer during the first period because an equal quantity of meconium feces collected across the treatments during period 1 would underestimate the calves fed the restricted quantity of milk replacer more. The data from the digestibility study indicate that calves not only tolerate greater quantities of milk during the first week of life, but they incorporate those nutrients into lean tissue growth. The gastrointestinal immune system and implications to enteric health should further be investigated.

Over the past 7 years, my laboratory has conducted research to better understand the how plane of nutrition during the pre-weaned period influences leukocyte responses and resistance to infectious disease during the pre- and immediate post-weaned periods (Ballou, 2012; Obeidat et al., 2012; Ballou et al., In Press, JDS; Liang and Ballou, unpublished; Sharon and Ballou, unpublished). The results indicate that plane of nutrition influences leukocyte responses of calves (Ballou, 2012; Obeidat et al., 2013; Ballou et al., In Press, JDS). In two studies, we reported that when calves were fed a lower plane of nutrition their neutrophils were more active during the pre-weaned period, as evident by increased surface concentrations of the adhesion molecule L-selectin (Figure 1) and a greater neutrophil oxidative burst (Obeidat et al., 2013; Ballou et al., In Press, JDS). After weaning the elevated neutrophil responses were no longer apparent in either of those studies. The exact mechanisms for the more active neutrophils among the low plane of nutrition calves are not known, but could be due to increased microbial exposure because of increased non-nutritive suckling, altered microbial ecology of the gastrointestinal tract, or reduced stress among the calves fed the low plane of nutrition. If the neutrophils are more active because of increased microbial exposure, calves fed a lower plane of nutrition could be at an increased risk for disease during the pre-weaned period if exposed to more virulent pathogens. Ongoing research in my laboratory is trying to understand the behavior and potential microbial exposure when calves are fed varying planes of nutrition and its influence on risk for enteric disease and immunological development. In fact, a few studies have shown that plane of nutrition during the pre-weaned period influence adaptive leukocyte responses. Pollock et al. (1994) reported that antigen-specific IgA and IgG_2 were reduced when calves were fed more milk. In agreement, Nonnecke et al. (2003) reported that less interferon-γ was secreted when peripheral blood mononuclear cells were stimulated with T-lymphocyte mitogens. However, not all data indicate that adaptive leukocyte responses are reduced when greater quantities of milk are fed; Foote et al. (2007) did not observe any difference in either the percentage of memory CD4+ or CD8+ T lymphocytes or antigen-induced interferon-γ secretion. All the leukocyte response data taken together suggest that calves fed lower planes of nutrition may have more active innate leukocyte responses driven by increased microbial exposure, which may explain the greater adaptive leukocyte responses. In a relatively sanitary environment this increased microbial exposure may improve adaptive immune development in the absence of clinical disease, but in a dirty environment it would likely increase the risk of enteric disease.

How plane of nutrition influences resistance to enteric disease is even less clear than how the leukocyte responses are affected. Quigley et al. (2006) reported that feeding a variable, greater plane of nutrition to high-risk Holstein bull calves, purchased from a sale barn and raised on bedding contaminated with coronavirus, increased the number of days calves had scours by 53% and also increased the number of days calves received antibiotics, 3.1 versus 1.9 days. In contrast, a more recent study reported that calves fed a greater plane of nutrition had improved hydration and fecal scores improved faster when they were challenged with *Cryptosporidium parvum* at three days of age (Ollivett et al., 2012). In a recent study from my lab, we orally challenged calves fed either a restricted plane or a greater plane of milk replacer at 10 days of age with an opportunistic pathogen, *Citrobacter freundii* (Liang and Ballou, unpublished). The calves fed the greater plane of nutrition had a greater clinical response to the challenge as evident by increased rectal temperatures (P = 0.021) and numerically greater peak plasma haptoglobin concentrations (511 versus 266 ± 108 μg/mL; P = 0.118). There also was a tendency for total mucosal height of the ileum to be increased among calves fed the greater plane of nutrition (921 versus 752 ± 59.1 μm; P = 0.059). The increased surface area of the lower gastrointestinal tract could partially explain the increased clinical response among the calves fed the greater planes of nutrition. Current data indicate that their likely is a pathogen:host interaction on the effects that plane of nutrition influence enteric disease resistance. Larger data sets with naturally occurring disease incidence and more experimentally controlled relevant disease challenges that are focused on the gastrointestinal immune system are needed before definitive conclusions on the role that plane of nutrition plays on enteric health of calves during the first few weeks of life. However, current data do not support that feeding greater planes of nutrition during the first few weeks of life are going to dramatically reduce enteric disease, so if you hear, “We have high incidences of disease and death in dairy calves because we restrict the quantity of milk they are fed” this is likely not true.

In contrast to health during the first few weeks of life, the plane of nutrition calves are fed during the pre-weaned period seems to be influence leukocyte responses and disease resistance among calves after they are weaned (Ballou, 2012; Ballou et al., In Press, JDS; Sharon and Ballou, unpublished). Jersey bull calves that were fed a greater plane of fluid nutrition had improved neutrophil and whole blood *E. coli* killing capacities after they were weaned when compared to Jersey calves fed a more conventional, low plane of nutrition (Ballou, 2012). These effects were only observed among the Jersey calves in this study and not the Holstein calves. In a follow-up study, Jersey calves that were previously fed a greater plane of milk replacer had a more rapid up-regulation of many leukocyte responses, including neutrophil oxidative burst and the secretion of the pro-inflammatory cytokine tumor necrosis factor-α, after they were challenged with an oral bolus of 1.5×10^7 colony-forming units of a *Salmonella enterica* serotype *Typhimurium* (Ballou et al., In Press, JDS). The increased activation of innate leukocyte responses among the calves previously fed the greater plane of nutrition calves reduced (P=0.041) the increase in plasma haptoglobin and those calves also had greater concentrations of plasma zinc. The calves fed the greater plane of nutrition also had improved intake of calf starter beginning 3 days after the challenge (P = 0.039). These data indicate that the Jersey calves previously fed a greater plane of nutrition had improved disease resistance to an oral *Salmonella typhimurium* challenge approximately a month after weaning.

Recently, my lab recently completed a viral-bacterial respiratory challenge on calves a month after weaning that were previously fed either a restricted quantity or a greater plane of milk replacer (Sharon and Ballou, unpublished). Each calf was challenged intranasal with $1.5x10^8$ plaque forming units of bovine herpes virus-1 per nostril and 3 days later were given either 10^6, 10^7, or 10^8 colony forming units of *Mannheimia haemolytica* intratracheal in 50 mL of sterile saline (n=5 per plane of nutrition and bacteria dose combination; N=30). Calves were observed for 10 days after the *Mannheimia haemolytica* challenge. The bovine herpes virus-1 challenge decreased calf starter intake by 21.2% in both planes of nutrition treatments. The *Mannheimia haemolytica* challenge further decreased calf starter intake, but again was not different between planes of nutrition (7.6%). All calves survived the entire observation period, but 2 calves were euthanized (were completely anorexic and did not respond to antimicrobial / anti-inflammatory treatments) 2 days after the end of the observation period and 2 calves died within a week of completing the observation period. All calves that died or were euthanized were previously fed the restricted plane of nutrition (1, 2, and 1 calves challenged with 10^6, 10^7, or 10^8 *Mannheimia haemolytica*, respectively). Necropsies of all four calves were consistent with severe pneumonia. Hematology and plasma data during both challenges indicated that calves previously fed the restricted quantity had a greater clinical response as evident by greater percentages of neutrophils in peripheral circulation (P=0.041) and plasma haptoglobin concentrations ($P \leq 0.097$). Therefore, the calves previously fed the restricted quantities of milk replacer had a more severe response to the combined viral-bacterial respiratory challenge, and the response was relatively independent of the *Mannheimia haemolytica* dose.

Therefore, the three studies from my lab are promising that early plane of milk replacer nutrition can influence the health of dairy calves within one month of weaning. Further, it appears that both enteric and respiratory health is improved with feeding greater planes of nutrition during the pre-weaned period. As was noted for enteric health during the pre-weaned period, larger data sets with naturally occurring disease and additional experimentally controlled challenges with leukocyte responses are needed before definitive conclusions can be draw. Further, it is of interest whether or not the improved health observed within one month of weaning would persist later into life and improve resistance to other diseases that are common during the life cycle of dairy cattle, including: gastro-intestinal, respiratory, metritis, and mastitis.

Implications

Dairy calves are extremely susceptible to disease in the first few weeks of life, which may be related to the naïve gastrointestinal immune system of calves. Increasing the plane of nutrition in the first week or two appears to increase fecal scores, although the dry matter percentages of the feces were not different. Additionally, the digestibility of nutrients during the first week of life is great and does not appear to be impaired by feeding a greater quantity of milk replace solids. However, resistance to enteric disease during the first few weeks of life does appear to be influenced by plane of nutrition, but more data are needed before more definitive conclusions can be made. Some early data are suggesting that feeding a greater plane of nutrition during the pre-weaned period may improve leukocyte responses and disease resistance of calves that extends beyond the pre-weaned period, but as with the effects of plane of nutrition on risk for enteric disease, more data are needed before we fully understand how early life plane of nutrition influences disease resistance later in life.

In addition to plane of nutrition, the uses of prebiotics, probiotics, and proteins from hyper-immunized egg or spray-dried plasma were all shown to reduce the incidence of gastro-intestinal disease. If you have a high early mortality I would recommend you look into using a research-backed product with prebiotics, probiotics, or proteins from hyper-immunized egg or spray-dried plasma.

Acknowledgements

Many current and past graduate students and visiting scientists have helped collect most of the data presented in this paper. I would like to thank Clayton Cobb, Dr. Lindsey Hulbert, Yu Liang, Dr. Belal Obeidat, Tyler Harris, Matthew Sellers, Dr. Amanda Pepper-Yowell, Devin Hansen, and Kate Sharon. I would also like to acknowledge that some of this work was conducted in collaboration with Dr. Jeff Carroll with the USDA-ARS Livestock Issues Research Unit located in Lubbock, TX. I appreciate our collaboration and would like to thank his lab group for all their hard work, especially Jeff Dailey.

Literature cited

Abe, F., N. Ishibashi, and S. Shimamura. 1995. Effect of administration of Bifidobacteria and Lactic Acid Bacteria to newborn calves and piglets. J. Dairy Sci. 78:2838-2848.

Ballou, M.A. 2011. Case Study: Effects of a blend of prebiotics, probiotics, and hyperimmune dried egg protein on the performance, health, and innate immune responses of Holstein calves. Prof. Anim. Sci. 27:262-268.

Ballou, M.A. 2012. Immune responses of Holstein and Jersey calves during the preweaning and immediate postweaned periods when fed varying planes of milk replacer. 95:7319-7330.

Ballou, M.A., D.L. Hanson, C.J. Cobb, B.S. Obeidat, T.J. Earleywine, J.A. Carroll, M.D. Sellers, and A.R. Pepper-Yowell. 2014. Plane of nutrition influences the performance, innate leukocyte responses, and the pathophysiological response to an oral *Salmonella typhimurium* challenge in Jersey calves. *In Press, J. Dairy Sci*

Bartlett, K. S., F. K. McKeith, M.J. VandeHaar, G.E. Dahl, and J.K. Drackley. 2006. Growth and body composition of dairy calves fed milk replacers containing different amounts of protein at two feeding rates. J. Anim. Sci. 84:1454-1467.

Foote, M. R., B. J. Nonnecke, D. C. Beitz, and W. R. Waters. 2007. High growth rate fails to enhance adaptive immune responses of neonatal calves and is associated with reduced lymphocyte viability. J. Dairy Sci. 90:404-417.

Guilloteau, P., R. Zabielski, J.W. Blum. 2009. Gastrointestinal tract digestion in the young ruminant: ontogenesis, adaptations, consequences and manipulations. J. Physiol. Pharmacol. 60:37-46.

Morrill, J. L., J. M. Morrill, and A. M. Feyerherm. 1995. Plasma proteins and a probiotic as ingredients in milk replacer. J. Dairy Sci. 78: 902-907.

National Animal Health Monitoring System. 1993. Dairy heifer morbidity, mortality, and health management focusing on preweaned heifers. Ft. Collins, CO: USDA:APHIS:VS.

National Animal Health Monitoring System. 1996. Part 1: Reference of 1996 Dairy Management Practices. Ft. Collins, CO: USDA:APHIS:VS.

National Animal Health Monitoring System. 2007. Dairy 2007: Heifer calf health and management practices on U.S. dairy operations, 2007. Ft. Collins, CO:USDA:APHIS:VS.

Nonnecke, B. J., M.R. Foote, J.M. Smith, B.A. Pesch, and M.E. Van Amburgh. 2003. Composition and functional capacity of blood mononuclear leukocyte populations from neonatal calves on standard and intensified milk replacer diets. J. Dairy Sci. 86:3592-3604.

Obeidat, B.S., C.J. Cobb, M.D. Sellers, A.R. Pepper-Yowell, T.J. Earleywine, and M.A. Ballou. 2013. Plane of nutrition during the preweaning period but not the grower phase influences the neutrophil activity of Holstein calves. J. Dairy Sci. 96:7155-7166.

Ollivett, T.L., D.V. Nydam, T.C. Linden, D.D. Bowmann, and M.E. Van Amburgh. 2012. Effect of nutritional plane on health and performance in dairy calves after experimental infection with Cryptosporidium parvum. J. Am. Vet. Med. Assoc. 241:1514-1520.

Pollock, J. M., T. G. Rowan, J. B. Dixon, and S. D. Carter. 1994. Level of nutrition and age at weaning: Effects on humoral immunity in young calves. Br. J. Nutr. 71:239-248.

Quigley, J.D., III, C.J. Kost, and T.A. Wolfe. 2002. Effects of spray-dried animal plasma in milk replacers or additives containing serum and oligosaccharides on growth and health of calves. J. Dairy Sci. 85:413-421.

Quigley, J.D., T. A. Wolfe and T. H. Elsassert. 2006. Effects of additional milk replacer feeding on calf health, growth, and selected blood metabolites. J. Dairy Sci. 89:207-216.

Soberon, F., E. Raffrenato, R.W. Everett, and M.E. Van Amburgh. 2012. Preweaning milk replacer intake and effects on long-term productivity of dairy calves. J. Dairy Sci. 95:783-793.

Notes:

Precision Dairy Monitoring Opportunities, Limitations, and Considerations

J.M. Bewley, R.A. Russell, K.A. Dolecheck, M.R. Borchers, A.E. Stone, B.A. Wadsworth, L.M. Mayo, and I-Ching Tsai
University of Kentucky
Lexington, KY, USA
jbewley@uky.edu

Abstract

Technologies are changing the shape of the dairy industry across the globe. In fact, many of the technologies applied to the dairy industry are variations of base technologies used in larger industries such as the automobile or personal electronic industries. Undoubtedly, these technologies will continue to change the way that dairy animals are managed. This technological shift provides reasons for optimism for improvements in both cow and farmer well-being moving forward. Many industry changes are setting the stage for the rapid introduction of new technologies in the dairy industry. Dairy operations today are characterized by narrower profit margins than in the past, largely because of reduced governmental involvement in regulating agricultural commodity prices. The resulting competition growth has intensified the drive for efficiency, resulting in increased emphasis on business and financial management. Furthermore, the decision-making landscape for a dairy manager has changed dramatically, with increased emphasis on consumer protection, continuous quality assurance, natural foods, pathogen-free food, zoonotic disease transmission, reduction of the use of medical treatments, and increased concern for the care of animals. Lastly, powers of human observation limit dairy producers' ability to identify sick or lame cows or cows in heat. Precision dairy management may help remedy some of these problems. Precision dairy management is the use of automated, mechanized technologies toward refinement of dairy management processes, procedures, or information collection. Precision dairy management technologies provide tremendous opportunities for improvements in individual animal management on dairy farms. Although the technological "gadgets" may drive innovation, social and economic factors dictate technology adoption success.

Introduction

Technologies are changing the shape of the dairy industry across the globe. This rapid introduction of new technologies should come as no surprise given the technological culture shift in every facet of our society. In fact, many of the technologies applied to the dairy industry are variations of base technologies used in larger industries such as the automobile or personal electronic industries. Undoubtedly, these technologies will continue to change the way that dairy animals are managed. This technological shift provides reasons for optimism for improvements in both cow and farmer well-being moving forward. Many industry changes are setting the stage for the rapid introduction of new technologies in the dairy industry. Across the globe, the trend towards fewer, larger dairy operations continues. Dairy operations today are characterized by narrower profit margins than in the past, largely because of reduced governmental involvement in regulating agricultural commodity prices. Consequently, small changes in production or efficiency can have a major impact on profitability. The resulting competition growth has intensified the drive for efficiency, resulting in increased emphasis on business and financial management. Furthermore, the decision-making landscape for a dairy manager has changed dramatically, with increased emphasis on consumer protection, continuous quality assurance, natural foods, pathogen-free food, zoonotic disease transmission, reduction of the use of medical treatments, and increased concern for the care of animals. Lastly, powers of human observation limit dairy producers' ability to identify sick or lame cows or cows in heat.

Precision Dairy Farming

Precision Dairy Farming is often used to describe many technologies aimed at improving dairy management systems. Bewley (2010) described Precision Dairy Farming as the use of technologies to measure physiological, behavioural, and production indicators on individual animals to improve management strategies and farm performance. Eastwood et al. (2004) defined Precision Dairy Farming as "the use of information technologies for assessment of fine-scale animal and physical resource variability aimed at improved management strategies for optimizing economic, social, and environmental farm performance." Spilke and Fahr (2003) stated that Precision Dairy Farming, with specific emphasis on technologies for individual animal monitoring, "aims for an ecologically and economically sustainable production of milk with secured quality, as well as a high degree of consumer and animal protection." With Precision Dairy Farming, the trend towards group management may be reversed, with focus returning to individual cows through the use of technologies (Schulze et al., 2007). Technologies included within Precision Dairy Farming range in complexity from daily milk yield recording to measurement of specific attributes (e.g. fat content or progesterone) within milk at each milking. The main objectives of Precision Dairy Farming are maximizing individual animal potential, early detection of disease, and minimizing the use of medication through preventive health measures. Precision Dairy Farming is inherently an interdisciplinary field incorporating concepts of informatics, biostatistics, ethology, economics, animal breeding, animal husbandry, animal nutrition, and engineering (Spilke and Fahr, 2003). The ideal Precision Dairy Farming technology explains an underlying biological process that can be translated into meaningful action with information readily available to the farmer and a reasonable return on investment. Additionally, the best technologies are flexible, robust and reliable and demonstrated to be effective through research and commercial demonstrations.

The list of Precision Dairy Farming technologies used for animal status monitoring and management continues to grow. Because of rapid development of new technologies and supporting applications, Precision Dairy Farming technologies are becoming more feasible. Many Precision Dairy Farming technologies, including daily milk yield recording, milk component monitoring (e.g. fat, protein and SCC), pedometers, automatic temperature recording devices, milk conductivity indicators, accelerometers for monitoring lying behaviour, rumination monitors, automatic oestrus detection monitors, and daily body weight measurements are already being utilized by dairy producers. Despite its seemingly simplistic nature, the power of accurate milk weights should not be discounted in monitoring cows, as it is typically the first factor that changes when a problem develops (Philpot, 2003). Other new Precision Dairy Farming technologies have been introduced to measure jaw movements, ruminal pH, reticular contractions, heart rate, animal positioning and activity, vaginal mucus electrical resistance, feeding behaviour, biological components (enzymes, antibodies or microorganisms), odour, glucose, acoustics, progesterone, individual milk components, colour (as an indicator of cleanliness), infrared udder surface temperatures, gain analysis and respiration rates. Unfortunately, the development of technologies tends to be driven by availability of a technology, transferred from other industries in market expansion efforts, rather than by need. Compared with some industries, the dairy industry is relatively small, limiting corporate willingness to invest extensively in development of technologies exclusive to dairy farms. Many Precision Dairy Farming technologies measure variables that could be measured manually, while others measure variables that could not have been obtained previously.

Realistically, the term "Precision Dairy" should not be limited to monitoring technologies. Perhaps a more encompassing definition of Precision Dairy Management is the use of automated, mechanized technologies for refinement of dairy management processes, procedures or information collection. This definition incorporates monitoring technologies, automated milking systems, automated calf feeding systems and precision feeding systems. Automated milking systems have already been widely adopted in Europe. Adoption rates in North America have increased in recent years. The introduction of robotic milking components to rotary parlours will increase mechanization of milking in larger farms in the near future. Automated calf feeding systems have created a paradigm shift in how to raise dairy calves. Despite initial concerns about increased disease transmission, the benefits to automated calf feeding seem to outweigh the drawbacks when managed properly. New options for monitoring total mixed ration delivery and consumption will also improve how lactating dairy animals are fed. This is a particularly important economic and social concern given increased feed prices and concern for dairy efficiency and greenhouse gas emissions.

Benefits

Perceived benefits of Precision Dairy Farming technologies include increased efficiency, reduced costs, improved product quality, minimized adverse environmental impacts, and improved animal health and well-being. These technologies are likely to have the greatest impact in the areas of health, reproduction and quality control (de Mol, 2000). Realized benefits from data summarization and exception reporting are anticipated to be higher for larger herds, where individual animal observation is more challenging and less likely to occur (Lazarus et al., 1990). As dairy operations continue to increase in size, Precision Dairy Farming technologies become more feasible because of increased reliance on less skilled labour and the ability to take advantage of economies of size related to technology adoption.

A Precision Dairy Farming technology allows dairy producers to make more timely and informed decisions, resulting in better productivity and profitability (van Asseldonk et al., 1999). Real time data can be used for monitoring animals and creating exception reports to identify meaningful deviations. In many cases, dairy management and control activities can be automated (Delorenzo and Thomas, 1996). Alternatively, output from the system may provide a recommendation for the manager to interpret (Pietersma et al., 1998). Information obtained from Precision Dairy Farming technologies is only useful if it is interpreted and utilized effectively in decision making. Integrated, computerized information systems are essential for interpreting the mass quantities of data obtained from Precision Dairy Farming technologies. This information may be incorporated into decision support systems designed to facilitate decision making for issues that require compilation of multiple sources of data.

Historically, dairy producers have used experience and judgment to identify outlying animals. While this skill is invaluable and can never be fully replaced with automated technologies, it is inherently flawed by limitations of human perception of a cow's condition. Often, by the time an animal exhibits clinical signs of stress or illness, it is too late to intervene. These easily observable clinical symptoms are typically preceded by physiological responses which are evasive to the human eye (e.g. changes in temperature or heart rate). Thus, by identifying changes in physiological parameters, a dairy manager may be able to intervene sooner. Technologies for physiological monitoring of dairy cows have great potential to supplement the observational activities of skilled herdspersons, which is especially critical as more cows are managed by fewer skilled workers (Hamrita et al., 1997). Dairy producers with good "cow sense" are the ones who will benefit the most from technology adoption. Those who view technologies as a way to do something they don't like to do are likely to struggle.

Adoption

The list of Precision Dairy Farming technologies used for animal status monitoring and management continues to grow. Despite widespread availability, adoption of these technologies in the dairy industry has been relatively sparse thus far (Gelb et al., 2001, Huirne et al., 1997). Perceived economic returns from investing in a new technology are always a factor influencing technology adoption. Additional factors impacting technology adoption include degree of impact on resources used in the production process, level of management needed to implement the technology, risk associated with the technology, institutional constraints, producer goals and motivations, and having an interest in a specific technology (Dijkhuizen et al., 1997, van Asseldonk, 1999). Characteristics of the primary decision maker that influence technology adoption include age, level of formal education, learning style, goals, farm size, business complexity, increased tenancy, perceptions of risk, type of production, ownership of a non-farm business, innovativeness in production, average expenditure on information, and use of the technology by peers and other family members. Research regarding adoption of Precision Dairy Farming technologies is limited, particularly within North America.

To remedy this, a five-page survey was distributed to all licensed milk producers in Kentucky (N=1074) on July 1, 2008. Two weeks after the first mailing, a follow-up postcard was mailed to remind producers to return the survey. On August 1, 2008, the survey was re-sent to producers who had not returned the survey. A total of 236 surveys were returned; 7 were omitted due to incompleteness, leaving 229 for subsequent analysis (21%). The survey consisted of questions covering general farm descriptive demographics, extension programming and decision-making behaviour. With regard to Precision Dairy Farming the following question was presented to survey participants: *"Adoption of automated monitoring technologies (examples: pedometers, electrical conductivity for mastitis detection) in the dairy industry has been slow thus far. Which of the following factors do you feel have impacted these modest adoption rates? (check ALL that apply)."* Data were entered into an online survey tool (KeySurvey, Braintree, MA). Statistical analyses were conducted using SAS® (Cary, NC). Surveys were categorized by herd size, production system, operator age and production level. Least squares means among categories were calculated for quantitative variables using the GLM procedure of SAS®. Statistical differences were considered significant using a 0.05 significance level using Tukey's test for multiple comparisons. For qualitative variables, χ^2 analyses were conducted using the FREQ procedure of SAS®. Statistical differences were considered significant at a 0.05 significance level.

Among the 229 respondents, mean herd size was 83.0 ± 101.8 cows and mean producer age was 50.9 ± 12.9. Reasons for modest adoption rates of Precision Dairy Farming technologies and dairy systems software are presented in Table 1. The reasons selected by the highest percentage of respondents were (1) not being familiar with technologies that are available (55%), (2) undesirable cost to benefit ratios (42%) and (3) too much information provided without knowing what to do with it (36%). The high percentage of producers who indicated that they were unfamiliar with available technologies indicates that marketing efforts may improve technology adoption. Actual or perceived economic benefits appear to influence adoption rates, demonstrating the need for economic models to assess technology benefits and re-examination of retail product prices. As herd size increased, the percentage of producers selecting "poor technical support/training" and "compatibility issues" increased ($P < 0.05$), which may be reflective of past negative experiences. In developing technologies, manufacturers should work with end-users during development and after product adoption to alleviate these customer frustrations. Few significant differences were observed among age groups, though the youngest producers were more likely to select "better alternatives/easier to accomplish manually." Prior to technology development, market research should be conducted to ensure that new technologies address a real need. Utilizing this insight should help Precision Dairy Farming technology manufacturers and industry advisors develop strategies for improving technology adoption. Moreover, this information may help focus product development strategies for both existing and future technologies.

Table 1. Factors influencing slow adoption rates of Precision Dairy Farming technologies

Factor	N	Percent
Not familiar with technologies that are available	101	55%
Undesirable cost to benefit ratio	77	42%
Too much information provided without knowing what to do with it	66	36%
Not enough time to spend on technology	56	31%
Lack of perceived economic value	55	30%
Too difficult or complex to use	53	29%
Poor technical support/training	52	28%
Better alternatives/easier to accomplish manually	43	23%
Failure in fitting with farmer patterns of work	40	22%
Fear of technology/computer illiteracy	39	21%
Not reliable or flexible enough	33	18%
Not useful/does not address a real need	27	15%
Immature technology/waiting for improvements	18	10%
Lack of standardization	17	9%
Poor integration with other farm systems/software	12	7%
Compatibility issues	12	7%

Borchers et al (2014, unpublished data) submitted another survey to assess dairy producer technology needs. A survey to identify producer perception of precision dairy farming technologies was distributed in March 2013 through written publications and email. Responses were collected in May 2013 (n = 109) and statistical analysis was performed using SAS (SAS Institute, Inc. Cary, NC). Herd size, producer age and role on the farm were collected and analysed but significant differences were not found ($P > 0.05$). Producers were asked to indicate parameters currently monitored on their farm from a predetermined list and producers most often selected daily milk yield (52.3%), cow activity (41.3%), and not applicable (producers not currently implementing technologies: 1.2%). Producers were asked to rank the same list on usefulness using a 5-point Likert Scale (1: not useful and 5: useful). Least-squares means were calculated using the GLM procedure of SAS and producers indicated (mean ± SE) mastitis (4.77 ± 0.47), standing heat (4.75 ± 0.55), and daily milk yield (4.72 ± 0.62) to be most useful. Pre-purchase technology selection criteria were ranked using a Likert Scale (1: not important and 5: important) by producers and benefit to cost ratio (4.57 ± 0.66), total investment cost (4.28 ± 0.83), and simplicity and ease of use (4.26 ± 0.75) were found most important. Producers were categorized into United States or an “other countries” category based upon their farm location. Significant differences ($P < 0.05$) were identified between country and the adoption of technologies monitoring animal position and location, body weight, cow activity, daily milk yield, lying and standing time, mastitis, milk components, rumen activity and rumination, with other countries being higher in all cases. Producers were categorized based upon technology use (using technology vs. not using technology) and least-squares means were calculated across technology usefulness, with daily milk yield (using technologies: 4.83 ± 0.07, vs. not using technologies: 4.50 ± 0.10) and standing heat (using technologies: 4.68 ± 0.06, vs. not using technologies: 4.91 ± 0.09) differing significantly ($P < 0.05$). Least-squares means were calculated for technology use categories, with producer pre-purchase considerations and availability of local support (using technologies: 4.25 ± 0.11, vs. not using technologies: 3.82 ± 0.16) differing significantly ($P < 0.05$).

Pre-Adoption Considerations

Precision Dairy Farming technology investments should be considered on an individual operation basis. These technologies do not follow a “one size fits all” model well. Each dairy is different and what works on one may not work on another. To assess whether a technology will work for your operation, start by asking these questions:

Does your dairy’s management currently involve a computer? Being comfortable around a computer is important in Precision Dairy Farming. Almost all Precision Dairy Farming technologies work through a computer program and will require daily interaction to produce useful reports and information for decision-making. Dairy operations which are most likely to benefit from these technologies are those that already use dairy management software (i.e. PCDART, DairyComp 305). However, regardless of an individual’s familiarity with computers, working with any new computer program will require some training and adjustment.

Is the farm currently using good management practices? Precision Dairy Farming cannot completely correct poor management nor does it replace current management systems. In fact, when applied to unorganized systems, Precision Dairy Farming technologies may make managing the operation harder through information overload. Technologies and computers do not replace good management but can enhance it. Dairy farmers who already understand, evaluate and respond to cow signs and needs and the animal management associated with them are those who will benefit most from these technologies.

Does the operation know its own strengths and weaknesses? Being aware of which areas need improvement on a dairy farm will allow easier decisions to be made about investment in Precision Dairy Farming, including which technologies will work best for you. Focusing on areas that are already strong will result in very few observed benefits. For example, a farm that is already doing a good job with heat detection may not see as much benefit from investing in a heat detection technology.

What is the dairy's willingness to take risks? Many Precision Dairy Farming technologies are rather new and not yet widely adopted. Sometimes investing in an early technology may involve some risk (i.e. the company going out of business or development of a newer, improved model). However, the first adopters of new technologies are generally the ones who benefit from them most because they see returns first.

Do you understand the economic benefits? An investment analysis considers how a potential investment will affect a business. No matter how great a technology is, the benefits of investing in the technology must outweigh the costs. Before investing in any technology, farm management should set a threshold for minimum acceptable returns. A net present value analysis will help determine the true investment and profitability. Some technologies may not prove to be profitable, but investment may still be worthwhile because of improvements in quality of life.

The answers to these questions will help determine whether Precision Dairy Farming technologies are a good fit for an operation. However, it is still important to consider other farm-specific and economic factors when making this decision. If Precision Dairy Farming technologies are not a realistic option now, they may be in the future. Continually reassess the dairy operation to determine when Precision Dairy Farming technologies may become a good choice for improving dairy management.

Choosing a Technology

The list of available Precision Dairy Farming technologies is growing rapidly. Once you have decided you are ready for Precision Dairy Farming, the next step is to choose a technology (or multiple ones) to use. An ideal technology will be low-cost, reliable, robust, flexible, easy to maintain and update, and will provide information about something going on within an animal that a producer can immediately turn into an on-farm action. Consider some of these other questions when looking at potential technologies for your operation:

Technology Purpose: Determine whether the technology will bring value to the operation.

- Does the technology fulfill a need for the operation or is it addressing something that does not require changing?
- What will improve on the operation by getting/using this technology?

Company Interaction: Installing Precision Dairy Farming technologies will involve long-term interaction with the company that manufactures it. Be sure to talk to farmers or extension agents who have worked with the company previously to answer these questions.

- Has the technology been used on commercial farms, not just the manufacturing company's research farms?
- What kind of customer service, training and technical support does the manufacturer provide and for what length of time?
- Does the company value farmers' opinions when updating or making changes to the device?

How the Technology Works: Know whether the technology will work in a way that is convenient for your operation before committing your time and money to it. Again, talking to other farmers and extension agents about these concerns may be beneficial.

- What is required for collection of data from the technology?
- How reliable is the technology? How often does it fail to perform as desired?
- Is data measured continuously or does the animal have to make a trip to the parlour to collect the data?
- How frequently are tags misread?
- How do notifications about animals appear on the computer? Are reports easy to understand?
- Does the computer specify what to do with detected animals or do you have to interpret it?
- If the technology is designed for event detection (i.e. heat, mastitis or disease):
    - Can the manufacturer provide data indicating what percentage of cases (sensitivity) are detected (Goal>80%)? A technology should capture most of the desired events to be worthwhile.
- Can the manufacturer provide data indicating how many false alerts (specificity) occur (Goal: <1%)? This is where some technologies fall short. Although this is a strict criterion to use, false alerts can waste time and resources for a dairy producer. A 1% false alert means you will receive 10 false alerts for every 1000 milkings. By comparison, 10% or 25% false alert rates would lead to 100 or 250 false alerts per day.
- How long is the data stored on the computer?
- How does the system handle transferring units (tags, etc.) from one animal to another?

Outlook

Though Precision Dairy Farming is in its infancy, new Precision Dairy Farming technologies are introduced to the market each year. As new technologies are developed in other industries, engineers and animal scientists find applications within the dairy industry. More importantly, as these technologies are widely adopted in larger industries, such as the automobile or personal computing industries, the costs of the base technologies decrease, making them more economically feasible for dairy farms. Because the bulk of research focused on Precision Dairy Farming technologies is conducted in research environments, care must be taken when trying to transfer these results directly to commercial settings. Field experiments or simulations may need to be conducted to alleviate this issue. Because there is a gap between the impact of Precision Dairy Farming technologies in research versus commercial settings, additional effort needs to be directed towards implementation of the management practices needed in order to fully utilize information provided by these technologies. To gain a better understanding of technology adoption shortcomings, additional research needs to be undertaken to examine the adoption process, not only for successful adoption of technology but also for technology adoption failures. Before investing in a new technology, a formal investment analysis should be conducted to make sure that the technology is right for your farm's needs. Examining decisions with a simulation model accounts for more of the risk and uncertainty characteristics of the dairy system. Given this risk and uncertainty, a stochastic simulation of investment analysis will show that there is uncertainty in the profitability of some projects. Ultimately, the dairy manager's level of risk aversion will determine whether or not he or she invests in a technology using the results from this type of analysis. Precision dairy farming technologies provide tremendous opportunities for improvements in individual animal management on dairy farms. In the future, Precision Dairy Farming technologies will change the way dairy herds are managed.

References

Bewley, J.M. 2010. Precision dairy farming: advanced analysis solutions for future profitability. Proceedings of the first North American Conference on Precision Dairy Management, Toronto, Canada.

de Mol, R. M. 2000. Automated detection of oestrus and mastitis in dairy cows. Page 177. Vol. PhD Thesis. Wageningen University, Wageningen, The Netherlands.

Delorenzo, M. A. and C. V. Thomas. 1996. Dairy records and models for economic and financial planning. J Dairy Sci 79(2):337-345.

Dijkhuizen, A. A., R. B. M. Huirne, S. B. Harsh, and R. W. Gardner. 1997. Economics of robot application. Computers and Electronics in Agriculture 17(1):111-121.

Eastwood, C., D. Chapman, and M. Paine. 2004. Precision dairy farming-taking the microscope to dairy farm management.

Gelb, E., C. Parker, P. Wagner, and K. Rosskopf. 2001. Why is the ict adoption rate by farmers still so slow? Pages 40-48 in Proc. Proceedings ICAST, Vol. VI, 2001, Beijing, China.

Hamrita, T. K., S. K. Hamrita, G. Van Wicklen, M. Czarick, and M. P. Lacy. 1997. Use of biotelemetry in measurement of animal responses to environmental stressors.

Huirne, R. B. M., S. B. Harsh, and A. A. Dijkhuizen. 1997. Critical success factors and information needs on dairy farms: The farmer's opinion. Livestock Production Science 48(3):229-238.

Lazarus, W. F., D. Streeter, and E. Jofre-Giraudo. 1990. Management information systems: Impact on dairy farm profitability. North Central Journal of Agricultural Economics 12(2):267-277.

Philpot, W. N. 2003. Role of technology in an evolving dairy industry. Pages 6-14 in Proc. 2003 Southeast Dairy Herd Management Conference, Macon, Georgia.

Pietersma, D., R. Lacroix, and K. M. Wade. 1998. A framework for the development of computerized management and control systems for use in dairy farming. J Dairy Sci 81(11):2962-2972.

Schulze, C., J. Spilke, and W. Lehner. 2007. Data modeling for precision dairy farming within the competitive field of operational and analytical tasks. Computers and Electronics in Agriculture 59(1-2):39-55.

Spilke, J. and R. Fahr. 2003. Decision support under the conditions of automatic milking systems using mixed linear models as part of a precision dairy farming concept. Pages 780-785 in Proc. EFITA 2003 Conference, Debrecen, Hungary.

van Asseldonk, M. A. P. M. 1999. Economic evaluation of information technology applications on dairy farms. Page 123. Vol. PhD. Wageningen Agricultural University.

van Asseldonk, M. A. P. M., A. W. Jalvingh, R. B. M. Huirne, and A. A. Dijkhuizen. 1999. Potential economic benefits from changes in management via information technology applications on dutch dairy farms: A simulation study. Livestock Production Science 60(1):33-44.

Notes:

Bovine Respiratory Disease Prevention: Opportunities for Genetic Selection

Alison L. Van Eenennaam
Department of Animal Science, University of California
Davis, CA 95616-8521, USA
Telephone: 530 752-7942
Fax: 530 752-0175
Email: alvaneenennaam@ucdavis.edu

The Bovine Respiratory Disease Complex Coordinated Agricultural Project Research Team: Sharif Aly, University of California Davis; Noah Cohen, Texas A&M University; Alan Dabney, Texas A&M University; Scott Dindot, Texas A&M University; Mark Enns, Colorado State University; Laurel Gershwin, University of California Davis; Robert Hagevoort, New Mexico State University; Terry Lehenbauer, University of California Davis; Holly Neibergs, Washington State University; Shannon Neibergs, Washington State University; Tim Ross, New Mexico State University; Christopher Seabury, Texas A&M University; Loren Skow, Texas A&M University; Jeremy Taylor, University of Missouri Columbia; Milton Thomas, Colorado State University; Cassandra Tucker, University of California Davis; Curtis Van Tassell, USDA ARS; Adroaldo Zanella, University of São Paulo, Brazil; and J.E. Womack, PD, Texas A&M University.

Summary

The Bovine Respiratory Disease (BRD) Complex Coordinated Agricultural Project (BRD CAP) is a 5-year USDA funded research project, the primary objective of which is to use genomics to identify cattle that are less susceptible to BRD. This paper describes the research progress made on this project to date including the identification of genetic markers associated with BRD susceptibility in Holstein cattle, scoring systems for the improved field diagnosis of BRD in pre-weaned dairy calves, survey results of California dairy calf rearing practices, and some practical findings and considerations of how all this information might be used in the future to select and manage calves to reduce the prevalence of BRD in the U.S. dairy industry.

Background

There is growing interest in the selective breeding of livestock for enhanced disease resistance. The dairy industry has a history of selection for a disease trait. Since 1994, selection programs have been developed to take advantage of genetic variability in mastitis resistance. Selection has been based on the indicator trait of somatic cell score (SCS), meaning that it provides a selection criterion which can be used to indicate which animals are less susceptible to mastitis. Currently, 7% of the emphasis in the 2014 Net Merit (NM$) index is assigned to lowering SCS. This is done despite the fact that the heritability of SCS is low (0.12) and mastitis resistance has an adverse correlation with production traits (Rupp and Boichard, 2003).

Bovine respiratory disease (BRD) is a disease of the lower respiratory tract of cattle that is multifactorial in origin and results in bronchopneumonia. It is commonly observed in dairy calves and has both acute and long term effects on the performance of those calves. Calves that were treated with antibiotics produced 493 kg less milk in the first lactation ($P > 0.01$) than calves with no record of being treated (Soberon et al., 2012).

Bovine respiratory disease is the largest single natural cause of death in US beef and dairy cattle, and BRD resistance represents an obvious target for selective breeding programs. However, unlike mastitis, there is no obvious indicator trait to use for selection against BRD. Given the multifactorial nature of BRD the genetic basis of BRD susceptibility is likely complex, and governed by the effects of multiple genes.

The heritability (h^2) of BRD susceptibility, defined as the proportion of observed variation that can be attributed to inherited genetic factors in contrast to environmental ones, tends to be low under field conditions. This is partly as a result of suboptimal diagnosis (i.e. not all sick animals are identified, healthy animals may be incorrectly diagnosed as ill, and some susceptible animals will appear resistant when in fact they have not been exposed to the disease agent (viruses and/or bacteria in the case of BRD)). These confounding factors add environmental noise to field data which decreases heritability. Field studies therefore likely underestimate the true importance of genetics in BRD incidence, and thus also undervalue the potential gains that could be made by breeding for disease resistance.

Newly-available genomic tools offer an opportunity to employ novel genetic approaches to select for more disease-resistant cattle. In 2011, the USDA AFRI funded a 5-year Coordinated Agricultural Project entitled "**Integrated Program for Reducing Bovine Respiratory Disease Complex (BRDC) in Beef and Dairy Cattle.**" The overarching research objective of this multi-institutional "BRD CAP" project is to use newly-available genomic tools to identify host genome regions associated with susceptibility to BRD.

As a part of this project, a large case:control study was undertaken to identify genetic markers associated with BRD susceptibility in pre-weaned Holstein calves. This paper describes the research progress made on this project to date, some of the practical findings and considerations, and how this information might be used in the future to select for cattle with reduced susceptibility to BRD.

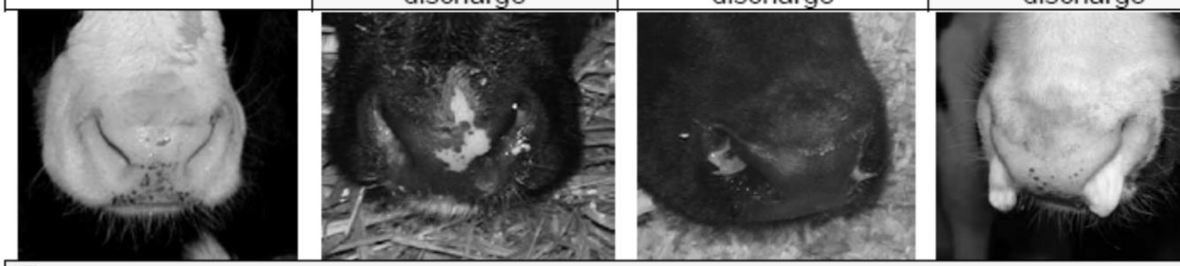
Identification of genetic markers associated with BRD susceptibility

Pre-weaned Holstein calves between the ages of 27-60 days housed in hutches were observed in the early morning before feeding and were enrolled as a BRD case or control based on the McGuirk health scoring system (McGuirk, 2008). This standardized scoring system (**Figure 1**) relies on assigning a score of normal (0), slightly abnormal (1), abnormal (2), or severely abnormal (3) for each of 5 attributes: rectal temperature, cough, nasal discharge, eye discharge, and ear tilt. A calf with a cumulative score of ≥ 5 was assigned as a case, and a calf adjacent to that calf with a cumulative score of ≤ 3 was assigned as a control. A total of 1382 case calves, and 1396 control calves from a large dairy calf ranch in California (2,011 calves) and from dairies in New Mexico (767 calves) were enrolled in the trial. All calves were sampled for the identification of any bacterial and viral pathogens in their nasal or pharyngeal passages. The calves were also genotyped using a panel containing over 700,000 genetic markers known as single nucleotide polymorphisms (SNPs).

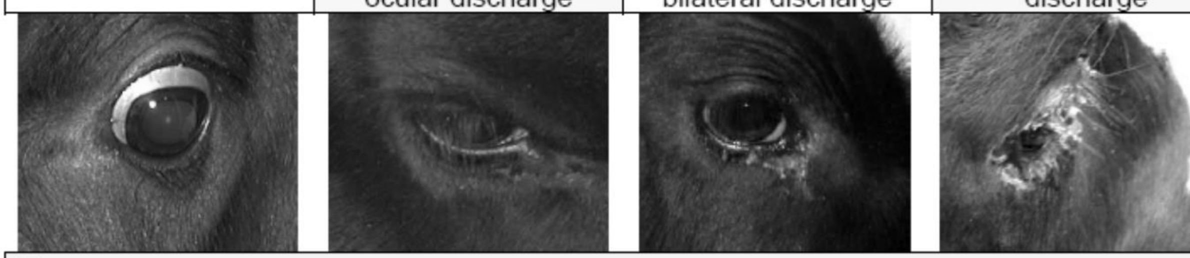
This information was then used to determine whether there were regions of the genome, as indicated by marker associations, associated with BRD susceptibility (Neibergs et al., 2014).

Calf Health Scoring Criteria

0	1	2	3
Rectal temperature			
100-100.9	101-101.9	102-102.9	≥103
Cough			
None	Induce single cough	Induced repeated coughs or occasional spontaneous cough	Repeated spontaneous coughs
Nasal discharge			
Normal serous discharge	Small amount of unilateral cloudy discharge	Bilateral, cloudy or excessive mucus discharge	Copious bilateral mucopurulent discharge



0	1	2	3
Eye scores			
Normal	Small amount of ocular discharge	Moderate amount of bilateral discharge	Heavy ocular discharge



0	1	2	3
Ear scores			
Normal	Ear flick or head shake	Slight unilateral droop	Head tilt or bilateral droop

Figure 1. The Calf Respiratory Scoring Criteria (McGuirk, 2008). Available for download at http://www.vetmed.wisc.edu/dms/fapm/fapmtools/8calf/calf_respiratory_scoring_chart.pdf

The observed pathogen profiles of the CA and NM animals differed for all pathogens with the exception of bovine herpes virus and bovine viral diarrhea virus, which were rarely detected in either population (**Table 1**). The genetic analysis of the study data showed moderate (~ 0.21) heritability estimates for BRD susceptibility in pre-weaned Holstein calves. This is higher than previous estimates of the heritability of BRD, likely due to the use of the standardized scoring system to objectively categorize cases and controls which minimized the probability that sick animals were not identified, and/or that healthy animals were incorrectly diagnosed as ill.

<u>Table 1</u>. *Pathogens identified from deep pharyngeal and mid-nasal swabs in pre-weaned Holstein calves from California and New Mexico*. Table reprinted from Neibergs et al. (2014).

Pathogen	***California** n = 2,014	***New Mexico** n = 748	**California & New Mexico** n = 2,763	**+Odds Ratio**	**Odds Ratio *P* value**
Arcanobacterium pyogenes	0.3 (0)	10.7 (4.3)	3.1 (1.2)	2.8	0.0003
Histophilus somni	1.7 (0.4)	3.2 (0.5)	2.1 (0.4)	4.9	<0.0001
Mannheimia haemolytica	23.5 (11.1)	4.5 (3.5)	18.4 (9)	2.3	<0.0001
Pasteurella multocida	36.3 (23.6)	61.1 (54.8)	43.0 (32)	1.6	<0.0001
Mycoplasma spp.	64.6 (57.1)	57.4 (48.7)	62.6 (54.8)	1.4	<0.0001
Bovine corona virus	9.6 (7.7)	50.0 (35.0)	19.9 (14.5)	1.5	0.0004
Bovine respiratory syncytial virus	20.8 (7.7)	4.9 (2.5)	16.3 (6.3)	2.9	<0.0001
Bovine viral diarrhea virus	0 (0)	1.3 (0)	0.4 (0)	NA	NA
Bovine herpes virus	0 (0)	0 (0)	0 (0)	NA	NA

*Percent of cases and controls (in parentheses) where individual pathogens were present in the pre-weaned Holstein calves. Animals classified as undetermined with respect to case-control status were not included in the summary statistics presented here.
+Odds ratio of being affected with BRDC when the pathogen was present when the animal was swabbed.

The analyses revealed approximately 116 genomic regions that were significantly associated with BRD in both the NM and CA populations, many of which were associated with biologically meaningful genes. Among them were genes that are known to mediate herpes virus entry into host cells, a gene associated with viral susceptibility, and a gene associated with inflammation. The fact that so many regions of interest were identified supports the idea that many genes are associated with susceptibility to this multifactorial disease. As with other "quantitative" traits associated with many genes, the best way to develop genomic-enhanced genetic merit estimates is to develop a genomic prediction for the trait based on the SNP genotype of the animal. Like other traits of economic importance to dairy production, the appropriate weighting to place on genetic merit estimates of BRD susceptibility will have to be calculated based on the relative economic value of this trait versus other traits of importance to dairy production in the NM$ index.

The importance of genetics as it relates to BRD susceptibility is illustrated by looking at the distribution of AI sires among the case:control calves that were enrolled in this study. Genotype information on AI sires was used to assign sires to the calves based on the 50K sire genotypes on file at the **Animal Improvement Programs Laboratory (AIPL).** A total of 1952 calves were sire-identified to a total of 707 AI sires. Approximately 370 of these sires had more than one calf. We examined the data on the 34 sires that had 10 or more calves represented in the data to determine whether sires generated case and control calves at an equal rate, or if there was a tendency for some sires to produce a disproportionately high number of either category. The data was tested for significance using a **chi-square** contingency table **analysis with Yates correction (Table 2).**

<u>Table 2</u>. *Number of cases, and controls sired by the 34 sires that sired ≥10 offspring in the BRD case:control study undertaken in pre-weaned Holstein calves* (unpublished BRD CAP data).

Sire	# offspring	# cases	# controls	% cases	% controls	P <0.05
1	36	19	17	53%	47%	
2	30	12	18	40%	60%	
3	**25**	**18**	**7**	**72%**	**28 %**	**
4	19	11	8	58%	42%	
5	18	12	6	67%	33%	
6	18	12	6	67%	33%	
7	16	5	11	31 %	69%	
8	15	7	8	47%	53%	
9	15	9	6	60%	40%	
10	14	8	6	57%	43%	
11	14	10	4	71%	29%	
12	**14**	**3**	**11**	**21%**	**79%**	**
13	13	7	6	54%	46%	
14	13	8	5	62%	38%	
15	13	5	8	38%	62%	
16	13	9	4	69%	31%	
17	13	9	4	69%	31%	
18	13	4	9	31%	69%	
19	**13**	**12**	**1**	**92%**	**8%**	**
20	12	7	5	58%	42%	
21	12	5	7	42%	58%	
22	12	5	7	42 %	58%	
23	12	9	3	75%	25%	
24	11	6	5	55%	45%	
25	11	6	5	55%	45%	
26	11	5	6	45%	55%	
27	11	7	4	64%	36%	
28	11	4	7	36%	64%	
29	11	3	8	27%	73%	
30	**11**	**2**	**9**	**18%**	**82%**	**
31	10	6	4	60%	40%	
32	10	6	4	60%	40%	
33	10	7	3	70%	30%	
34	10	3	7	30%	70%	

It can be seen from Table 2 that some sires produce significantly higher than expected proportions of case (e.g. sire 3 and 19), and control (e.g. sire 12 and 30) calves. This simple analysis shows how the finding of a 0.21 heritability estimate for BRD susceptibility might play out on farm. If sire 12 and 30 have acceptable NM$, then their use could offer an approach to effect a sustained decrease in the incidence of BRD in dairy cattle. Future work includes further refining the genetic markers associated with BRD susceptibility, and working to incorporate genomic predictions for this trait into the national dairy cattle genetic evaluation scheme.

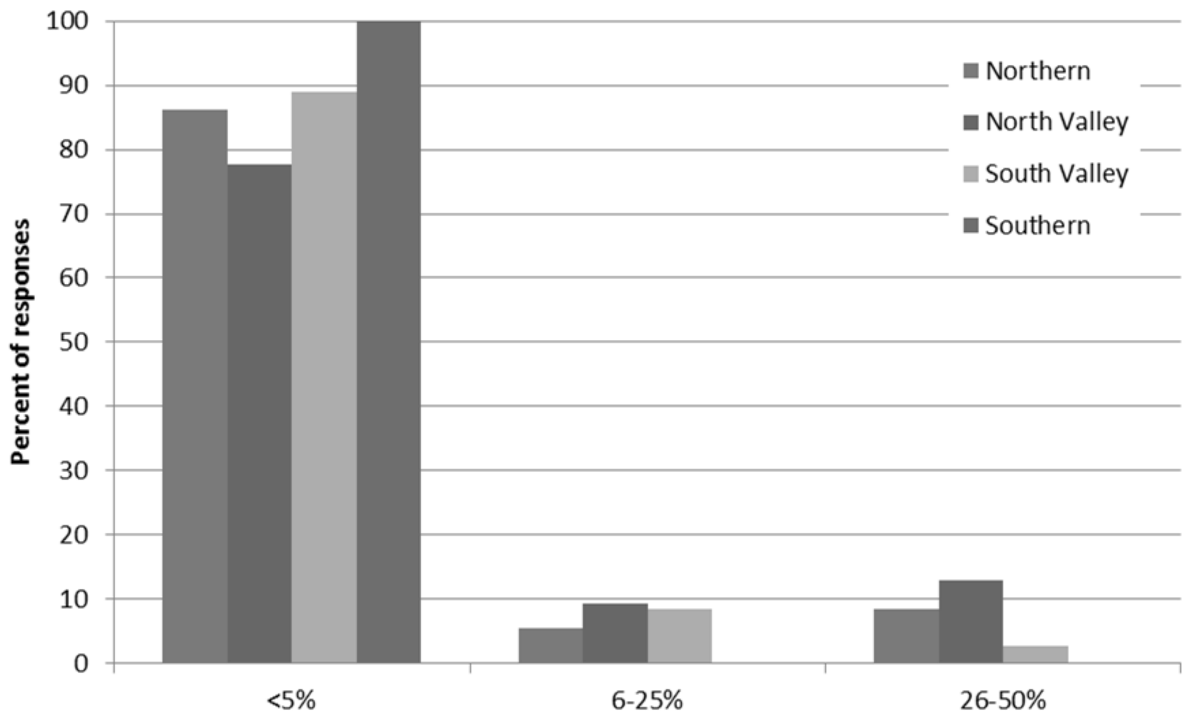
A Survey of California Dairy Calf Rearing Practices

A survey was designed to collect information about calf rearing practices on California dairies. Questions addressed calving and newborn calf management, colostrum management, pre-weaning calf management, and disease monitoring and prevention. Several methods were used to recruit responses from California dairy producers. Paper copies were mailed to 1,523 California Grade A milk producing dairies with the option to respond by mail or online. Responses were also recruited in-person at the World Ag Expo in Tulare, CA (2013) and by Cooperative Extension personnel. Responses were collected between February 2013 and January 2014. Both statewide and regional data were analyzed (Karle et al., 2014). Four geographic regions were identified: Northern California ("NC", Sacramento County and remaining northern counties), North Central Valley ("NV", San Joaquin to Madera Counties), South Central Valley ("SV", Fresno to Kern Counties) and Southern California ("SC", counties south of Kern).

In total, 234 respondents (15%) completed the survey. The average respondent herd size was 1420 milking cows (95% CI (1230, 1611)) which was larger than the 2013 California average herd size of 1164 cows/herd and may indicate a greater response rate from larger herds. The response rate was geographically consistent with the distribution of dairies in California with 40 responses from the NC region (16%), 96 from the NV region (18%), 78 from the SV region (14%), and 8 from the SC region (7%).

Of the respondents in NC, 70% left calves with their dams for greater than 1 hour after birth, compared to 44% in NV, 27% in SV, and 50% in SC. Of respondent dairies from NC and SC, the individual dam was the most common source of colostrum fed to heifer calves, 53% and 50%, respectively. In contrast, pooled colostrum was the most common source of colostrum fed to heifer calves on 58% and 63% of NV and SV respondent dairies, respectively. Statewide, 12% of respondents reported that colostrum was pasteurized and 32% measured IgG content in colostrum before feeding. In NC, 98% of respondent dairies raised pre-weaned calves on site. In contrast, approximately only half of the respondent dairies in the remaining regions raised pre-weaned calves onsite. Rather they contracted out heifer raising to specialized calf-raising operations. These calf ranches may have as many as 40,000 pre-weaned calves and a similar number of weaned calves in group pens. Statewide, waste or hospital milk was the most frequently reported source of milk fed to pre-weaned calves (72%).

A scoring system or an on-farm protocol was used to diagnose BRD on 21% of respondent dairies; however, based on our experience, we suspect these are primarily protocols based on simple observations rather than an objective scoring system. Cough (82%), depression (79%), ear droop (63%), nasal discharge (71%) and rapid respiration (77%) were the most common signs used to diagnose BRD on-farm. Listening to lung sounds using a stethoscope (22%), fever (25%), head tilt (34%), and eye discharge (27%) were less commonly used. The majority of respondents (83%) reported treating fewer than 5% of pre-weaned calves for BRD, although some were much higher and in the range of 26-50% (**Figure 2**). Intranasal respiratory vaccines were administered within 2 weeks of birth according to 50% of the respondents. A higher proportion of respondents reported rarely or never using killed respiratory vaccine compared to modified live vaccines (47% and 13%, respectively). This survey data will be combined with future research to develop and validate a BRD risk assessment tool to allow producers to identify calf management practices associated with BRD.

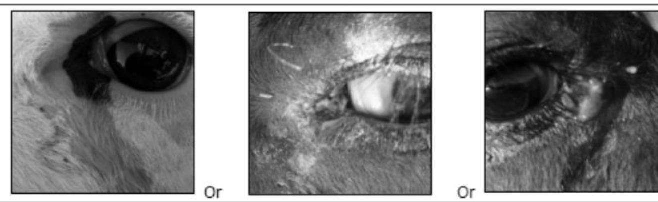
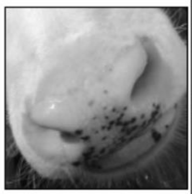
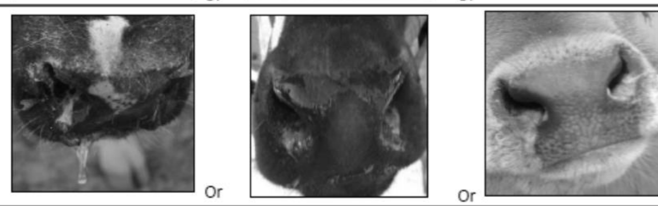
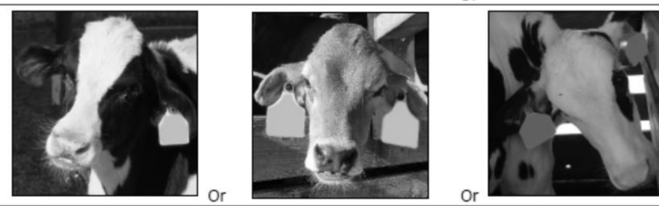


<u>Figure 2</u>. Percentage of pre-weaned calves that are typically being treated for pneumonia at any given time according to survey of California dairy producers (Karle et al., 2014).

A simplified BRD scoring system for pre-weaned dairy calves

Data from the large BRD case:control study was used to develop a simplified scoring system for pre-weaned calves. The rationale behind this development was the need to determine the BRD health status of a large number of calves on extensive calf-raising facilities in a relatively short amount of time, and the difficulty and time required to take temperature measurements on calves housed in California-style calf hutches. This simplified scoring used six clinical signs: eye discharge, spontaneous cough, breathing, fever (≥ 39.2°C/102.5°F), nasal discharge, and ear droop/head tilt each classified as either abnormal or normal. Each of the first 4 signs is assigned 2 points, nasal discharge is 4 points, and ear droop/head tilt is 5 points (**Figure 3**). A score of 5 or greater for this system called "BRD3" was determined to be the optimum cut-off to classify a case (Love et al., 2014), meaning that ear droop/head tilt is an automatic case. Users would need to obtain a temperature if the calf had a nasal discharge only, or only two of the other 2 point signs. This simplified scoring system had a 57% sensitivity for pneumonia and a specificity of 89.9% for calves without pneumonia (Aly et al., 2014), which were not significantly different from the values obtained for the WI scoring system shown in Figure 1. The comparable sensitivity and specificity, simple normal/abnormal categorization for each clinical sign, and the reduced calf handling may make this BRD3 scoring system advantageous for on-farm use, especially on large calf-raising facilities where hundreds if not thousands of calves may be evaluated daily.

Field diagnosis remains a challenge for the control and treatment of BRD, and it is hoped that this simplified standardized scoring system will be routinely used by dairy producers and calf raisers to diagnose cases of BRD on farm. It is available in both English and Spanish at the following URL: http://www.vmtrc.ucdavis.edu/laboratories/epilab/scoringsystem.pdf.

Clinical sign	Score if normal		Score if abnormal (any severity)[2]	
Eye discharge	0		2	 Or … Or
Nasal discharge	0		4	 Or … Or
Ear droop or Head tilt	0		5	 Or … Or
Cough	0	No cough	2	Spontaneous cough
Breathing	0	Normal	2	Rapid or difficult breathing
Temperature	0	< 102.5° F	2	≥ 102.5° F

Add scores for all clinical signs, if total score is ≥ 5, calf may be positive for bovine respiratory disease

Figure 3. The simplified BRD3 calf respiratory scoring system (Love et al., 2014).

The Future

Historically, breeding goals in dairy cattle focused on increased milk production. Selection for milk production has negative genetic correlations with many health and fitness traits, and there is a growing interest in including these traits in selection programs. It is interesting to view the evolution of the NM$ Index over time (**Table 3**). Two new fertility traits (heifer conception rate (HCR) and cow conception rate (CCR)) were included in the 2014 update to NM$ index. It is likely that more health traits will be included in future updates to the NM$ index.

Several studies show that the use of direct health observations is an effective way to incorporate heath traits into breeding programs. Such observations require a standardized system to record diagnoses to ensure phenotypes are comparable between farms. Consistent recording of health data is more difficult than for other traits due to subjectivity of diagnosis and reporting. Several studies have shown that for use in genetic evaluations, common health disorders recorded by farmers are of a similar quality as those documented by veterinarians (Egger-Danner et al., 2014). A recent study showed that genetic selection for health traits (including cystic ovaries, displaced abomasum, ketosis, lameness, mastitis, metritis, and retained placenta) using producer-recorded health data collected from on-farm computer systems is feasible in the United States (**Table 4**; Parker Gaddis et al., 2014). The authors go on to conclude that "The development of genomic selection methodologies, with accompanying substantial gains in reliability for low-heritability traits, may dramatically improve the feasibility of genetic improvement of dairy cow health."

Table 3. A history of the main changes in USDA genetic-economic indexes for dairy cattle and the percentage of relative emphasis on traits included in the indexes (VanRaden and Cole, 2014)

Traits included	**USDA genetic-economic index (and year introduced)**								
	PD$ (1971)	**MFP$ (1976)**	**CY$ (1984)**	**NM$ (1994)**	**NM$ (2000)**	**NM$ (2003)**	**NM$ (2006)**	**NM$ (2010)**	**NM$ (2014)**
Milk	52	27	−2	6	5	0	0	0	−1
Fat	48	46	45	25	21	22	23	19	22
Protein	…	27	53	43	36	33	23	16	20
Productive Life	…	…	…	20	14	11	17	22	19
Somatic Cell Score	…	…	…	−6	−9	−9	−9	−10	−7
Udder composite	…	…	…	…	7	7	6	7	8
Feet/legs composite	…	…	…	…	4	4	3	4	3
Body size composite	…	…	…	…	−4	−3	−4	−6	−5
Daughter Pregnancy Rate	…	…	…	…	…	7	9	11	7
Cow Conception Rate	…	…	…	…	…	…	…	…	2
Heifer Conception Rate	…	…	…	…	…	…	…	…	1
Calving Ability $ Index	…	…	…	…	…	…	6	5	5

Table 4. Mean reliabilities of sire PTA computed with pedigree information and genomic information for health traits based on producer records of health events in U.S. dairy cattle. The right column shows how genomics can improve the overall gain (Parker Gaddis et al., 2014).

Health Event	Pedigree information			Blended pedigree and genomic information			
	Overall mean	Unproven sires[1]	Proven sires[2]	Overall mean	Unproven sires	Proven sires	Overall gain[3]
Displaced abomasum	0.44	0.22	0.65	0.55	0.38	0.71	0.11
Ketosis	0.35	0.18	0.52	0.48	0.35	0.61	0.13
Lameness	0.24	0.15	0.32	0.39	0.31	0.47	0.15
Mastitis	0.39	0.26	0.52	0.51	0.40	0.612	0.12
Metritis	0.35	0.24	0.46	0.48	0.38	0.57	0.13
Retained Placenta	0.55	0.42	0.67	0.64	0.54	0.73	0.09

[1] Unproven sires considered sires with less than 10 daughters.
[2] Proven sires considered sires with at least 10 daughters.
[3] The increase in mean reliability calculated as the difference in overall mean reliability between the blended model and the traditional (pedigree data only) model.

Genomics has the potential to accelerate the rate of genetic improvement in low heritability, hard-to-measure traits such as disease status. However, phenotypes are still required to develop the genomic breeding values (GEBVs) for the trait of interest, and to keep the genetic marker effect estimates current. For BRD to become routinely included in dairy cattle genetic evaluations, standardized BRD health event data will need to be recorded on farm and fed into the national genetic evaluation system. To be successful, there needs to be a balance between the effort required to collect these data and subsequent benefits. Electronic systems that make such data capture easy and automated are likely key to the long-term success.

Summary

- Bovine respiratory disease (BRD) is a significant cause of morbidity, mortality, economic loss and is an animal welfare concern.

- Economic costs associated with BRD include treatment expense, mortality, premature culling, reduced growth, impaired fertility and reduced milk production in adulthood.

- Efforts are underway to develop large BRD case:control Holstein populations to enable the development of genomic breeding values (GEBVs) for BRD susceptibility.

- Preliminary data show BRD susceptibility has moderate heritability (0.13-0.21) suggesting there is an opportunity for improved animal health through selection.

- In the long-term, incorporation of BRD as a health trait into genetic evaluation programs will require a system to record standardized BRD diagnoses on farm to enable the development of a large data set of producer-recorded health data.

- Selection for animals with less susceptibility to BRD offers a promising long-term and permanent approach to decrease the incidence of this most common infectious disease and leading natural cause of death among cattle in the United States.

Acknowledgements

The authors acknowledge the Bovine Respiratory Disease Consortium Coordinated Agricultural Project (BRD CAP) team members and funding from the USDA Agriculture and Food Research Initiative (Competitive Grant no. 2011-68004-30367; J. E. Womack, PI) from the USDA National Institute of Food and Agriculture**.** The BRD3 scoring system was developed using case–control data that were collected as part of the BRD CAP. Development of the scoring system was funded by the University of California, Davis Division of Agriculture and Natural Resources (Grant no. 1753; S. S. Aly, PI). The authors thank the study dairies and calf ranch owners for their participation, and Mr. Paul Rossitto. More information about the BRD CAP can be found at http://www.brdcomplex.org/.

References

Aly, S. S., W. J. Love, D. R. Williams, T. W. Lehenbauer, A. L. Van Eenennaam, C. Drake, P. H. Kass, and T. B. Farver. 2014. Agreement between bovine respiratory disease scoring systems for pre-weaned dairy calves. Animal Health Research Reviews 15: 148-150.

Egger-Danner, C., J. B. Cole, J. E. Pryce, N. Gengler, B. Heringstad, A. Bradley, and K. F. Stock. 2014. Invited review: overview of new traits and phenotyping strategies in dairy cattle with a focus on functional traits. Animal : An International Journal of Animal Bioscience: 1-17.

Karle, B. M., W. J. Love , T. W. Lehenbauer, A. L. Van Eenennaam, L. Hulbert, and R. J. Anderson. 2014. A Survey of Calf Rearing Practices on California Dairies In: American Association of Bovine Practitioners (AABP), Albuquerque, NM

Love, W. J., T. W. Lehenbauer, P. H. Kass, A. L. Van Eenennaam, and S. S. Aly. 2014. Development of a novel clinical scoring system for on-farm diagnosis of bovine respiratory disease in pre-weaned dairy calves. PeerJ 2: e238.

McGuirk, S. M. 2008. Disease management of dairy calves and heifers. The Veterinary Clinics of North America. Food Animal Practice 24: 139-153.

Neibergs, H. M. et al. 2014. Susceptibility loci revealed for Bovine Respiratory Disease Complex in pre-weaned Holstein calves. BMC Genomics **15**:1164.

Parker Gaddis, K. L., J. B. Cole, J. S. Clay, and C. Maltecca. 2014. Genomic selection for producer-recorded health event data in US dairy cattle. Journal of Dairy Science 97: 3190-3199.

Rupp, R., and D. Boichard. 2003. Genetics of resistance to mastitis in dairy cattle. Veterinary research 34: 671-688.

Soberon, F., E. Raffrenato, R. W. Everett, and M. E. Van Amburgh. 2012. Preweaning milk replacer intake and effects on long-term productivity of dairy calves. Journal of Dairy Science 95: 783-793.

VanRaden, P. M., and J. B. Cole. 2014. Net merit as a measure of lifetime profit: 2014 revision. http://aipl.arsusda.gov/reference/nmcalc-2014.htm.

Notes:

Milk vs. Blood - Which is Best for PAG Pregnancy Prediction?

Paul M. Fricke, Alessandro Ricci, Paulo D. Carvalho, and Mason C. Amundson
Department of Dairy Science
University of Wisconsin-Madison
Madison, Wisconsin 53706
pmfricke@wisc.edu

Introduction

Identification of nonpregnant dairy cows early after AI improves reproductive efficiency and the 21-day pregnancy rate by decreasing the interval between AI services thereby increasing the AI service rate (Fricke, 2002). Thus, new technologies to identify nonpregnant dairy cows early after AI may play a key role in management strategies to improve reproductive efficiency and profitability on dairy farms. Assays for detecting pregnancy-associated glycoprotein (PAG) levels in maternal circulation originating from mononucleated and binucleated cells of the embryonic trophoblast have been developed and commercialized to determine pregnancy status in cattle (Sasser et al., 1986; Zoli et al., 1992; Green et al., 2000).

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 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 and is now being assessed in field trials (LeBlanc, 2013).

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. This paper overviews results from an experiment conducted to assess factors associated with PAG levels in plasma and milk during early gestation in Holstein cows and to determine the accuracy of pregnancy outcomes based on PAG levels in plasma and milk compared to pregnancy outcomes based on transrectal ultrasonography (Ricci et al., 2015).

Materials and methods

Lactating Holstein cows (n = 141) were synchronized for first timed artificial insemination (TAI) using a Double Ovsynch protocol (Souza et al., 2008). Pregnancy diagnosis was initially performed 32 d after TAI for all cows using transrectal ultrasonography. Pregnant cows diagnosed with singletons (n = 48) based on transrectal ultrasonography 32 d after TAI continued the experiment in which pregnancy status was assessed weekly using transrectal ultrasonography from 39 to 102 d after TAI. Blood and milk samples were collected weekly from 25 to 102 d after TAI. From 32 to 102 d after TAI, blood and milk samples were collected from cows on the same day that pregnancy status was assessed using transrectal ultrasonography once a week.

After completion of sample collection at the end of the experiment, frozen plasma samples were shipped overnight in a cooled container by courier from the University of Wisconsin to IDEXX laboratories for analysis of plasma PAG levels using a commercial ELISA kit (the IDEXX Bovine Pregnancy Test, IDEXX Laboratories, Westbrook, ME). Milk samples were delivered weekly to AgSource headquarters (Verona, WI) on the day of collection throughout the experiment and then to AgSource Laboratories (Menomonie, WI) for analysis of milk PAG levels using a commercial ELISA kit (The IDEXX Milk Pregnancy Test, IDEXX Laboratories, Westbrook, ME). Results 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. Each microplate included negative and positive controls.

Pregnancy outcomes were determined based on cutoff values determined by the PAG ELISA manufacturer. For the plasma PAG ELISA, when the S-N value was < 0.300, the cow was classified "not pregnant"; when the S-N value was > 0.300 to < 1.000, the cow was classified "recheck"; and when the S-N value was ≥ 1.000, the cow was classified "pregnant." For the milk PAG ELISA, when the S-N value was < 0.100, the cow was classified "not pregnant"; when the S-N value was > 0.100 to < 0.250, the cow was classified as "recheck"; and when the S-N value was ≥ 0.250, the cow was classified "pregnant."

Results and discussion

Plasma and Milk PAG Profiles. Overall, the weekly PAG profile in both plasma and milk from 25 to 102 d after TAI for pregnant cows was similar (Figure 1); however, plasma PAG levels were approximately 2-fold greater compared to milk PAG levels. Temporal PAG profiles from the present study are similar to other studies reporting PAG profiles in serum. In the first study to evaluate PAG-1 concentrations throughout gestation in Holstein cows (Sasser et al., 1986), serum PAG-1 concentrations were detectable in some but not all cows 15 d after AI, increased to about 40 d after AI and stayed constant until about 70 d, then steadily increased until the end of gestation. A study that evaluated the same commercial PAG ELISA test kits evaluated in the present experiment reported similar relative PAG profiles (S-N values) in both plasma and milk (Lawson et al., 2014).

Plasma and milk PAG levels were affected by both week after TAI and parity (Figure 1). When all cows that maintained pregnancy from 25 to 102 d after TAI were analyzed, plasma and milk PAG levels increased from 25 d after TAI to an early peak 32 d after TAI. Plasma and milk PAG levels then decreased from 32 d after TAI to a nadir from 53 to 60 d after TAI for the plasma PAG ELISA and from 46 to 67 d after TAI for the milk PAG ELISA followed by a gradual increase in PAG levels from 74 to 102 d after TAI. Primiparous cows had greater plasma and milk PAG levels compared to multiparous cows.

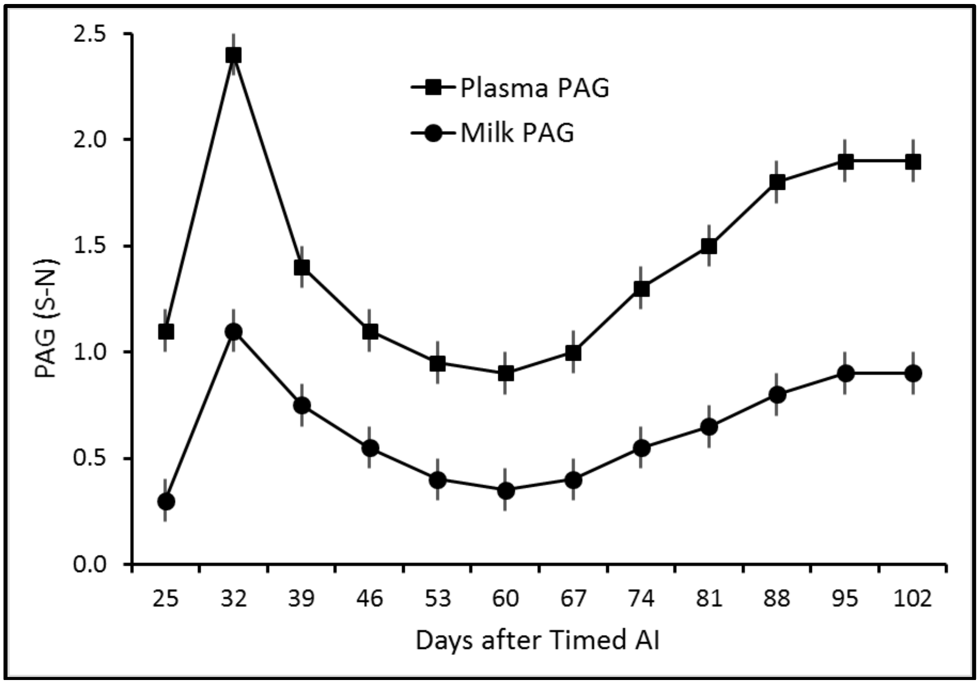


Figure 1. Plasma and milk pregnancy-associated glycoprotein (PAG) profiles for Holstein cows (n = 48) that maintained pregnancy from 25 to 102 d after AI. ELISA outcomes were calculated from the optical density (OD) of the sample (corrected by subtraction of the reference wavelength OD of the sample (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.

Accuracy of Pregnancy Outcomes 32 d after TAI. To evaluate pregnancy outcomes from the plasma and milk PAG ELISA tests in cows of unknown pregnancy status, 2 × 2 contingency tables were constructed to calculate sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and accuracy of the pregnancy outcomes for the plasma and milk PAG ELISA tests 32 d after TAI, and these outcomes were compared to those based on transrectal ultrasonography 32 d after TAI (Table 1).

Sensitivity for both the plasma and milk PAG ELISA tests in the present experiment was high (100% and 98%, respectively), compared to specificity (87% and 83%, respectively). As a result, the NPV for the plasma and milk PAG ELISA tests in the present experiment was high (100% and 99%, respectively) compared to the PPV of both tests (84% and 79%, respectively). The overall accuracy of the plasma and milk PAG ELISA tests 32 d after TAI was 92% and 89%, respectively. Results from this sensitivity analysis support that the accuracy of using plasma or milk PAG levels as an indicator of pregnancy status in dairy cows 32 d after AI is high, and our results agree with others who have conducted similar analyses from 27 to 39 d in gestation when PAG levels in both plasma and milk are at early peak levels (Silva et al., 2007; Lawson et al., 2014; Sinedino et al., 2014).

Table 1. Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV) and accuracy of plasma and milk pregnancy-associated glycoprotein (PAG) ELISA tests for determination of pregnancy status 32 d after AI. Adapted from Ricci et al., 2005.

PAG ELISA	PPV[1] % (no./no.)	NPV[2] % (no./no.)	Sensitivity[3] % (no./no.)	Specificity[4] % (no./no.)	Accuracy[5] % (no./no.)
Plasma	84 (57/68)	100 (73/73)	100 (57/57)	87 (73/84)	92 (130/141)
Milk	79 (52/66)	99 (68/69)	98 (52/53)	83 (68/82)	89 (120/135)

[1]Proportion of cows diagnosed pregnant using the PAG ELISA that truly were pregnant.
[2]Proportion of cows diagnosed as not-pregnant using the PAG ELISA that truly were not-pregnant.
[3]Proportion of pregnant cows with a positive PAG ELISA outcome.
[4]Proportion of not-pregnant cows with a negative PAG ELISA outcome.
[5]Proportion of pregnancy status outcomes, pregnant and not-pregnant, that were correctly classified by the PAG ELISA.

From an economic perspective, the sensitivity of an early nonpregnancy test (i.e., correct identification of pregnant cows) is more important than the specificity (i.e., correct identification of nonpregnant cows) based on two economic simulations (Galligan, 2011; Giordano et al., 2013). Further, to obtain a positive economic value for an early chemical nonpregnancy test, the sensitivity had to be greater than 96% when the test is used 31 d and greater than 94% when used 24 d after AI (Giordano et al., 2013). The sensitivity of both the plasma and the milk PAG ELISA tests evaluated in the present study (Table 1) as well as the sensitivity reported by others (Silva et al., 2007; Romano and Larson, 2010) exceed those criteria and support that use of these commercial tests to diagnose pregnancy status 32 d after AI would economically benefit a dairy farm.

Results from the present study support use of plasma PAG testing around 32 d after TAI and milk PAG testing 32 to 39 d after TAI when PAG levels in pregnant cows are at an early peak and pregnancy outcomes for pregnant cows approach 100% accuracy. By contrast, the advantages of the plasma and milk PAG ELISA tests are diminished when conducted during the temporal nadir in plasma and milk PAG levels from 46 to 74 d after TAI due to an increase in pregnant cows with outcomes of not pregnant or recheck. Pregnant cows incorrectly diagnosed not pregnant ultimately may undergo iatrogenic pregnancy loss if they continue the resynchronization protocol and are treated with $PGF_{2\alpha}$ thereby resulting in an economic loss (Galligan, 2009; Giordano et al., 2013).

Accuracy of Pregnancy Outcomes during the First Trimester of Gestation. To determine the accuracy of plasma and milk PAG ELISA outcomes during the first trimester of gestation, pregnancy outcomes from cows that maintained a singleton pregnancy from 25 to 102 d after TAI (n = 48) were analyzed. Cows diagnosed pregnant 32 d after TAI based on transrectal ultrasonography continued the experiment in which pregnancy outcomes based on PAG levels in plasma and milk were classified based on cutoff levels specified by the manufacturer. Overall, pregnancy outcomes for all pregnant cows based on both plasma and milk PAG ELISA tests were a reflection of PAG levels in plasma and milk (Figure 1). Plasma and milk PAG ELISA outcomes of "not pregnant" and "recheck" occurred 25 d after TAI for pregnant cows. Plasma PAG ELISA outcomes for pregnant cows, however, were 100% pregnant 32 d after TAI, whereas the milk PAG ELISA exceeded 98% pregnant outcomes 32 d and 39 d after TAI. Plasma and milk PAG ELISA outcomes of "not pregnant" and "recheck" increased concomitant to the temporal decrease in plasma and milk PAG levels during the nadir and then decreased as plasma and milk PAG levels increased as gestation ensued.

In a study to assess aggressive early nonpregnancy diagnosis with a strategy for resynchronization of ovulation, pregnancy status of cows initiating the first GnRH injection of an Ovsynch protocol 25 d after TAI was determined 27 d after TAI by using a PAG ELISA test (Silva et al., 2009). Cows diagnosed not pregnant continued the Resynch protocol by receiving an injection of $PGF_{2\alpha}$ 7 d after the initial GnRH injection and a second GnRH injection 54 h after the $PGF_{2\alpha}$ injection. Cows received TAI approximately 16 h after the second GnRH injection 35 d after AI. The authors concluded that earlier detection of nonpregnant cows using the PAG ELISA in conjunction with a protocol for resynchronization of ovulation and TAI increased the rate at which cows became pregnant in a dairy herd compared with transrectal ultrasonography conducted at a later stage after TAI. This agrees with an economic simulation of use of chemical tests for identification of nonpregnant cows early after AI in conjunction with a protocol for resynchronization of ovulation and TAI which concluded that the major economic advantage of using a chemical test was to decrease the interbreeding interval (Giordano et al., 2013).

Pregnancy Loss. The incidence of pregnancy loss in the present study for cows diagnosed with singleton pregnancies 32 d after TAI during the experiment was 13% (7/55) which agrees with the 13% loss reported to occur from 27 to 31 and 38 to 50 d of gestation based on transrectal ultrasonography 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 tested recheck based on the plasma PAG test before the loss occurred compared to 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 to transrectal ultrasonography. Because PAG levels are high during late gestation, it takes up to 60 d for residual PAG to be cleared from maternal circulation after parturition in cows (Sasser et al., 1986; Zoli et al., 1992) and other ruminants (Haugejorden et al., 2006). Because of the PAG half-life in circulation, cows submitted for a pregnancy diagnosis before 60 d postpartum can test positive due to residual PAG levels from the previous pregnancy (Giordano et al., 2012), and the manufacturer of the plasma and milk PAG ELISA tests evaluated in this experiment recommends that cows be > 60 d after parturition when tested.

Based on serum samples assayed using the same PAG ELISA test evaluated in the present experiment to determine how rapidly PAG concentrations decrease after an induced pregnancy loss in dairy cows at 39 d in gestation (Giordano et al., 2012), approximately 5 to 7 d elapsed before PAG levels returned to basal levels when luteal regression was induced with PGF2α or when the embryo died. Thus, most cows undergoing pregnancy loss will test pregnant or recheck at an early pregnancy diagnosis conducted using either the plasma or the milk PAG ELISA test. Because it is impossible to distinguish between the pregnancy outcomes of cows undergoing pregnancy loss and those of pregnant cows that test as “recheck” or “not pregnant” during the temporal PAG nadir, it is important that all cows with “pregnant” or “recheck” outcomes at an early test be retested at a later time. Based on temporal PAG profiles in the present study, the best time to conduct a first pregnancy test is around 32 d after TAI with all pregnant cows submitted for a pregnancy recheck 74 d after AI or later when PAG levels in plasma and milk of pregnant cows are rebounding from their nadir.

Effect of Milk Production on Plasma and Milk PAG Levels. Plasma PAG levels in pregnant cows were negatively correlated with milk production for both primiparous ($P = 0.002$; $R^2 = 0.05$) and multiparous ($P < 0.01$; $R^2 = 0.18$) cows. Similarly, milk PAG levels in pregnant cows were negatively correlated with milk production for both primiparous ($P < 0.01$; $R^2 = 0.14$) and multiparous ($P < 0.01$; $R^2 = 0.23$) cows. López-Gatius et al (2007) first reported a negative association between plasma PAG levels and milk production in dairy cows. Because relative PAG concentrations decreased in both plasma and milk with increasing milk production, the negative association between PAG levels and milk production is not a result of dilution of PAG levels in milk with increasing production. One possible explanation not tested in this experiment is that PAG production by the conceptus decreases with increasing milk production. If PAG production by the conceptus is a proxy for embryonic growth and development during early pregnancy, the decrease in plasma and milk PAG levels with increasing milk production might suggest that cows with greater milk production may have had slower growing embryos during early development. Further experiments are needed to fully understand the relationship between increased milk production and decreased PAG levels in plasma and milk and what, if any, implications this may have on the health of the developing embryo.

Which pregnancy test is Better - Blood or Milk? Based on the sensitivity analysis in this experiment (Table 1), both the plasma and milk PAG ELISA tests are accurate for pregnancy diagnosis when conducted 32 d after AI based on the temporal plasma and milk PAG profiles (Figure 1). Further, several economic analyses support the use of early nonpregnancy tests for improving reproduction within a dairy herd (Galligan et al., 2009; Giordano et al., 2013). Thus, the choice of whether to use the blood or the milk test to diagnose pregnancy is determined by the availability of the test, and the ability to collect the samples.

From a practical perspective, neither the plasma nor the milk PAG tests are cow-side or on-farm tests. Cows must be identified and restrained to collect a blood or a milk sample, and the samples must be sent to an off-farm laboratory that can run the ELISA test. Within several days and after receiving the pregnancy outcome, cows diagnosed not pregnant must again be identified and restrained to submit them to a strategy for rapidly returning them to AI. This is best achieved as part of an aggressive resynchronization strategy for nonpregnant cows as we have described in a number of experiments (Fricke et al., 2003; Sterry et al., 2006; Silva et al., 2009; Bilby et al., 2013; Lopes et al., 2013). It is important to note that no matter what method of pregnancy testing you use (i.e., transrectal palpation, transrectal ultrasonography, or chemical testing) that there are three possible outcomes: 1) pregnant; 2) not pregnant; and 3) recheck. For the plasma and milk PAG tests evaluated in this experiment, the proportion of recheck outcomes is highly dependent on when after AI blood or milk samples are collected (Figure 1); however, a few cows will test recheck even at 32 d after AI due to the occurrence of pregnancy loss and the variation in PAG levels among pregnant cows.

Depending on the farm, milk samples may be easier to collect than blood samples. The only commercially available milk PAG ELISA (IDEXX Laboratories, Westbrook, ME) is marketed through regional DHIA testing centers throughout the United States making the test widely accessible to most farms. A pregnancy diagnosis can be easily conducted on the same milk samples sent for DHIA testing on a monthly basis; however, monthly pregnancy examinations are not frequent enough to drive the reproductive program on a dairy farm. This makes it necessary to conduct additional tests on a weekly or bi-weekly basis. By contrast, many farms can easily collect blood samples, and three commercial blood pregnancy tests are available in North America (BioPRYN, BioTracking, LLC, Moscow, ID; DG29, Conception Animal Reproduction Technologies, Beaumont, QC; IDEXX Bovine Pregnancy Test, IDEXX Laboratories, Inc, Westbrook, ME). The blood ELISA tests are run in regional laboratories located around North America and should be accessible to most farms. Care should be taken, however, to make sure samples are labeled correctly.

Conclusions

The experiment described herein (Ricci et al., 2015) is one of the first studies to directly compare factors associated with plasma and milk PAG levels during the first trimester of gestation in Holstein cows. Stage of gestation, parity, pregnancy loss, and milk production were associated with relative PAG levels in both plasma and milk in a similar manner; however, milk PAG levels were about 2-fold lower than plasma PAG levels. Based on PAG profiles in plasma and milk samples collected weekly, the optimal time to conduct a first pregnancy diagnosis is around 32 d after TAI when plasma and milk PAG levels are at an early peak, whereas conducting either the plasma or milk PAG test during the temporal nadir in plasma and milk PAG levels would result in poor overall accuracy. Because of the occurrence of pregnancy loss, all pregnant cows should be submitted for a pregnancy recheck 74 d or later after AI when relative PAG levels in plasma and milk of pregnant cows have rebounded from their nadir.

References

Bilby, T. R., R. G. S. Bruno, K. J. Lager, R. C. Chebel, J. G. N. Moraes, P. M. Fricke, G. Lopes, Jr., J. O. Giordano, J. E. P. Santos, F. S. Lima, S. L. Pulley, and J. S. Stevenson. 2013. Supplemental progesterone and timing of resynchronization on pregnancy outcomes in lactating dairy cows. J. Dairy Sci. 96:7032-7042.

Fricke, P. M. 2002. Scanning the future – Ultrasonography as a reproductive management tool for dairy cattle. J. Dairy Sci. 85:1918-1926.

Fricke, P. M., D. Z. Caraviello, K. A. Weigel, and M. L. Welle. 2003. Fertility of dairy cows after resynchronization of ovulation at three intervals after first timed insemination. J. Dairy Sci. 86:3941-3950.

Galligan, D. T., J. Ferguson, R. Munson, D. Remsburg, and A. Skidmore. 2009. Economic concepts regarding early pregnancy testing. Pages 48–53 in Proc. Am. Assoc. Bovine Pract., Omaha, NE. Am. Assoc. Bovine Pract., Auburn, AL.

Giordano, J. O., J. N. Guenther, G. Lopes Jr., and P. M. Fricke. 2012. Changes in plasma pregnancy-associated glycoprotein (PAG) pregnancy specific protein B (PSPB), and progesterone concentrations before and after induction of pregnancy loss in lactating dairy cows. J. Dairy Sci. 95:683-697.

Giordano, J. O., P. M. Fricke, and V. E. Cabrera. 2013. Economics of resynchronization strategies including chemical tests to identify nonpregnant cows. J. Dairy Sci. 96:949-961.

Green, J. A., S. Xie, X. Quan, B. Bao, X. Gan, N. Mathialagan, J. F. Beckers, and R. M. Roberts. 2000. Pregnancy-associated bovine and ovine glycoproteins exhibit spatially and temporally distinct expression patterns during pregnancy. Biol. Reprod. 62:1624-1631.

Green, J. A., T. E. Parks, M. P. Avalle, B. P. Telugu, A. L. McLain, A. J. Peterson, W. McMillan, N. Mathialagan, R. R. Hook, S. Xie, and R. M. Roberts. 2005. The establishment of an ELISA for the detection of pregnancy-associated glycoproteins (PAGs) in the plasma of pregnant cows and heifers. Theriogenology 63:1481-1503.

Haugejorden, G., S. Waage, E. Dahl, K. Karlbert, J. F. Beckers, and E. Ropstad. 2006. Pregnancy associated glycoproteins (PAG) in postpartum cows, ewes, goats and their offspring. Theriogenology 66:1976-1984.

Humblot, P. 2001. Use of pregnancy specific proteins and progesterone assays to monitor pregnancy and determine the timing, frequencies and sources of embryonic mortality in ruminants. Theriogenology 56:1417-1433.

Lawson, B. C., A. H. Shahzad, K. A. Dolecheck, E. L. Martel, K. A. Velek, D. L. Ray, J. C. Lawrence, and W. J. Silva. 2014. A pregnancy detection assay using milk samples: evaluation and considerations. J. Dairy Sci. 97:6316-6325.

LeBlanc, S. J. 2013. Short communication: Field evaluation of a pregnancy confirmation test using milk samples in dairy cows. J. Dairy Sci. 96:2345-2348.

Lopes, G. Jr., J. O. Giordano, A. Valenza, M. M. Herlihy, M. C. Wiltbank, and P. M. Fricke. 2013. Effect of timing of initiation of resynchronization and presynchronization with GnRH on fertility of resynchronized inseminations in lactating dairy cows. J. Dairy Sci. 96:3788-3798.

López-Gatius, F., J. M. Garbayo, P. Santolaria, J. Yaniz, A. Ayad, N. M. de Sousa, and J. F. Beckers. 2007. Milk production correlates negatively with plasma levels of pregnancy-associated glycoprotein (PAG) during the early fetal period in high producing dairy cows with live fetuses. Dom. Anim. Endocrinol. 32:29-42.

Prakash, B., V. L. Telugu, A. M. Walker, and J. A. Green. 2009. Characterization of the bovine pregnancy-associated glycoprotein gene family – analysis of gene sequences, regulatory regions within the promoter and expression of selected genes. BMC Genomics 10:185-202.

Ricci, A., P. D. Carvalho, M. C. Amundson, R. H. Fourdraine, L. Vincenti, and P. M. Fricke. 2015. Factors associated with pregnancy-associated glycoprotein (PAG) levels in plasma and milk of Holstein cows during early pregnancy and their impact on the accuracy of pregnancy diagnosis. J. Dairy Sci. (in press).

Santos, J. E. P., W. W. Thatcher, R. C. Chebel, R. L. A. Cerri, and K. N. Galvão. 2004. The effect of embryonic death rates in cattle on the efficacy of estrus synchronization programs. Anim. Reprod. Sci. 82-83:513-535.

Sasser, G. R., C. A. Ruder, K. A. Ivani, J. E. Butler, and W. C. Hamilton. 1986. Detection of pregnancy by radioimmunoassay of a novel pregnancy-specific protein in plasma of cows and a profile of plasma concentrations during gestation. Biol. Reprod. 35:936-942.

Silva, E., R. A. Sterry, D. Kolb, N. Mathialagan, M. F. McGrath, J. M. Ballam, and P. M. Fricke. 2007. Accuracy of a pregnancy-associated glycoprotein ELISA to determine pregnancy status of lactating dairy cows twenty-seven days after timed artificial insemination. J. Dairy Sci. 90:4612-4622.

Silva, E., R. A. Sterry, D. Kolb, N. Mathialagan, M. F. McGrath, J. M. Ballam, and P. M. Fricke. 2009. Effect of interval to resynchronization of ovulation on fertility of lactating Holstein cows when using transrectal ultrasonography or a pregnancy-associated glycoprotein enzyme-linked immunosorbent assay to diagnose pregnancy status. J. Dairy Sci. 92:3643-3650.

Sinedino, L. D. P., F. S. Lima, R. S. Bisinotto, R. A. A. Cerri, and J. E. P. Santos. 2014. Effect of early or late resynchronization based on different methods of pregnancy diagnosis on reproductive performance of dairy cows. J. Dairy Sci. 97:4932-4941.

Souza, A. H., H. Ayres, R. M. Ferreira, and M. C. Wiltbank. 2008. A new presynchronization system (Double-Ovsynch) increases fertility at first postpartum timed AI in lactating dairy cows. Theriogenology 70:208-215.

Sterry, R. A., M. L. Welle, and P. M. Fricke. 2006. Effect of interval from timed AI to initiation of resynchronization of ovulation on fertility of lactating dairy cows. J. Dairy Sci. 89:2099-2109.

Zoli, A. P., L. A. Guilbault, P. Delahaut, W. B. Ortiz, and J. F. Beckers. 1992. Radioimmunoassay of a bovine pregnancy-associated glycoprotein in plasma: Its application for pregnancy diagnosis. Biol. Reprod. 46:83-92.

Notes:

How are Genomics Working on the Dairy?

Corey Geiger
Managing Editor, Hoard's Dairyman
28 Milwaukee Avenue West
Fort Atkinson, WI 53538
(920) 563-5551 extension 120
cgeiger@hoards.com

Dovetailing on Dr. Kent Weigel's presentation, "Future impact of genomics in sire selection and herd management," our panel will include observations by four dairy producers who have been working with genomics in the replacement side of their herds for nearly five years. The panelists include: John Andersen, Double A Dairy in Idaho; Brett Barlass, Yosemite Jersey Dairy in California; Jonathan Lamb, Oakfield Corners & Lamb Farms in New York; and Dan Siemers, Siemers Holsteins in Wisconsin. As panel moderator, I will also weave in some experiences from the Hoard's Dairyman Farm. Together, this group who milks some 25,000-plus cows has perhaps run more genomic tests than any other collective group of herds in the country.

From the dairy producer's perspective, the question is how genomic testing might fit into a herd setting. What are the potential returns to the dairy operation? How might it transform the handling of replacements on a dairy?

Think the cost of incorporating genomics is too high? Then consider all of the dollars spent on seed corn genetics. While valuable, that investment lasts merely one cropping year. Doesn't dairy genetics deserve the same investment? If we raise and calve in our own replacements, these genetics are built upon each generation and we continue to reap rewards each year.

Dairy producer's perspective

As far as genetic progress is concerned, "The whole genetic paradigm has brought us back to generation intervals and pushed us to look at the younger generation," said Dan Siemers, who maintains a 34,000-pound herd average on 2,400 head. "Also, the genomic test profile allows us to correctively mate heifers much better."

"The benefits far outweigh the negatives on genomics," said John Andersen of Jerome, Idaho. "If there is a downside, we are moving quite fast, and there are a number of bulls with two and some with even three generations without actual progeny or production information."

"Inbreeding may be an issue, but you must remember that everyone wants to use the best bulls and acquire the best genes. That is the main cause of inbreeding in the first place," said Wisconsin dairyman Dan Siemers.

Genomics also opened a whole new door to evaluating different traits. Traits that could better improve fertility, feed efficiency and perhaps one day even hoof health.

As for future improvements on genetic selection, "The trait I'd like to see an index for and more research on is foot health," said Jonathan Lamb, Oakfield N.Y. "I think it's a real black eye for the industry, and we can always do better on our farm," said the chairman of the Holstein Association USA's Genetic Advancement Committee. "I don't think we measure foot health adequately from a phenotypic standpoint right now."

"Daughter pregnancy rate is a great success story in the Holstein breed," expressed Lamb. "Just a few years ago, we stopped the longtime decline in fertility. Eight years ago, we had preg rates hovering in the 19 to 20 percent range. Now, we easily reach 25 to 28 percent."

As for the trait that pays all our bills — production — with an eye to the future, Lamb noted both the present and things yet to come.

"After many discussions over the past year, I am more convinced than ever that protein is more important than fat," said Lamb. "We need to keep selection pressure on protein production because it's in demand and it drives our milk checks."

From an implementation standpoint, Yosemite Jerseys fully employed genomics in 2010.

Herd manager Brett Barlass started using genomics in 2010, testing every heifer calf at one day of age. "Our original goal was to use genomic information primarily to determine which heifers to keep as replacements on the dairy and which ones to sell," says Barlass.

That strategy changed when the family who owns the herd decided to build a second dairy in Texas. Currently, all of the California herd's heifers are retained to expand the Texas herd, but Barlass says the genomic results still provide value. Because they use a lot of young sires, "we're getting a jump on genetic information well in advance of bull proofs," he says.

The identification of Jersey fertility haplotype 1 (JH1)-carrier females also allows Barlass to avoid breeding them to JH1-carrier bulls, since that particular halotype can negatively affect fertility. And correction of parentage errors helps him prevent inbreeding.

So what might implementing a genomic testing system on your dairy involve?

While Andersen, Barlass, Lamb and Siemers have been working with genomic tests on their replacements for over five years, the Hoard's Dairyman Farm got started just last year. This real-world experience also could provide the audience questions for the panel or additional insight on how genomics might fit into their operation.

What Hoard's learned from our genomic test results

Do individual cows in high-producing herds have an improved or reduced capacity to express their genetic potential?

"If we have good management on a farm, genetics matter more because a cow's genetic ability has an even greater opportunity to express itself," Vita Plus' Pat Hoffman explained at a meeting we attended earlier this year.

Such is the case at the Hoard's Dairyman Farm where the Jersey herd is averaging 20,223 M, 984 F and 761 P. As a result, the combination of high production and genetic potential has caused our Jerseys to outperform their genetic predictions.

That's right, by comparing real-world production results with predicted transmitting abilities for milk, we know that, on average, cows from a 1,000-pound-plus milk bull are actually averaging 1,590 pounds more milk than a typical daughter of sires at zero (0) predicted transmitting ability for milk (PTAM).

Put another way, we are getting 50 percent more milk from our genetics than the national average. That was one of the many items the Hoard's Dairyman team learned about our herd's genetics as Cheryl Marti of Zoetis sat down with us to review our genomic test results on the CLARIFIDE platform.

Likewise, the Hoard's team also found our daughter pregnancy rate (DPR) or the likelihood of our cows conceiving expressed itself more dramatically. While it would normally be expected that we'd see four fewer days open for each improvement to a sire's DPR. In our herd, we saw slightly more genetic difference to each positive 1.0 gain in DPR as it yielded five fewer days open.

Besides herd management, accurate sire ID also contributes to individuals outperforming genetic predictions. Thanks to relatively solid pedigree data recorded through registrations and herd records, the reliability of our herd started out at 31 percent for Net Merit. Then, due to the power of studying DNA, that reliability doubled to 62 percent. Milk reliability was even more robust, moving from 34 to 67 percent. Marti, who had held the role of dairy production specialist with Zoetis, noted that the 31 percent was among the highest in commercial herds — either Jersey or Holstein — that she has worked with when studying results.

As we learn more about genetics through genomics, it also spread out the bell-shape curve on our herd's genetic potential. Prior to the test, the 162 individuals ranged from 12 to 416 NM$ with an average of 223. After the test results came back, the spread moved from -60 to $558 NM$ with a mean of 252 (based on August 2014 genetic evaluations).

We also found out that our Jerseys were slightly less inbred as a whole. Our pedigree-based inbreeding levels were 6.3 percent, but that number fell to 5.6 percent after reviewing the genomic tests. That compares to an industry average of roughly 7.3 percent for pedigree-based inbreeding for the Jersey breed. As far as haplotypes are concerned, the 13.6 percent prevalence of JH1, which reduces fertility, was also lower than the 20 percent level found in the breed. Knowing these results will allow us to make better mating decisions for the next generation.

Some mis-ID'd calves

At first, the entire Hoard's team was alarmed to learn that 8 percent of our calves had misidentified sires. However, after talking to Marti, she pointed out that many herds average rates of 8 to 20 percent with an industry average hovering near 14 percent of misidentified animals. While she assured us our 8 percent figure was good, we wanted to delve deeper into those eight misidentified sires.

Due to good on-farm records and the power of genomics, the Hoard's crew was able to rectify all eight incorrectly identified sires among those tested individuals. All eight originated on ovsynch days when multiple cows were bred on the same day. On ovsynch day, the inseminator was more likely to not double-check the straw after pulling it out of the gun warmer before inseminating the cow. Steps have been taken to correct this issue in the future.

In addition to those errors, the test revealed we did have one misidentified dam. On a very good note, 161 of the 162 maternal grandsires were confirmed to be exact matches due to the genomic tests. The one that could not be verified didn't have a genomic test profile.

Finding a different career

By using the genomic tests, we were able to run some numbers on our heifer crop. In one scenario, culling the bottom 20 percent (all those with NM$ under 160) could dramatically improve our profitability. In addition, if we had a group of our top individuals in our herd, they would be expected to outperform the worst calves by approximately $1,200 over their entire lifetime as measured by income over feed costs and other health costs, which are included in $NM.

While the Hoard's team winced at culling 20 percent of young calves, the idea does have merit. As we looked at each age group on a bar graph, the calves that were the poorest genetic doers were even outranked by cows already in the milking herd. A similar situation would exist in nearly every herd in the nation.

A more plausible scenario might be culling the bottom 5 to 8 percent immediately after getting the genomic results back. To make the best use of this strategy, young calves would have to be tested every 30 days. Even though the largest daily expense is sunk into calves during the first 60 days of life, those heifers still eat a lot of feed before they calve in at an average age of 1 year 11 months, Hoard's Dairyman Farm manager Jason Yurs pointed out. Zoetis has a dashboard tool where we can evaluate economics and different culling levels. It will prove useful in looking further into culling genetically inferior heifers.

The discussion turned to the farm's use of sexed semen. "All our Jersey heifers are serviced to sexed semen on the first service," Yurs reminded those attending the meeting. "We might be better served to breed the top half of the heifer herd to sexed semen twice and the bottom half to conventional semen," Yurs noted as he thought how to implement the strategy easily in the day-to-day operations.

"Can we load the genomic test results into Dairy Comp 305 and mark the genetically superior heifers?" he went on to ask.

"We could easily do that after the meeting," replied Marti.

That just may be one of our first action plans. Of course, there also will be follow-up with some genetically superior heifers that quickly received A.I. interest.

While we have more concepts to follow-up with, we were pleased to learn our herd is on the right track for genetic improvement. We definitely believe the genomic test results can help fine-tune our herd and bottom line.

Notes:

Use of Technologies in Reproductive Management: Economics of Automated Activity Monitoring Systems for Detection of Estrus

Julio O. Giordano
272 Morrison Hall,
Department of Animal Science
Cornell University
Ithaca, NY 14853
jog25@cornell.edu

Take Home Messages

- Automated activity monitoring systems (**AAM**) can be incorporated as a tool to replace visual observation of estrus.

- General considerations before an AAM system acquisition include: current estrus detection (**ED**) efficiency, system cost, visual observations cost, and system life expectancy. Purchasing a system with a life expectancy of at least 5 years would be critical under all conditions.

- Improvement in ED efficiency necessary to breakeven or improve profitability largely depends on the: (1) baseline proportion of cows inseminated in estrus with the current ED program; (2) life expectancy of the AAM system and its cost: and (3) cost of the program for visual observation of estrus.

- AAM systems may be a feasible and economically beneficial solution for dairy farms with limitations to conduct an efficient ED program or dairy farms that prefer to allocate personnel to other activities.

Introduction

Insemination of cows based on estrual behavior continues to be a widespread strategy to service lactating dairy cows in a vast majority of dairy farms in the U.S. and elsewhere (Caraviello et al., 2006; Ferguson and Skidmore, 2013). Therefore, dairy farmers that rely on detection of estrus should strive to develop and maintain a successful estrus-detection (**ED**) program that leads to excellent reproductive performance and maximizes profitability. Success of any ED program will depend, at least in part, on the ability of cows to display estrus, which is affected by a myriad of physiological and management factors that either favor or suppress estrus expression (Roelofs et al., 2005; Wiltbank et al., 2006; Palmer et al., 2010). Another critical factor to the success of the program is the ability of farm personnel to identify cows in estrus. Such endeavor requires a significant effort and dedication by farm personnel that many farms fail to maintain, whereas others may prefer to avoid altogether. In this regard, adopting new technologies such as automated activity monitoring (**AAM**) systems may be a viable alternative to dairy farms that either struggle with their ED program or prefer to allocate their resources and time to other activities.

Although numerous devices and technologies with different levels of complexity have been developed and are available to dairy farms to either replace or aid with ED in dairy farms (Nebel et al., 2000; Firk et al., 2002; Hockey et al., 2010; Valenza et al., 2012; Chanvallon et al., 2014), the interest and adoption by dairy farms of the new generation of AAM systems has increased in recent years. Indeed, to date at least 7 to 10 different AAM systems are available to dairy farms in the U.S. These systems can be integrated with other technologies or installed as a stand-alone system for detection of estrus. Details on how AAM systems work are beyond the scope of this paper and can be found elsewhere (Firk et al., 2002; Valenza et al., 2012; Michaelis et al., 2014). Likely this trend for adoption of technologies will continue as better, more cost-effective, and user-friendly technologies become available for dairy farms. Nevertheless, like for any other capital investment, farms incur in a substantial upfront cost to cover the purchase, installation, and maintenance of AAM systems. Therefore, the potential benefits to farm management of incorporating an AAM system should be weighed in with the cost of adopting this new technology for detection of estrus. To this date very few studies have thoroughly evaluated the economics of adding an AAM system for ED in dairy farms and those available were focused on very particular research scenarios (Larson, 2007; Fricke et al., 2014).

Thus, the objective of this paper was to evaluate the economic implications of incorporating an AAM system for detection of estrus in a dairy herd. Different reproductive management scenarios and economic aspects of purchasing an AAM system were considered to represent the conditions of commercial dairy farms evaluating the adoption of this technology for detection of estrus.

Activity Monitors for Detection of Estrus

In recent years several research studies have been conducted around the world to evaluate the performance of the new generation of AAM systems on commercial dairy farms under more intensive confinement (Neves et al., 2012; Valenza et al., 2012; Chanvallon et al., 2014; Fricke et al., 2014; Michaelis et al., 2014; Stevenson et al., 2014) or pasture-based conditions (Hockey et al., 2010; Aungier et al., 2012).

The majority of the recent studies performed in North America (Neves et al., 2012; Valenza et al., 2012; Fricke et al., 2014; Stevenson et al., 2014) seem to indicate that AAM systems can be successfully used by dairy farmers to inseminate cows based on activity. Nevertheless, due to physiological limitations presented by lactating dairy cows (Valenza et al., 2012; Stevenson et al., 2014) or technical limitations of these systems that lead to inaccuracy of detection of estrus (Hockey et al., 2010; Holman et al., 2011; Chanvallon et al., 2014; Stevenson et al., 2014), it seems clear that AAM systems should be used in combination with synchronization of estrus and ovulation protocols before TAI. Induction of estrus with 1 or more prostaglandin $F_{2\alpha}$ (PGF) injections maximizes the proportion of cows that are inseminated immediately after the end of the VWP or non-pregnancy diagnosis (Fricke et al., 2014; Giordano et al., 2014; Stevenson et al., 2014), whereas inclusion of a TAI protocol ensures timely AI of cows that are not detected with increased activity after the end of the VWP (Fricke et al., 2014; Stevenson et al., 2014) or after failing to conceive to a previous AI service (Giordano et al., 2014). Whether estrus synchronization with PGF is used and the time interval at which the TAI protocol is initiated depends on the known or expected success of the farm to identify cows displaying estrus and the resulting fertility of AI services based on activity. Farms able to achieve average or above average ED efficiency without estrus synchronization could avoid it altogether and potentially consider delaying the initiation of the TAI program. Conversely, farms that struggle with ED should consider favoring estrus expression with the use of estrus inducing agents and avoid overextending the period until initiation of the TAI protocol to have better control of the timing of insemination.

Economic Assessment of Automated Activity Monitoring Systems

Based on the research results discussed and observations from commercial dairy farms that employ AAM systems, it is clear that AAM systems can be used to perform ED on a dairy farm, and that in general, AAM systems must be combined with a TAI program to achieve maximal reproductive performance.
These systems can be an alternative for dairy farms that:

1-struggle to maintain an efficient and consistent ED program,

2-farms that prefer to automate ED in order to reduce the number of activities performed by certain personnel at the farm (i.e., owner, herd managers, herdspersons, AI technician, or milkers).

Numerous biological and management factors obviously affect the performance of an AAM system on a particular dairy farm and because they are very specific, a myriad of scenarios could be explored. Some general questions, however, apply to the majority of farms and should be addressed before making the decision of incorporating an AAM system for detection of estrus. Specifically, it is relevant to determine:

1-the economic impact of adding the AAM system according to the current reproductive performance

2-labor efficiency of the ED program in place at the farm

3-impact of the AAM system cost on the profitability of the farm reproductive program.

Thus, the specific objectives of this simulation study were to explore the following concepts:

(1) what is the economic value of incorporating an AAM system when a farm has varying levels of ED efficiency (poor vs. average)

(2) what is the impact of the AAM system life expectancy and upfront cost on its economic value?

(3) what is the economic value of incorporating an AAM system with varying levels of labor efficiency and cost of performing visual ED?

A simulation study was performed to evaluate several scenarios that would reflect the conditions of a commercial dairy farm considering incorporation of an AAM system. All analyses were created and

run using the UWCU-Repro$ decision support system. This software tool has the capability of comparing multiple scenarios for a current versus and alternative reproductive management program for a dairy farm. Details about the simulation model used to create the software tool are not described herein because they can be found elsewhere (Giordano et al., 2012). Development of this software tool was the result of research collaboration between Dr. Victor Cabrera's laboratory at the University of Wisconsin-Madison and Dr. Giordano at Cornell University. The tool is available to users at no cost at:
http://ansci.cals.cornell.edu/extension-outreach/adult-extension/dairy-management/wisconsin-cornell-dairy-repro-giordano and
http://dairymgt.uwex.edu/tools.php.

It is important to note that the following analysis is <u>strictly limited to detection of estrus</u> which excludes the potential benefits that some of the new AAM systems may include. For example, some systems can integrate automated monitoring of biological traits indicative of health status (i.e., rumination, body temperature), parlor identification, daily milk weights, milk components, etc. Assuming that the information generated by these systems is reliable and can be utilized by dairy farms to make management decisions beyond ED, potential economic added value was not all accounted for in this analysis and should be considered at the time making a purchase.

Farm Description and General Economic Input Measures

The conditions simulated were for a typical commercial confined dairy herd in the Northeast U.S. with 1,000 milking cows. Cows were housed in freestall barns with headlocks at the feed line that could be used to facilitate AI. Milk production was based on lactation curves extracted from a 1,100 milking cow herd in NY producing approximately 28,000 lb of milk per cow-yr, involuntary culling rate of 28%, mortality rate at 5%, and stillbirth rate at 5%.

General economic measures included: milk price of $22.80 per cwt (all milk price from USDA National Agricultural Statistics Service for last 12 months), cost of feeding lactating cows of $0.14 lb of DM, and cost of feeding dry cows at $0.10 lb of DM, female and male calf value at $175 and $25, respectively, heifer replacement cost at $1,750, and salvage value of cows at $0.90 per lb of live weight. Cost of insemination was set at $10 per AI (including semen and labor), pregnancy testing at $110 per hour, whereas GnRH and PGF for synchronization of ovulation were set at $2.50 per dose.

Comparison of Reproductive Programs

Baseline reproductive management program consisted of a combination of ED and TAI for all inseminations. For first postpartum AI service cows were eligible to be inseminated if detected in estrus from the end of the VWP at 50 days until 75 days when the Ovsynch-56 (Brusveen et al., 2008) protocol (GnRH-7 d-PGF-56 hours - GnRH-16 hours TAI) was initiated for cows not yet detected in estrus and AI (Figure 1). After their first AI service cows were eligible to receive AI if detected in estrus. If not inseminated in estrus by 32 days after a previous insemination cows were enrolled in an ovulation-resynchronization protocol (GnRH-7 d-PGF-56 hours - GnRH-16 hours TAI) to receive TAI 10 days later (Figure 1). Non-pregnancy diagnosis was performed at 39 d after AI by palpation per rectum of uterine contents (at the time of the PGF injection of the protocol). For programs that used ED it was assumed that it was performed by VO by an experienced technician at a cost of $12.5 dollars per hour of labor.

For scenarios that used an AAM system the cost was set at $8,000 for installation of hardware including antennas, PC, and software, whereas cost per activity tag was set at $90 or 120 per tag depending on the scenarios evaluated. A total of $1,500 per year was included to account for maintenance and lost tags (i.e., 2%). A salvage value of 10% of the initial equipment cost was included. It was assumed that 50% of the cows in the herd were fitted with monitors from the end of the VWP until reconfirmation of pregnancy at 67 days after AI.

Using the reproductive management program described previously as baseline, different hypothetical scenarios were generated.

Scenario 1. Determine the economic value of improving detection of estrus in a scenario of *current poor ED efficiency* (30% of cows EDAI as baseline). In this case, numerous scenarios were simulated to include improvements in ED efficiency that result in 10-percentage point increments of cows EDAI up to a maximum of 80% of the cows. In this case, the assumption was that installing the AAM system would improve ED efficiency. Thus, the percentage of cows EDAI from the end of the VWP to the beginning of Ovsynch for first TAI or in between TAI services varied from 30 to 80% (Figure 1). It was assumed that no change to the insemination outcome (P/AI) would occur for cows receiving EDAI, whereas a 1% reduction for every 10-percentage point increment in cows EDAI for cows receiving TAI was included (baseline P/AI was 35% for first service and 33% for subsequent AI services when 30% of cows received EDAI) to account for the change in the population of cows reaching TAI (i.e., more anovular, metabolically challenged, unhealthy cows). A second dimension to the analysis was added by including variation to the AAM system cost and the labor effort to perform ED by VO. To evaluate different AAM system cost scenarios the life expectancy (i.e., number of years that the system was functional) and cost of activity tags varied. The system life expectancy was set at 3, 5, and 7 years to reflect a wide variation in system lifespan, whereas cost of activity monitors was set at either $90 or $120 per tag. Likewise, to evaluate the impact of labor efficiency for VO of estrus, the amount of hours performing ED by farm personnel was set at 2 (30 min per pen for 4 pens) or 3 hours (45 min per pen for 4 pens) per day.

Scenario 2. A second set of scenarios was created to simulate the conditions of a dairy farm that presented *current average ED efficiency* (60% of cows EDAI as baseline). In this case it was assumed that the farm had acceptable performance of VO of estrus and that the AAM system could only improve the percentage of cows EDAI by 10- or 20-percentage points to reach a maximum of 80% of the cows receiving EDAI. As for the previous set of scenarios with poor ED efficiency, impact of the AAM system cost and labor efficiency for ED was included. In both cases all other variables remain unchanged.

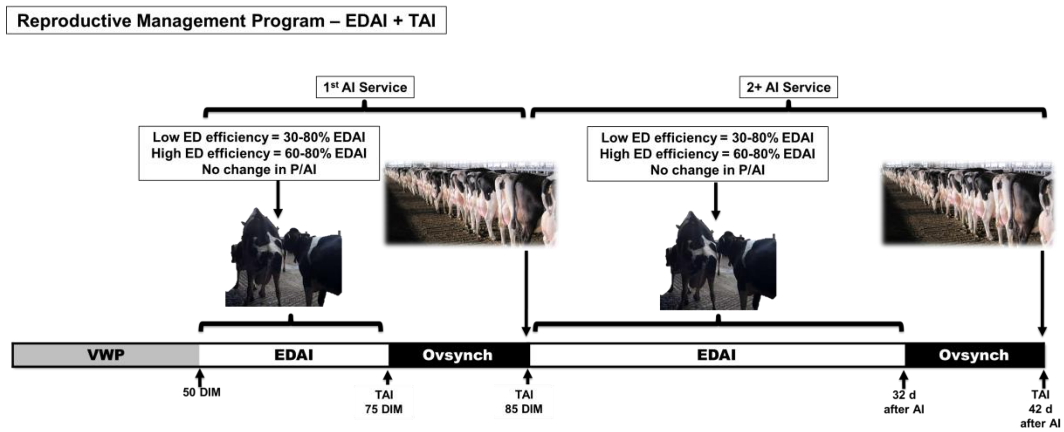


Figure 1. Schematic representation of baseline reproductive program simulated to assess the economics of adopting an automated activity monitoring system. EDAI = cows inseminated after estrus detected by visual observation or by increased physical activity; TAI = timed AI; ED = estrus detection; VWP = voluntary waiting period; P/AI = pregnancy per AI (conception risk).

Results and Discussion

Numerous economic scenarios were modeled to gain insight into some general questions that should be addressed by most dairy operations considering the integration of an AAM system to replace VO of estrus. It was assumed that the dairy of interest would prioritize a reproductive management program with reduced hormonal intervention, thereby synchronizing ovulation with the Ovsynch protocol was included only to ensure AI of cows not detected in estrus. No attempts were made to simulate conditions that would include more sophisticated synchronization protocols (e.g., Double-Ovsynch, Presynch-Ovsynch, G-6-G, etc.) known to improve the fertility of AI services in lactating dairy cows.

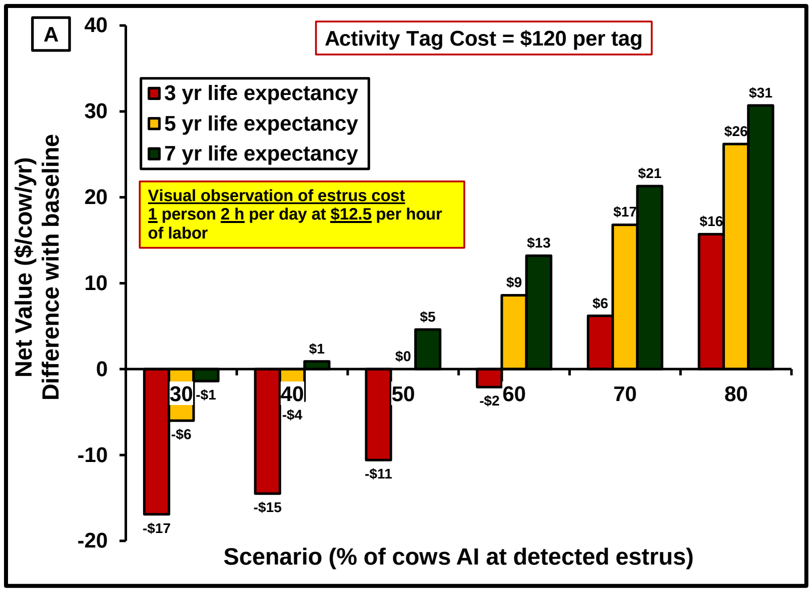
Current Poor-Estrus Detection Efficiency. Results for the scenarios simulated for a 1,000 cow herd with current poor ED efficiency (30% of the cows EDAI) are summarized (Figures 2 and 3). As expected, because of the concurrent evaluation of increases in the proportion of cows EDAI (from 30 to 80% in 10-percentage point increments), life expectancy (3, 5, or 7 years), and activity tag cost ($90 vs $120) for the AAM system, and the cost associated with different labor efficiency for VO (1 person at 2 or 3 hours per day), a wide range of results were obtained. Because the most likely current price for activity tags is $120, the results obtained for that base price will be discussed and only contrasted to those results for a tag price of $90. For this particular set of scenarios that assumed poor ED efficiency for the baseline program, incorporating the AAM system was associated with losses ($-17 to $-1 per cow-year), no change, or positive economic benefits ($1 to $39 per cow-year) depending on the increment in the proportion of cows EDAI and cost of the system. Economic impact of incorporating the AAM system at different levels of ED efficiency was dramatically affected by the life expectancy of the AAM system. For example, when the system life was set at 3 years, it would be necessary to increase the proportion of cows EDAI from 30 to 70% of the cows for the new program to be profitable ($6 cow per year; Figure 2A). Conversely, a 20- and 10-percentage point increment of cows EDAI would be necessary to breakeven or generate a $5 per cow-year gain in favor of the AAM system when the life expectancy was set at 5 and 7 years, respectively (Figure 2A). Impact of improving ED efficiency was anticipated because increasing the proportion of cows EDAI with no change in P/AI for cows EDAI would improve overall reproductive performance and reduce cost. As expected, a reduction in activity tag cost from $120 to $90 per tag would benefit programs that used the AAM system at all levels of longevity. In this case the increment in the proportion of cows EDAI to outperform the VO program was reduced by 10-percentage points for each one of the life expectancy scenarios evaluated. For example, for a life expectancy of 5 years, it was necessary to increase the proportion of cows EDAI from 30 to 50% when tag cost was $120 versus an increment from 30 to 40% cows EDAI when tag cost was set at $90 (Figure 2A and 2B).

Predicting the exact increase in ED efficiency for a particular dairy farm may not be possible because of the numerous intrinsic factors that affect the ability to inseminate cows in estrus. Nevertheless, because in most cases the major cause of poor ED efficiency is human error or insufficient resources (i.e., personnel and time) allocated to ED, it is possible to speculate that incorporating the AAM system could improve the percentage of cows EDAI by at least 20 to 30 percentage points. Under these circumstances and a tag cost of $120, the AAM system must remain functional for at least 5 years to breakeven and could generate as much as $13/cow per year in extra profits when life expectancy is 7 years (Figure 2A; 60% of cows EDAI). Assuming a similar improvement in proportion of cows EDAI (20 to 30%) and a tag cost of $90, the farm would benefit at all levels of life expectancy with improvements in profitability of $4, $12, and $16 per cow-year at each level of life expectancy (Figure 2B). Whether the farm can achieve above average ED efficiency with the AAM system to inseminate up to 70 and 80% of the cows in estrus will likely depend on providing the most optimal conditions for cows to display estrus (and increased activity) so that the system can maximize detection. Achieving such high level of ED efficiency, which would result in profits of as much as $21 to $31per cow-year (70 to 80% EDAI and LE of 7 years and $120 per tag), is unlikely to be observed for a majority of commercial dairy farms under confinement conditions; however, it may be observed in some very well managed dairy herds (Ferguson and Skidmore, 2013; Fricke et al., 2014).

Obviously numerous alternatives (e.g., induction of estrus with hormonal treatments, delaying the initiation of the TAI program) are available to maximize ED efficiency with an AAM system; however, the economic value of such programs was beyond the scope of this paper and were not evaluated because reproductive management scenarios to minimize the use of reproductive hormones were prioritized. Those interested in evaluating other programs that rely more heavily on TAI may use software tools such as the UWCU-Repro$ to evaluate their specific program of interests.

When cost for VO of estrus was greater because labor efficiency for ED was lower (3 hours per day), the same patterns were observed compared with the greater labor efficiency scenarios. In fact, for each of the scenarios simulated the difference with the high labor efficiency (2 hours per day) was exactly $6 per cow-year, which represents the extra cost for ED (Figure 3A). Because in this case VO of estrus was more expensive, the economic benefits of incorporating the AAM system were realized with smaller increments in the proportion of cows EDAI for the different life expectancy values. For example, an increment of 30 percentage points (from 30 to 60%) for cows EDAI at a tag cost of $120 would render the AAM system more profitable than VO by $4 per cow-year at a life expectancy of 3 years. In addition, under these conditions of greater VO cost, the AAM system would reach breakeven costs with a life expectancy of 5 years and could generate as much as $27 to 37 per cow-year in extra profits if 70 to 80% of cows are EDAI at a life expectancy of 7 years. Even more favorable conditions would be accrued when the tag cost was reduced to $90 and labor efficiency of VO was poor (< 50%). The AAM system would be more profitable than the VO program with no increase in the proportion of cows EDAI if life expectancy is at least 5 years and an increment in 20 percentage points for cows EDAI would make it profitable at a life expectancy of 3 years (Figure 3B). Under these conditions, the AAM system also could generate the greatest profitability observed in this study with $39 per cow-year with at least 80% of cows EDAI (Figure 3B).

When evaluated individually, the effect of changing the life expectancy of the AAM system was dramatic and consistent for the different cases of labor efficiency for VO of estrus. Although a relatively small increase (from 30 to 40%) in the proportion of cows EDAI was sufficient for the AAM system to be more profitable than the VO program at life expectancy of 7 years (Figure 2A), when the life expectancy was only 3 years the AAM system needed to increase the proportion of cows EDAI by 40 percentage points (Figure 2A), which may not be achievable for all dairy farms. As expected, more favorable conditions for the AAM system were observed when the efficiency of the VO program was lower and therefore VO cost was greater (Figure 3B). Under these conditions, at no change in the proportion of cows EDAI the AAM system would breakeven when life expectancy was 5 years and would be $5 per cow-year more profitable than VO when life expectancy was 7 years. When the tag cost was reduced to $90 the life expectancy of the system still caused major changes in profitability. The negative correlation between tag cost and profitability reduced the need to increment the proportion of cows EDAI to exceed the profitability of the VO program. Taken together, the results for scenarios of both low and high labor efficiency of VO of estrus, high and low tag cost, and different increments in the proportion of cows EDAI indicate that under most circumstances the LE of the AAM system should be at least 5 years. On the contrary, major improvements in ED efficiency are necessary to justify economically the incorporation of the AAM system when the life expectancy was 3 years. The impact of an AAM system LE on the differences in profitability between programs is, as for the increment in ED efficiency, not surprising because a longer life expectancy of the system significantly reduced the fixed costs of purchase and installation. Magnitude of the effect of a life expectancy of 3 versus 5 years, or 3 versus 7 years, on profitability was 1.8 and 2.7 times greater than that of a reduction in purchase price of $30 per tag. Therefore, producers may benefit more by acquiring a system that remains functional by a longer period of time rather than by paying less for activity tags. To the best of the author's knowledge, no published information is available regarding the LE of AAM systems. According to claims from some of the companies that market AAM systems in the U.S., life expectancy is projected to be 6 to 10 years.
(http://www.trackacowus.com/Heat_Detection_Faq.html,
http://www.microdairylogic.com/flash/heatime.swf).
Very likely, the timespan that an AAM system will remain functional will depend on the quality of the product as well as the care and maintenance provided by the farm.



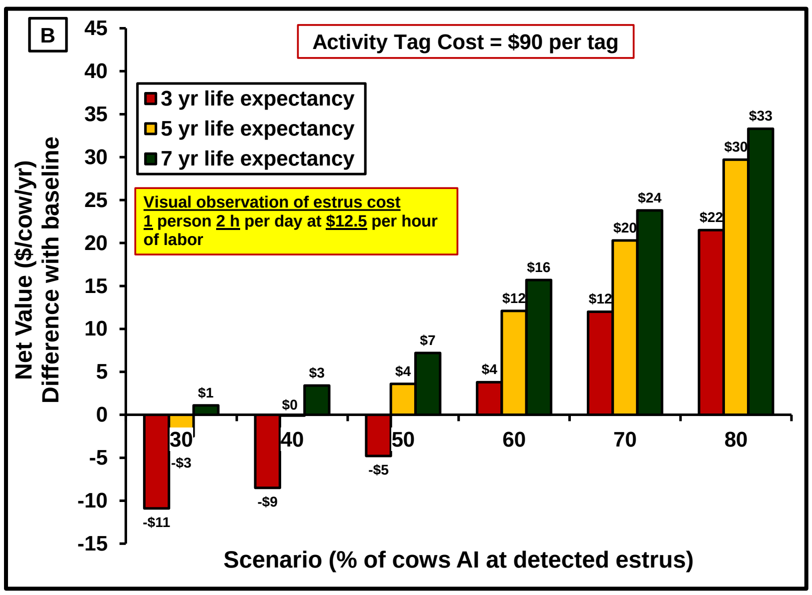


Figure 2. Net value differences ($ per cow-year) between a baseline program with poor estrus detection efficiency based on visual observation of estrus versus a program that uses activity monitors. Differences among programs reflect the change in profitability when visual observation is replaced by an automated activity monitoring system for detection of estrus. The scenarios represented a situation of high labor efficiency (2 hours per day) for visual observation of estrus and activity tag cost of $120 (A) or $90 (B) per tag.

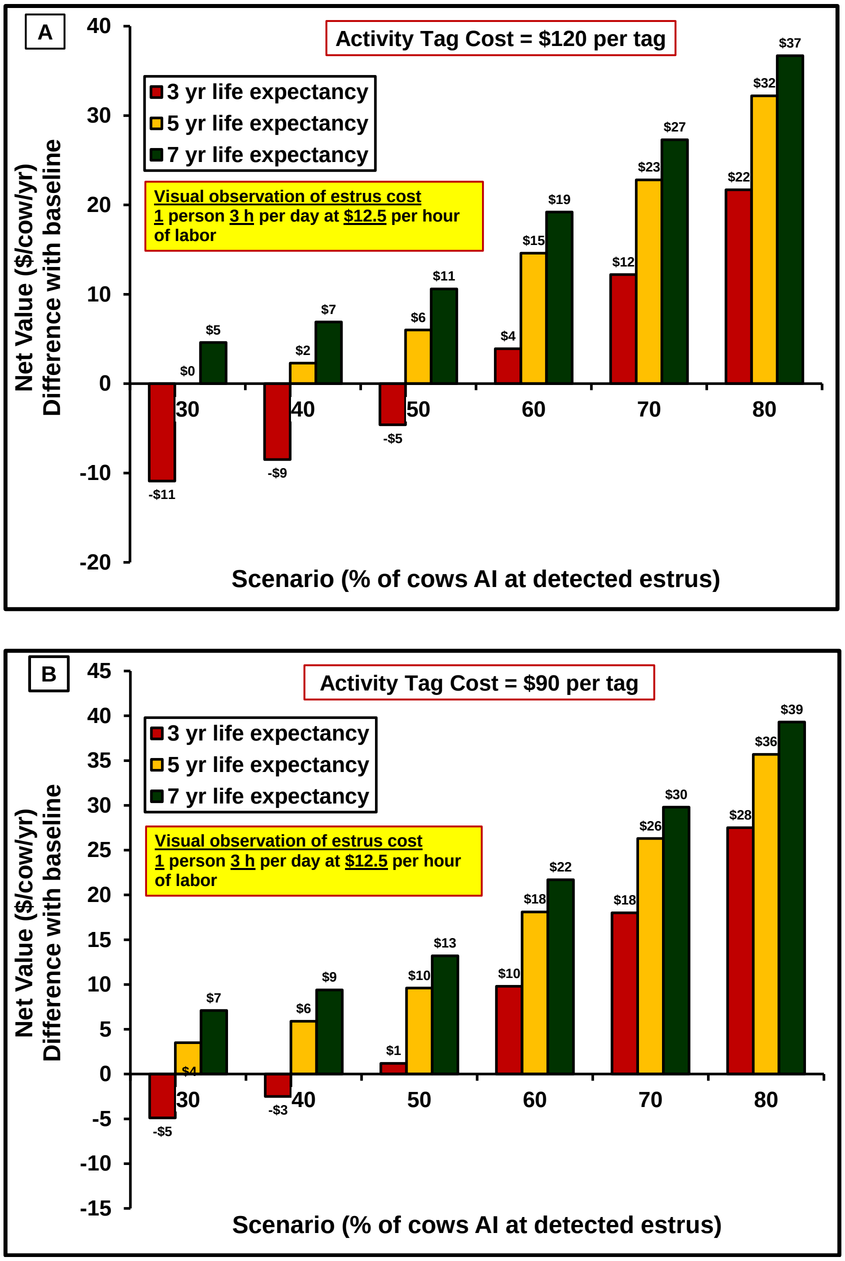


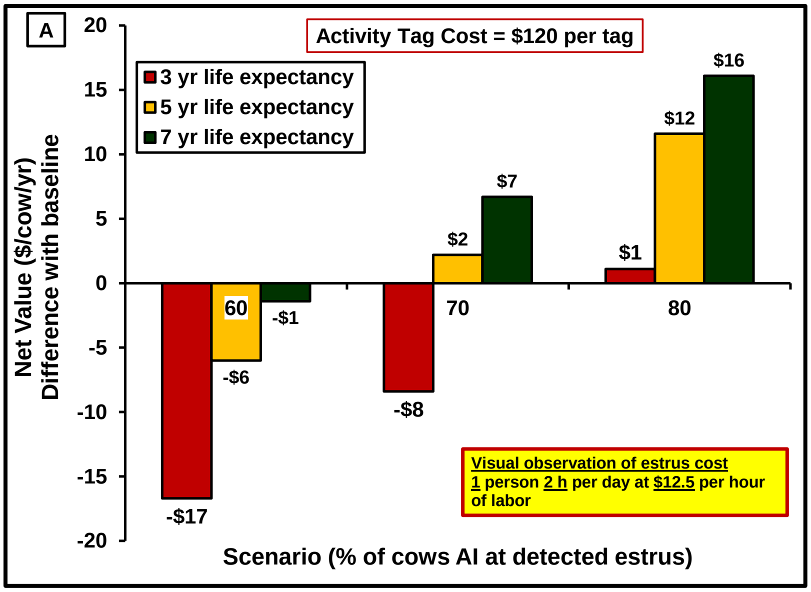
Figure 3. Net value differences ($ per cow-year) between a baseline program with poor estrus detection efficiency based on visual observation of estrus versus a program that uses activity monitors. Differences between programs reflect the change in profitability when visual observation is replaced by an automated activity monitoring system for detection of estrus. The scenarios represented a situation of poor labor efficiency (3 hours per day) for visual observation of estrus and activity tag cost of $120 (A) or $90 (B) per tag.

Current Average-Estrus Detection Efficiency. Unlike previous scenarios used to represent a farm with current poor ED efficiency, it is possible that farms with an effective ED program already in place may consider incorporating an AAM system to replace VO of estrus. Under such conditions the economic implications will likely differ because the farm may not experience major increments in the proportion of cows EDAI.

Indeed, when compared with the high labor efficiency scenarios for VO of estrus (2 hours per day) and life expectancy set at 3 years, the AAM system needed to increase the proportion of cows EDAI to the maximum of 80% (unlikely for a vast a majority of farms) to be marginally profitable even with a tag price of $90 (Figure 4A and B). Conversely, a 10 percentage point increment in cows EDAI was required to make the AAM system slightly more profitable than the VO program with high labor efficiency. In this case, $2 and 7 per cow-year could be obtained when life expectancy of the system was 5 and 7 years, respectively (Figure 4A). Reducing the cost of tags to $90 made the AAM system profitable when life expectancy was 7 years, despite no increase in the proportion of cows EDAI, but it did not dramatically change the profitability of the programs using AAM systems with a maximum difference of $6 per cow-year (Figure 4B).

Further, when compared with a program with lower labor efficiency for VO of estrus (3 hours per day) the scenarios were more favorable to the AAM system. Even with no change in the proportion of cows EDAI, a life expectancy of 5 years generated an almost negligible disadvantage of $1 per cow-year. When the minimum life expectancy of 5 years and the greatest success of the AAM system (80% cows EDAI) were assumed, the gains attainable by the AAM system were in the range of $22 to 25 per cow-year when tag cost was $120 and $90, respectively (Figure 5A and B). Although such gains are significant, they represent a reduction in additional profits of as much as 40 to 48% compared with similar scenarios for the baseline program with poor ED efficiency. In fact, reductions of more than 100% could be observed compared with the scenarios comparing the AAM system with a VO program with poor ED efficiency regardless of labor cost.

Taken together, these results indicate that for dairy farms with an efficient and consistent ED program that allows insemination of approximately 60% of the cows in estrus with acceptable fertility, the AAM system's minimum life expectancy should be at least 5 years, and at least 10% more cows should be EDAI. In general, relatively smaller gains in profitability will be accrued unless that the AAM system is capable of increasing the proportion of cows EDAI up to 80%.



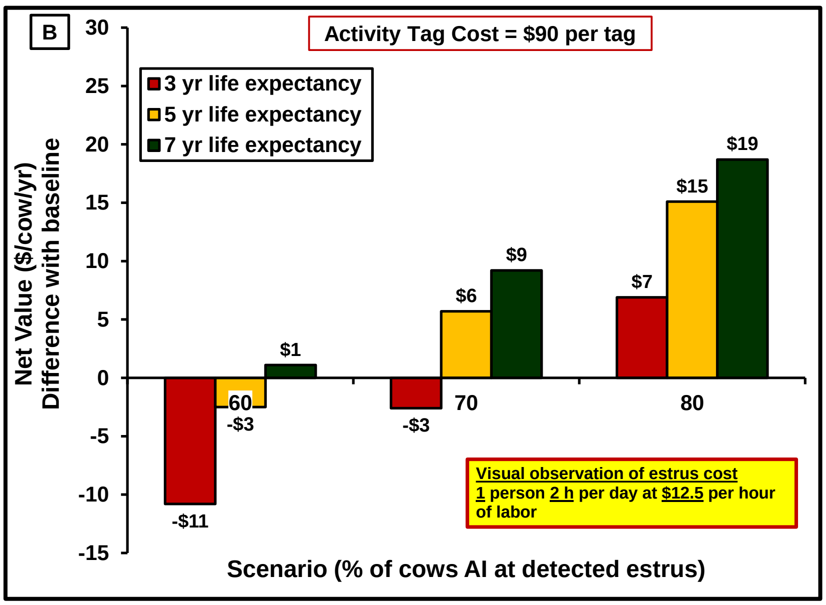


Figure 4. Net value differences ($ per cow-year) between a baseline program with high estrus detection efficiency based on visual observation of estrus versus a program that uses activity monitors. Differences between programs reflect the change in profitability when visual observation is replaced by an automated activity monitoring system for detection of estrus. The scenarios represented a situation of high labor efficiency (2 hours per day) for visual observation of estrus and activity tag cost of $120 (A) or $90 (B) per tag.

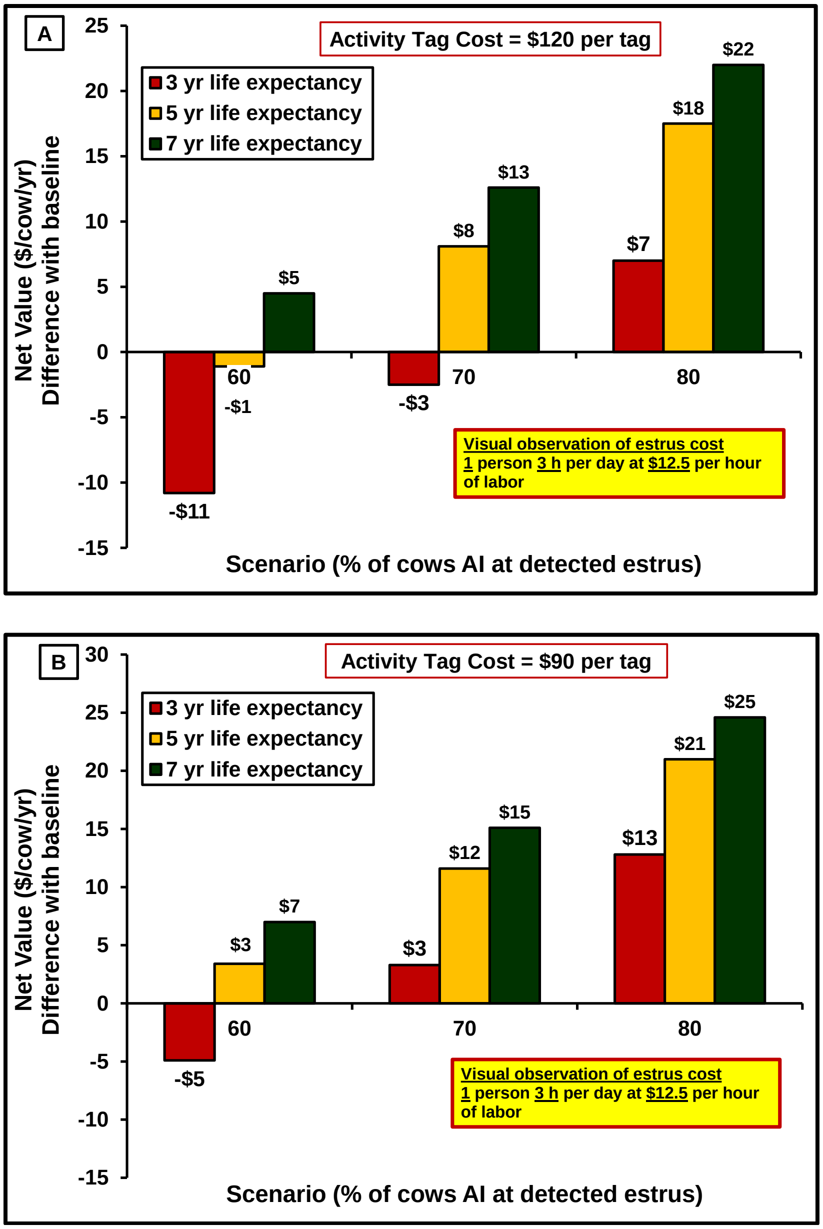


Figure 5. Net value differences ($ per cow-year) between a baseline program with high estrus detection efficiency based on visual observation of estrus versus a program that uses activity monitors. Differences between programs reflect the change in profitability when the farm replaces visual observation by an automated activity monitoring system for detection of estrus. The scenarios represented a situation of low labor efficiency (3 hours per day) for visual observation of estrus and activity tag cost of $120 (A) or $90 (B) per tag.

Impact of Reducing Fertility of Cows Inseminated in Estrus. A caveat of this simulation study is that for simplification purposes it was assumed that the fertility (P/AI) of cows that are inseminated based on detected estrus would not change regardless of the proportion of cows inseminated in estrus. Conversely, the P/AI of cows that reached TAI was reduced by 1 percentage point for every 10 percentage point increment in cows EDAI. This adjustment was included to reflect the change in the population of cows reaching the TAI after a majority was EDAI. Although it is certainly possible that same fertility for cows EDAI could be maintained as the proportion of cows EDAI increased, it would also be possible to observe a reduction in P/AI of cows EDAI because more cows may be inseminated at the wrong time or based on false positive alerts from the AAM system. Thus, the impact of reducing the fertility of cows EDAI when more cows are inseminated in estrus was briefly explored by reevaluating some of the extreme scenarios initially discussed. As expected, the reduction in profitability was dramatic. For example, when the proportion of cows EDAI increased from 30 to 80% in a scenario of high labor efficiency and activity tag cost of $120 (Figure 3A) reducing P/AI of cows EDAI to 30% for first AI and to 28% for second and subsequent AI (reductions assumed for TAI services) the change in profitability in favor of the AAM system was reduced from $31 to $4 per cow-year when life expectancy was 7 years and from $26 to a loss of $0.60 per cow-year when life expectancy was 5 years.

Although it is difficult to predict the reduction in P/AI as the proportion of cows EDAI increases, these results indicate that dairy farms should strive to maintain good fertility after inseminations based on activity to achieve good reproductive performance and maximize profitability. Otherwise, all the added benefits of the AAM system to profitability may vanish and incorporating the system could become less profitable.

Conclusions

Automated activity monitoring systems can be incorporated as a tool to replace visual observation (**VO**) of estrus. Although the decision to purchase these systems is farm specific, some general considerations should be made before its acquisition. Purchasing a system with a life expectancy of at least 5 years would be critical under all conditions. In addition, improvement in ED efficiency necessary to breakeven or improve profitability largely depends on the: (1) baseline proportion of cows inseminated in estrus with the current ED program; (2) life expectancy of the AAM system and its cost: and (3) cost of the program for VO of estrus. Automated activity monitoring systems may be a feasible and economically beneficial solution for dairy farms with limitations to conduct an efficient ED program or dairy farms that prefer to allocate personnel to other activities.

Acknowledgments

The author extends his appreciation to Dr. Paul Fricke and Dr. Victor Cabrera for discussion of this research and revision of this manuscript. Appreciation is also extended to Afshin Kalantari for the modeling effort during the UWCU-Repro$ software development.

Literature Cited

Aungier, S. P., J. F. Roche, M. Sheehy, and M. A. Crowe. 2012. Effects of management and health on the use of activity monitoring for estrus detection in dairy cows. J. Dairy Sci. 95:2452-2466.

Brusveen, D. J., A. P. Cunha, C. D. Silva, P. M. Cunha, R. A. Sterry, E. P. Silva, J. N. Guenther, and M. C. Wiltbank. 2008. Altering the time of the second gonadotropin-releasing hormone injection and artificial insemination (AI) during Ovsynch affects pregnancies per AI in lactating dairy cows. J. Dairy Sci. 91:1044-1052.

Caraviello, D. Z., K. A. Weigel, P. M. Fricke, M. C. Wiltbank, M. J. Florent, N. B. Cook, K. V. Nordlund, N. R. Zwald, and C. L. Rawson. 2006. Survey of management practices on reproductive performance of dairy cattle on large US commercial farms. J. Dairy Sci. 89):4723-4735.

Chanvallon, A., S. Coyral-Castel, J. Gatien, J. M. Lamy, D. Ribaud, C. Allain, P. Clement, and P. Salvetti. 2014. Comparison of three devices for the automated detection of estrus in dairy cows. Theriogenology 82:734-741.

Ferguson, J. D. and A. Skidmore. 2013. Reproductive performance in a select sample of dairy herds. J. Dairy Sci. 96:1269-1289.

Firk, R., E. Stamer, W. Junge, and J. Krieter. 2002. Automation of oestrus detection in dairy cows: a review. Livest. Prod. Sci. 75:219-232.

Fricke, P. M., J. O. Giordano, A. Valenza, G. Lopes, Jr., M. C. Amundson, and P. D. Carvalho. 2014. Reproductive performance of lactating dairy cows managed for first service using timed artificial insemination with or without detection of estrus using an activity-monitoring system. J. Dairy Sci. 97:2771-2781.

Giordano, J. O., A. S. Kalantari, P. M. Fricke, M. C. Wiltbank, and V. E. Cabrera. 2012. A daily herd Markov-chain model to study the reproductive and economic impact of reproductive programs combining timed artificial insemination and estrus detection. J. Dairy Sci. 95:5442-5460.

Giordano J.O., R.D. Watters, R. Wijma, and M. L. Stangaferro. 2014. Reproductive performance of lactating dairy cows after resynchronization with Ovsynch or a program aimed to maximize artificial insemination in estrus and fertility of timed artificial inseminations based on ovarian structures. J. Dairy Sci. 97 (E-Suppl. 1):264 (Abstr.).

Hockey, C., J. Morton, S. Norman, and M. McGowan. 2010. Evaluation of a neck mounted 2-hourly activity meter system for detecting cows about to ovulate in two paddock-based Australian dairy herds. Reprod. Domest. Anim. 45:e107-117.

Holman, A., J. Thompson, J. E. Routly, J. Cameron, D. N. Jones, D. Grove-White, R. F. Smith, and H. Dobson. 2011. Comparison of oestrus detection methods in dairy cattle. Vet. Rec. 169:47.

Larsson, P. 2007. Economic analysis of the De Laval activity meter system for heat detection. PhD Thesis. Swedish Agricultural University, Uppsala, Sweden.

Michaelis, I., O. Burfeind, and W. Heuwieser. 2014. Evaluation of oestrous detection in dairy cattle comparing an automated activity monitoring system to visual observation. Reprod. Domest. Anim. 49:621-628.

Nebel, R. L., M. G. Dransfield, S. M. Jobst, and J. H. Bame. 2000. Automated electronic systems for the detection of oestrus and timing of AI in cattle. Anim. Reprod. Sci. 60-61:713-723.

Neves, R. C., K. E. Leslie, J. S. Walton, and S. J. LeBlanc. 2012. Reproductive performance with an automated activity monitoring system versus a synchronized breeding program. J. Dairy Sci. 95):5683-5693.

Palmer, M. A., G. Olmos, L. A. Boyle, and J. F. Mee. 2010. Estrus detection and estrus characteristics in housed and pastured Holstein-Friesian cows. Theriogenology 74:255-264.

Ranasinghe, R. M., T. Nakao, K. Yamada, and K. Koike. 2010. Silent ovulation, based on walking activity and milk progesterone concentrations, in Holstein cows housed in a free-stall barn. Theriogenology 73:942-949.

Roelofs, J. B., F. J. van Eerdenburg, N. M. Soede, and B. Kemp. 2005. Pedometer readings for estrous detection and as predictor for time of ovulation in dairy cattle. Theriogenology 64:1690-1703.

Stevenson, J. S., S. L. Hill, R. L. Nebel, and J. M. DeJarnette. 2014. Ovulation timing and conception risk after automated activity monitoring in lactating dairy cows. J. Dairy Sci. 97:4296-4308.

Valenza, A., J. O. Giordano, G. Lopes, Jr., L. Vincenti, M. C. Amundson, and P. M. Fricke. 2012. Assessment of an accelerometer system for detection of estrus and treatment with gonadotropin-releasing hormone at the time of insemination in lactating dairy cows. J. Dairy Sci. 95):7115-7127.

Wiltbank, M., H. Lopez, R. Sartori, S. Sangsritavong, and A. Gumen. 2006. Changes in reproductive physiology of lactating dairy cows due to elevated steroid metabolism. Theriogenology 65:17-29.

Notes:

The Changing Veterinary Pharmaceutical Landscape

Dan Grooms DVM, PhD
Michigan State University
College of Veterinary Medicine

The use of pharmaceutical products in food animals is under close scrutiny by the general public and regulatory agencies around the world. The scrutiny is especially intense with respect to antimicrobial use (antibiotic and antimicrobial are the same thing). Increasing bacterial resistance to antimicrobials and fear of antimicrobial residues in food drives this scrutiny. Either of these situations have potentially life-threatening implications for anyone who might come in contact with a resistant bacteria or chemical residue, so the scrutiny is justifiable. More importantly, they put the dairy industry specifically, and the whole food animal industry in general, at risk for increased scrutiny, increased regulations and ultimately loss of public confidence. Confusion about use of antimicrobials in food animals adds to the scrutiny. Reasons for this confusion that have been postulated include 1) the fact that antimicrobial use in food animals is not a black-and-white issue; it is a complex issue that is frequently over simplified by both critics and proponents, 2) failure to understand that a concern is not equivalent to risk, 3) disconnect between consumers and agriculture, with most consumers being at least three generations removed from the farm and 4) activist messaging - the media and the internet are often inaccurate and misleading regarding antimicrobial use, and in particular antimicrobial resistance and its relationship to use in food-animal production.[1]

We can have a healthy debate about the source of antimicrobial resistance and if residues exist; however, the reality is that if we use antimicrobials in food animals, we contribute to the potential risk of antimicrobial resistance developing and antimicrobial residues showing up in human food. It is IMPERATIVE that we do everything we can to reduce these risks, while at the same time making sure we properly care for the health of our animals.

Prudent antimicrobial use is the responsibility of everyone involved in the care of food animals. This includes livestock owners, employees, allied industry personnel (e.g. nutritionists) and veterinarians, among others. This message needs to be heard and applied by all of us to take measures towards doing what’s right when it comes to responsible use of antimicrobials. No areas of the livestock industry are exempt from the need to use antimicrobials responsibly, as the majority of livestock eventually end up in the human food chain. Whether you run a dairy operation, a heifer raising operation, a feedlot, a cow-calf operation, or raise 4-H steers; how you care for those animals has potential human health impacts. And part of how you care for your animals includes the responsible use of antimicrobials.

By the way, although this discussion revolves around prudent antimicrobial use, the same arguments pertain to any pharmaceutical product used in food producing animals. Anthelmintics, non-steroidal anti-inflammatories, etc. Misuse of any of these drugs has animal health and public health consequences.

The Landscape

Antimicrobial use in food animals is regulated by the U.S. Food and Drug Administration Center for Veterinary Medicine (FDA CVM). However there are many other agencies involved in the oversight of drug use in cattle besides the FDA. These include the Environmental Protection Agency (EPA - approves pesticide labels), the US Department of Agriculture Food Safety and Inspection Service (FSIS - inspects cattle harvest ante- and postmortem and tests for drug residues), United States Department of Agriculture Center for Veterinary Biologics (CVB - vaccine approval), the Drug Enforcement Agency (DEA - defines and enforces regulations related to the distribution and use of controlled substances), individual state veterinary medical boards (define and enforce veterinary practice act), and individual state pharmacy boards (define and enforce pharmacy and drug distribution law).[2] For dairy operations, there is also the National Conference on Interstate Milk Shipments (NCIMS), which oversees the Pasteurized Milk Ordinance (PMO). The PMO defines procedures for milk sanitation and prevention of milk borne disease.[2] Regulatory oversight provides assurance in the development of safe products and that no harmful residues enter the food supply.

Efforts have been made to promote the judicious use antimicrobials in animals.[3, 4] These have been largely educational efforts to increase awareness and best practices with respect to prudent drug use in food animals. In 2012, the FDA finalized Guidance for Industry #209[5] which provides a framework for the voluntary adoption of practices to ensure the appropriate or judicious use of medically important antimicrobial drugs in food-producing animals. This framework includes the principles of phasing in such measures as 1) limiting medically important antimicrobial drugs to uses in food-producing animals that are considered necessary for assuring animal health and 2) limiting such drugs to uses in food-producing animals that include veterinary oversight or consultation. It is apparent that FDA will be introducing policies over time with this framework in mind. Let's examine each of these more carefully.

Principle 1: The use of medically important antimicrobial drugs in food-producing animals should be limited to those uses that are considered necessary for assuring animal health.

FDA believes the use of medically important antimicrobials in food-producing animals for production purposes (e.g., to promote growth or improve feed efficiency) represents an **injudicious** use of these important drugs.[5] FDA believes that use of medically important antimicrobials for treatment, control, or prevention of specific diseases (disease prevention is defined as administration of an antimicrobial drug to animals, none of which are exhibiting clinical signs of disease, in a situation where disease is likely to occur if the drug is not administered – see further discussion later), including administration through feed or water, to be a **judicious** use that is necessary for assuring the health of food-producing animals.[5] The term "medically important antimicrobials" generally refers to antimicrobials that are important for therapeutic use in humans. A list of "medically important antimicrobials" can be found in Appendix A of the FDA Guidance for Industry #152.[6] As an example and relevant to this proceedings, Table 1 outlines approved antimicrobials in lactating dairy cattle and their status as medically important or not.

Table 1: FDA approved antimicrobials for lactating dairy cattle and their status as medically important. Note: antimicrobials, for the purposes of this table, are defined as those products that have activity against bacteria or parasites.

	Medically Important?	
Antimicrobial	Yes	No
Ceftiofur (Excenel, Excede)	✔	
Penicillin	✔	
Ampicillin (Polyflex)	✔	
Cloxacillin (Dariclox)	✔	
Hetacillin (Hetacin K)	✔	
Oxytetracycline	✔	
Pirlimycin (Pirsue)	✔	
Monensin (Rumensin)		✔
Fenbendazole (Safe-Guard)		✔
Eprinectin (Eprinex)		✔
Moxidectin (Cydectin)		✔

Principle 2: The use of medically important antimicrobial drugs in food-producing animals should be limited to those uses that include veterinary oversight or consultation.

In addition to instituting voluntary measures that would limit use of medically important antimicrobial drugs in food-producing animals to uses that are considered necessary to assure the animals' health (Principle #1), FDA also believes it is important to phase-in the practice of including veterinary oversight or consultation in the use of these drugs. Essentially what this means is that all antimicrobials considered medically important will eventually fall under the oversight of veterinarians. There are three classes of animal drugs: Over-the-Counter (OTC), Prescription (RX), and Veterinary Feed Directive (VFD). OTC drugs can be sold by any person or establishment without the prescription of a veterinarian. Prescription drugs can only be sold to farmers by a veterinarian or pharmacist, and only with the prescription of a veterinarian. VFD covers drugs intended for use in or on feed, which is limited by an approved application to use under the professional supervision of a licensed veterinarian. Eventually, it is likely that all antimicrobials that are considered medically important will no longer be available OTC.

Examples of this would include injectable penicillin or oxytetracyline, or feed additive antimicrobials such as AS-700.

In 2013, FDA finalized Guidance for Industry #213.[7] This document essentially implemented the two principles of GFI #209 for feed and water antimicrobials. This document does two things; 1) it eliminated the use medically important antimicrobials for production uses (e.g. growth promotion) and 2) it requires that feed and water antimicrobials must be used under the guidance of licensed veterinarians. Accordingly, in December 2013, the FDA asked pharmaceutical companies to voluntarily phase out the use of medically important antimicrobials in food animals for production purpose. By March 2014, 25 of 26 companies, representing 99.6% of the total sales of medically important antimicrobials used for production purposes, agreed to the FDA's request.[8] In addition, the vendors intend to remove OTC use of these products in food producing animals and switch to use by veterinary prescription of VFD.

Importantly for the dairy industry, feed would include milk replacers. Therefore this change would affect milk replacers that include medically important antimicrobials (e.g. oxytetracycline). This change would not affect feed additive antimicrobials that are NOT considered medically important (e.g. Rumensin).

The Issue of Disease Prevention[9]

In GFI #209, one of the principles recommended by FDA was to limit the use of medically important antimicrobials in food-producing animals "to those uses that are considered necessary for assuring animal health". Specifically, production label claims – growth promotion or improved feed efficiency – represented an **injudicious** use of antimicrobials. However, the FDA also recognized in GFI #209 that there are important uses of antimicrobials that are necessary for assuring animal health. Among these uses are the treatment, control and **prevention** of specific diseases. The FDA specifically addresses prevention in GFI #209 and concerns with the appropriateness of these uses. A recent report by the Pew Charitable Trusts[10] has drawn into question the use of antimicrobials for prevention purposes as "judicious". Therefore, it is important for veterinarians, producers and consumers to understand how antimicrobials are used to **prevent** disease in food animals in a judicious manner. To begin with, it is necessary to define "disease prevention". Disease prevention uses of antimicrobials occur in situations where disease is likely to occur in a group of animals, but before any of the animals show signs of disease. Obviously, determining important risk factors for when disease is "likely to occur" requires professional judgment; thus, the FDA has deemed prevention uses to be "judicious" when veterinarians are involved and the following factors are considered:

- Prevention is targeted at a specific bacterial agent (e.g. oxytetracycline targeting *Pasteurella multocida* or *Mannheimia haemolytica*)
- There is evidence that the drug will be effective in treating the particular disease (e.g. know effectiveness of the antimicrobial against specific agents)

- The specific preventive use is consistent with accepted veterinary practice
- Preventive use is targeted to animals at risk for developing the specific disease (e.g. weaned dairy calves entering group transition barn)
- No reasonable alternate interventions exist (e.g. no effective vaccines)

GFI #209 also gives examples of what would and would not constitute judicious preventive use of antimicrobials. For example, a veterinarian, based on a client's production practices and health history of that herd, may appropriately authorize antimicrobials for prevention of a specific bacterial disease in cattle experiencing known stressors (transport). Another example given by FDA is the situation where concurrent disease increases the risk of bacterial infection, as is seen when broiler flocks experience *Clostridium perfringens* (necrotic enteritis) in the face of concurrent coccidiosis. On the other hand, FDA would not consider the administration of a drug to apparently healthy animals in the absence of any information that such animals were at risk of a specific disease to be a judicious use. To be considered judicious preventive use, the veterinarian should have: 1) information related to a specific bacterial disease and/or specific risk factors for that particular group of animals and 2) a defined duration of administration (the period of time when the animals are "at risk"). Following these guidelines will assure that veterinarians and producers are using antimicrobials in the most appropriate manner for the particular clinical situation.

Extra Label Drug Use (ELDU)

In short, it is illegal to use drugs in dairy cattle (or in fact all cattle) differently than how they are labeled. However, ELDU can occur under the guidelines laid out by the Animal Medicinal Drug Use Clarification Act (AMDUCA).[11] The key to ELDU under AMDUCA is that it must be done under the direction of a licensed veterinarian and a valid Veterinary-Client-Patient- Relationship (VCPR). After that, ELDU can occur as long as specific criteria are met. There are specific instances where ELDU is prohibited. For example, ELDU does not apply to drugs in feed – it is illegal to use drugs in feed (this includes milk replacers) differently that they are labeled – period amen. Some drugs are legal to use in cattle, but are specifically prohibited from being used extra label – for example enrofloxacin (Baytril) is illegal to use in an ELDU manner. Recently, cephalosporins, the most important in the dairy industry being ceftiofur (Excenel, Excede, Spectramast), became severely restricted in ELDU options.[11] There are some drugs that are completely illegal to use in food animals - chloramphenicol is a well-known example. A complete list drugs prohibited for use in a an ELDU manner are published in the FDA Code of Federal Regulations Title 21 Part 530.[13]

Compounded Drugs

Compounding of drugs is the customized manipulation of an approved drug(s) by a veterinarian, or by a pharmacist upon the prescription of a veterinarian, to meet the needs of a particular patient. **The use of drugs compounded from bulk ingredients in cattle is currently illegal.** FDA has exercised enforcement discretion when compounding from bulk ingredients in the case of certain poison antidotes. The AVMA policy on compounding in food animals states that compounding is only appropriate in cases of poison antidotes and euthanasia agents where appropriate.[14, 15] Bottom line, use of compounded drugs in food animal is inappropriate and illegal!!

What Should You Be Doing?

So, as people interested in the safe use of antimicrobials, what can we do to ensure responsible use of antimicrobials? Here are 5 things you can do TODAY to reduce risks of inappropriate antimicrobial use.

1. **Develop a relationship with a veterinarian who will work with you to manage the health of the herd, not just treat sick animals.** This relationship, called the veterinary-client-patient relationship or VCPR, is necessary to obtain most antimicrobials and likely will become more important in the future. The American Association of Bovine Practitioners has established guideline for a VCPR; "Establishing and Maintaining the Veterinarian-Client-Patient Relationship in Bovine Practice".[16] Key components of a VCPR include; 1) an agreement by both a veterinarian and producer that a VCPR exists, 2) a veterinarian of record with oversight of herd veterinary treatments, 3) clarity of relationships with consultants and other veterinarians, 4) written treatment protocols for all drugs to be used on the farm, 5) written or electronic treatment records, and 6) provision of drugs for only specific time frames and for specific protocols. Outside of future regulatory requirements, this relationship is really important in helping to ensure the health of your animals and the safety of the food they produce.
2. **Use antimicrobials according to their label directions unless specifically directed to use "extra-label" by your veterinarian.** Did you know it is <u>illegal</u> to use antimicrobials in an extra-label manner unless directed by your veterinarian? There is a reason for this. When antimicrobials are used different than their label directions (extra-label or off-label), it can significantly change the time it takes for that drug to clear the animal's system. When drug residue violations are investigated, one of the most common reasons cited as causing slaughter or milk residues is extra-label use of antimicrobials. Here is an example. The label dose of Procaine Penicillin is 1 cc/100 lbs. with a slaughter withhold time of 14 days. When the dose is doubled or tripled, the recommended slaughter withhold time increases up to 21 days. Important items to find and follow on the label include disease indications, dosage amount and frequency, route of administration (IV,

IM, SQ, orally), storage conditions, drug expiration date, and slaughter withdrawal period. REMEMBER, extra-label use of antimicrobials (or any drug for that matter) in food animals can only be done legally under the direction of a veterinarian. Whereas in the past, producers may have liberally winked at extra-label use and it was not an issue, in today's litigious environment, extra-label drug use is a legal and civil liability that opens the producer up to major consequences.

3. **Keep good records.** Records provide many GOOD things in terms of managing the health, safety, and productivity of our animals. Unfortunately, records are often one of the most neglected management tools. Whether it is to ensure we follow proper withdrawal times or monitoring our treatment success, records are critical for managing the safe use of antimicrobials, as well as the health of our herds. In fact, one of the best ways to keep yourself out of trouble with regulatory agencies (should you ever have a drug residue issue) is to have good records.
4. **Develop appropriate treatment protocols for common health problems.** Protocols help to avoid the "shotgun" approach to treating problems. Protocols should be developed for the most common health problems you face with the assistance of your veterinarian. They should be written down, easily accessible, and reviewed regularly (at least once a year). Protocols should not depend on routine extra-label use where there are alternatives that can be used. For example, talk with your veterinarian about alternatives to Procaine Penicillin that will be effective at the labeled dosage.
5. **Make sure you have a proper diagnosis.** I am going to use a real example to drive home the point of getting a proper diagnosis before giving antimicrobials to animals. Recently, a client had a 900 lb. heifer that suddenly became severely lame on its left rear leg, and was unable to bear any weight. Well, he thought that a good dose of oxytetracycline should fix the problem. Two days later, I get a call as the heifer was not any better. An examination revealed a fractured leg. So, what do you do with a 900 lb., three-legged lame heifer with a broken leg who also has oxytetracycline in its system and 28 days until it can go to slaughter??…BANG! The point is that there are many livestock health issues where antimicrobial therapy is not the treatment of choice. Antimicrobial use in these cases is expensive and increases risk of antimicrobial resistance and residues.

Let's be clear, the livestock industry as a whole has a great track record of providing safe food. However, times keep changing and the demands of not only consumers, but of the public as a whole make it essential that the livestock industry be above reproach in regard to antimicrobial use. That means that what we did yesterday, may not be good enough today. Let's all step forward and take a role in ensuring careful use of antimicrobials. It is in the best interest of the animals we care for and the public who buy our products. **It is the right thing to do.**

References

National Institute for Animal Agriculture. White Paper: Antimicrobial Use in Food Animals. Available at http://www.animalagriculture.org/Resources/Documents/Conf%20-%20Symp/Symposiums/2011%20Antimicrobials%20Symposium/Antimicrobials%20White%20Paper.pdf. Accessed 12/20/2014.

Fajt VR. Animal Medicinal Drug Use Clarification Act, extralabel drug use, and residue avoidance. Proceedings of the 46th Annual Conference of the American Association of Bovine Practitioners, Milwaukee, WI, September 19-21, 2013. pgs 49-51.
National Dairy Farm Program; Reside Prevention. Available at http://www.nationaldairyfarm.com/residue-prevention. Accessed 12/20/14.

Judicious Therapeutic Us of Antimicrobial in Cattle. Available at https://www.avma.org/KB/Policies/Pages/AABP-Prudent-Drug-Usage-Guidelines-for-Cattle.aspx Accessed 12/20/2014.

FDA Guidance for Industry #209. Available at http://www.fda.gov/downloads/animalveterinary/guidancecomplianceenforcement/guidanceforindustry/ucm216936.pdf. Accessed on 12/20/2014.

FDA Guidance for Industry #152. Available at http://www.fda.gov/downloads/AnimalVeterinary/GuidanceComplianceEnforcement/GuidanceforIndustry/UCM052519.pdf. Accessed 12/20/2014.

FDA Guidance for Industry #213. Available at http://www.fda.gov/downloads/AnimalVeterinary/GuidanceComplianceEnforcement/GuidanceforIndustry/UCM299624.pdf. Accessed 12/20/2014.

FDA Update on Animal Pharmaceutical Industry Response to Guidance #213. Available at http://www.fda.gov/AnimalVeterinary/SafetyHealth/AntimicrobialResistance/JudiciousUseofAntimicrobials/ucm390738.htm. Accessed 12/29/2014.

Personal Communications, Dr. Brian Lubbers, Director, Clinical Microbiology Kansas State Veterinary Diagnostic Laboratory.

The Pew Charitable Trusts – Gaps in FDA's Antimicrobials Policy. Available at: http://www.pewtrusts.org/en/research-and-analysis/issue-briefs/2014/11/gaps-in-fdas-antimicrobials-policy. Accessed 12/23/2014. Accessed 12/23/14

Animal Medicinal Drug Use Clarification Act (AMDUCA). Available at https://www.avma.org/KB/Resources/Reference/Pages/AMDUCA.aspx. Accessed 12/20/14.

Cephalosporin Order of Prohibition Questions and Answers. Available at http://www.fda.gov/AnimalVeterinary/NewsEvents/CVMUpdates/ucm054434.htm. Accessed 12/20/2014.

FDA Code of Federal Regulations Title 21 Part 530. Available at http://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?CFRPart=530. Accessed 12/20/2014.

AVMA Policy on Compounding. Available at https://www.avma.org/KB/Policies/Pages/Compounding.aspx. Accessed 12/23/2014.

AVMA Policy on Compounding from Unapproved (Bulk) Substances in Food Animals. Available at https://www.avma.org/KB/Policies/Pages/Compounding-from-Unapproved-Bulk-Substances-in-Food-Animals.aspx. Accessed 12/23/2014.

Establishing and maintaining the veterinarian-client-patient relationship in bovine practice. Available at http://aabp.org/resources/aabp_guidelines/vcprguidelinefinal11-2013.2.pdf. Accessed 12/20/2014.

Notes:

What Do Today's Forage Analyses Tell Us?

Mary Beth Hall
USDA-Agricultural Research Service
U. S. Dairy Forage Research Center, 1925 Linden Drive, Madison, WI 53706
Phone: 608-890-0078, Fax: 608-890-0076
marybeth.hall@ars.usda.gov

Two great truths:

- We need forage analyses to formulate rations and to assess feed quality for use and sale.
- Forage analyses have changed a lot over time, and seem to be changing more rapidly now.

Much of the change has been driven by advances in dairy cattle nutrition that drive the need to get a better handle on feed characteristics we think are important to meeting the cow's nutrient requirements. If/When an assay is decided to be nutritionally relevant, some ration formulation program may adopt the assay. Different programs can call for different versions of analyses, so you need to make sure to pick the right one. All well and good. So, how do we go about making sense of the analyses and what they tell us?

Carbohydrates

Some big changes have shown up in carbohydrate analyses (Fig. 1). We used to have acid detergent fiber (ADF), neutral detergent fiber (NDF), and nonfiber carbohydrates (NFC). Now we have different measures of NDF, and NFC has been split into different fractions.

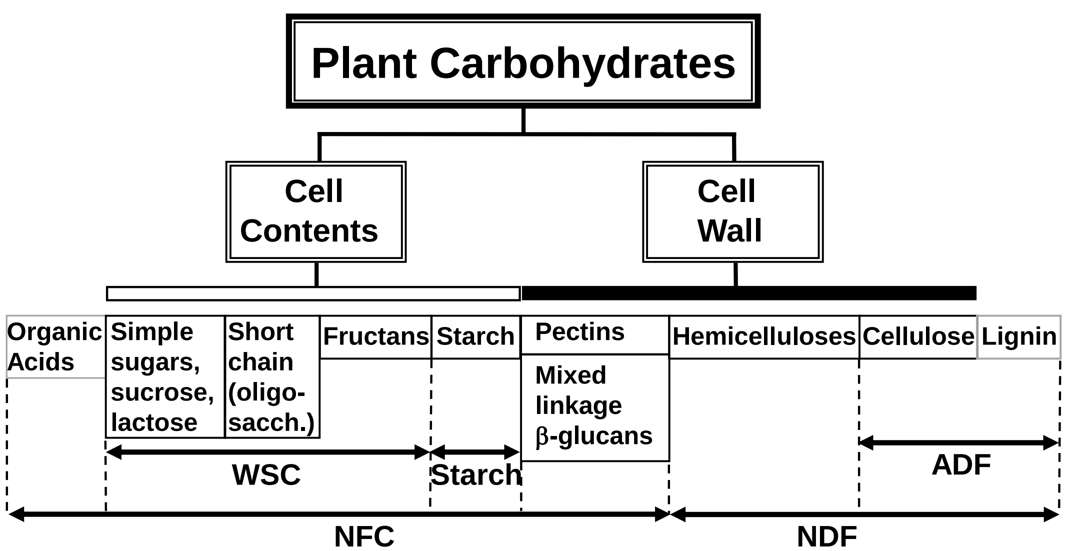


Figure 1. Carbohydrate analyses for ration formulation. ADF = acid detergent fiber, NFC = nonfiber carbohydrates, NDF = neutral detergent fiber, and WSC = water-soluble carbohydrates. Lignin and organic acids are not carbohydrates, but are grouped with them.
Presently, we don't have commercially available, affordable assays that specifically measure fructans and pectins in animal feeds.

NDF tells us about a slowly fermented fiber that is important for meeting the cow's nutrient needs and for keeping the rumen functioning well. It represents the plant cell wall that contains carbohydrates (cellulose, hemicellulose), some protein (neutral detergent insoluble protein = NDICP or NDFCP), and lignin. Cows can't digest fiber, but NDF is fermented by rumen microbes. Forage NDF is used as an indicator of the physically effective form of the feed that enhances rumination and rumen function.

NDF analyses come with a variety of options: with and without sulfite (Na2SO3), and on a with or without ash / ash-free basis. Almost all NDF analyses are already run using a starch degrading enzyme (amylase) to keep this fiber fraction from being contaminated with starch. The analysis option you choose depends on what you want to do with the number (see NDF table). The "no sulfite" option is used when you need an NDICP value for ration formulation. Sodium sulfite removes protein from the NDF and reduces the NDICP value. Using sulfite may give an NDF value that more correctly describes the carbohydrate available for microbes to ferment. Regarding NDF analysis with or without ash: "ash" is the same as "mineral". Ash is not fiber, but some mineral, like that in soil, is counted as fiber in the NDF analysis. For speed of turnaround, and because the amount of mineral may usually not be large enough to be a concern, most commercial labs have historically analyzed for NDF "with ash". The use of "with ash" or "ash-free" may depend on what the ration formulation program calls for, and how contaminated the forage is with soil (a.k.a., how many mounds of dirt near woodchuck holes were harvested). Ash-free analysis gives a more reliably accurate fiber value because mineral won't be counted as fiber. For chemical analyses, it may take an extra day to get the ash-free results because the lab has to incinerate the sample to calculate the ash-free NDF. The NDF analyses you get with sulfite added or on an ash-free basis likely will have at least slightly lower values than without sulfite or with ash, respectively. There's an effort underway to have NDF abbreviations that tell how the analysis was run. "aNDF" means that amylase was used in the assay. "aNDFom" means that amylase was used and the sample is on an ash-free basis.

NDF Analysis Options	What is it used for?
With heat-stable alpha-amylase	Commonly used NDF assay. Removes starch so that starch is not counted as fiber. Abbreviated "aNDF".
Without sulfite (w/o Na2SO3)	Used for analyses for neutral detergent insoluble protein (NDICP, NDFCP).
With sulfite (w/ Na2SO3)	Removes most/all of the NDICP and gives a better idea of the carbohydrates+lignin, only.
With ash	There's mineral in the fiber!!! Soil or other mineral contamination analyzes as NDF. Most common NDF.
Without ash / ash-free	The NDF value is corrected for any ash contamination = the more accurate fiber value. Abbreviated "NDFom".

NFC, Sugars, and Starch tell us about very digestible carbohydrates that can be an excellent energy source for the cow, or support production of microbial protein if fermented by microbes in the rumen. The nonfiber carbohydrates (NFC) are calculated as 100 – crude protein – NDF – ash – ether extract, sometimes with a correction for NDICP to avoid double subtraction for the NDICP that is already counted in crude protein; if sulfites are used, the adjustment for NDICP is small or not needed. For years we assumed that all of the carbohydrates in NFC were used similarly by the cows and microbes. But, that's not true. Now, we are measuring fractions in NFC that may behave differently and seem to matter nutritionally to the cow and her microbes (See Fig. 1 and NFC table).

The soluble carbohydrates that we've been calling "sugars" are more than just "sugar", but rumen microbes use them relatively similarly. This group of carbohydrates includes simple sugars (glucose, fructose), sucrose, lactose, short chain carbohydrates ("oligosaccharides" like stachyose and raffinose which are in soybeans, and some short chain fructans which are found primarily in cool season grasses), and long chain fructans (also from cool season grasses). These carbohydrates are fermented more rapidly than NDF and may, but don't necessarily, produce lactic acid. Also, rumen microbes can turn them into glycogen, a carbohydrate with the same basic structure as starch that they store inside their cells to ferment later. The rates of fermentation seem to vary mostly by source (example: glucose faster than fructans). The two most popular assays that have been used to describe "sugars" are 80% ethanol-soluble carbohydrates (ESC) or water-soluble carbohydrates (WSC). The WSC include all of the "sugar" carbohydrates, whereas ESC does not include the long chain fructans or lactose. At the end of the day, WSC appeared to be a better assay to use than ESC because it gives a more complete value for this group of carbohydrates. We originally used ESC because we thought it would let us analyze for "sugars" (glucose, fructose, sucrose), but it turned out to measure more than that. So, no more "sugars", and let's just call it WSC: that's what it is, and it's more than just sugars.

Starch, like cellulose, is made up entirely from glucose, but the way the glucose molecules are linked in starch allows both the cow and rumen microbes to digest it. Starch can be a great source of energy to support performance, or can cause digestive upset if fed in excess, so it is important to measure it and formulate with it properly. We have reliable assays that labs are using to analyze for starch content of feeds.

We're working with evolving recommendations for starch in dairy cattle rations that balance against fiber and rate of starch fermentation that support good performance but help to avoid acidosis. Rate of starch fermentation is mentioned here because it is important to consider at least relative rates of fermentation and not just starch amount in ration formulation to keep cows healthy and productive; brief discussion on starch fermentation assays is included later. Rates of starch fermentation in the rumen can vary greatly, but these are not reflected by the starch composition assay. Differences in how rapidly starch ferments are affected by the crystal structure of the starch (think dry ground vs. steam flaked corn), the protein matrix around the starch granules that limit access of microbes and enzymes to the starch (think "hard"/flinty corn vs high moisture corn that's been ensiled for months), how finely ground the corn is (more finely ground ferments faster than coarsely ground), and source of the starch (wheat and oats is faster than corn or sorghum).

NFC Analyses	What's in it? What does it tell you?
"Sugars"	These are glucose, fructose, sucrose, and lactose and other simple sugars. The "sugars" on feed analysis sheets are usually ESC or WSC results, but those assays include more carbohydrates than just "sugars" proper. Need to find out how the lab defines its "sugar" assay.
ESC (80% ethanol-soluble carbohydrate)	Simple sugars (glucose, fructose), sucrose, short chain carbohydrates (stachyose, raffinose, short chain fructans).
WSC (water-soluble carbohydrate)	Everything that is in ESC plus lactose and long chain fructans. Readily fermented carbohydrates excluding pectins.
Starch	Contains only starch.
Calculated NFC	All non-NDF carbohydrates, and the mistakes we made in all the analyses we used to calculate it.

Fat

Fat is an energy rich portion of the diet that can be used by the cow, but not by the rumen microbes, though biohydrogenation of fatty acids in the rumen may affect milk fat test.

Fat Analyses	What is it?
Crude fat	Fats, waxes, cutin, pigments, and other ether-soluble things, whether they are digestible or not. Also called Ether Extract.
Total fatty acids	This is the portion of the crude fat that is digestible by the cow.
Individual fatty acids	The individual types of fatty acids that make up the total fatty acids. Different fatty acids can have different effects on cow performance (repro, butterfat test).

Energy

Net energy of lactation (NEL) values estimate the energy available to the cow during lactation to support maintenance, milk, reproduction, growth, and putting on body condition. In feed analysis reports, the energy values are calculated based on the composition of the feed, and the energy equations are based on extensive research with cows, much of it done at USDA, to measure how cows converted feed to energy. The 2001 Dairy NRC used the OARDC (Ohio Agricultural Research and Development Center) equation developed by Dr. Bill Weiss (of THE Ohio State University). It estimated digestible nutrients that contributed to energy by adding together NFC assumed to be 98% digestible, CP adjusted for ADICP, fat as ether extract percentage minus 1 (to adjust for indigestible ether extract) or using the measured value for total fatty acids, and NDF carbohydrate adjusted for lignin effects or using a 48 hour in vitro NDF digestibility value determined in the lab by the Goering and Van Soest method. Energy is only counted as coming from portions of the diet that are predicted to be digested. This is why, after estimating what portions of the feed are digestible for an animal at maintenance, the total digestible nutrient values are discounted for the intake of the animal – the more a given animal eats, the more rapidly feed passes through her system, and the digestibility decreases.

The number of variations in NEL values has expanded beyond the National Research Council (NRC) equation as variations that incorporate digestibility assays have been developed. To calculate NEL values, commercial labs are using equations that are based on 1) the Dairy NRC - OARDC equation or 2) ADF, or may include 3) NDF digestibility based on in vitro fermentation or, 4) predicted starch digestibility. And there may be more variations out there. The NEL values for a feed can differ among the equations. The laboratory measures of digestibility can differ between labs (see digestibility assay section below). So, which analysis should you use? There's no absolute answer to that. If cow performance agrees with the Dairy NRC NEL value, and no other obvious ration or environment issues appear to be holding the cows back, that value may be "right" and good for use. If cow performance disagrees with the feed analysis, it is not the cows that are wrong. As you are investigating and addressing other potential contributors (feeding management, cow comfort, ventilation, fresh water supply, spoilage in feeds, etc.), getting further information on NDF and starch digestibilities that can be integrated into the NEL values could be useful for sorting out what is affecting the herd in order to come up with an energy value that is closer to the truth. Remember, all energy values are calculated estimates. Different ration software programs adjust them differently – you need to verify which values are needed for the program used to run your herd's rations.

Protein

Protein tells us about the nitrogen and amino acid containing compounds in a feed that can support rumen microbe and cow needs, and may be used to describe digestibility of starch.

Protein Analyses	What is it? What does it tell you?
Crude protein (CP)	Nitrogen measured in the feed x 6.25 is a gross measure of "protein" in a feed. Useful with ruminants because rumen microbes can convert nitrogen to amino acids that the cow can use. Does not describe digestibility.
Soluble protein	CP soluble in buffer. Used to describe readily rumen available CP, including nonprotein nitrogen and true protein. In fermented high moisture shell corn, has been related to increased starch digestibility.
Ammonia (NH_3)	In fermented feeds represents protein that was broken down by microbes; high levels may be found in butyric acid fermentations. In high moisture shell corn, together with particle size, it has been used as an indicator of starch fermentation rate (Hoffman et al., 2012).
Neutral detergent insoluble protein (NDICP, NDFCP)	The CP associated with NDF. Used in some ration programs to describe a slowly degrading CP fraction. Also used to correct for CP in NDF when sulfite is not used for NDF analysis to give an NDF value that more accurately reflects NDF carbohydrate content.
Acid detergent insoluble protein (ADICP, ADFCP)	The CP associated with ADF. High values may indicate heat damage of feeds. Used in some ration programs to describe an indigestible or very slowly degrading CP fraction.
Prolamins	A type of slowly degrading protein in corn grain. In dry ground corn, together with particle size, it has been used as an indicator of starch fermentation rate (Hoffman et al., 2012).
Amino acids	The building blocks of true protein & what the cow uses to meet her nutritional requirements. Amino acid analysis does not indicate whether they are ruminally degradable or undegradable, so this analysis may be less useful for cattle diets than for swine or poultry.
Nonprotein nitrogen (NPN)	Includes nitrogen containing compounds not found in true protein, including ammonia, urea, free amino acids not in protein molecules, short chains of amino acids (peptides), nucleic acids (DNA, RNA), etc. These can be used by rumen microbes. Except for free amino acids and peptides, cannot be used by cows to meet protein needs.

Fiber Digestibility

Fiber digestibility measured in the lab gives a way to estimate the potential for fiber to be converted to nutrients that the cow can use. In vitro NDF digestibility (NDFD or IVNDFD) is measured by using rumen microbes to ferment a ground feed sample in the lab, and measuring how much NDF remains after a certain number of hours of fermentation. The curves in Figure 1 show patterns of how feed NDF disappears over the course of a fermentation. Initially, there's a lag time where not much fermentation occurs, then the microbes go into full swing, fermenting

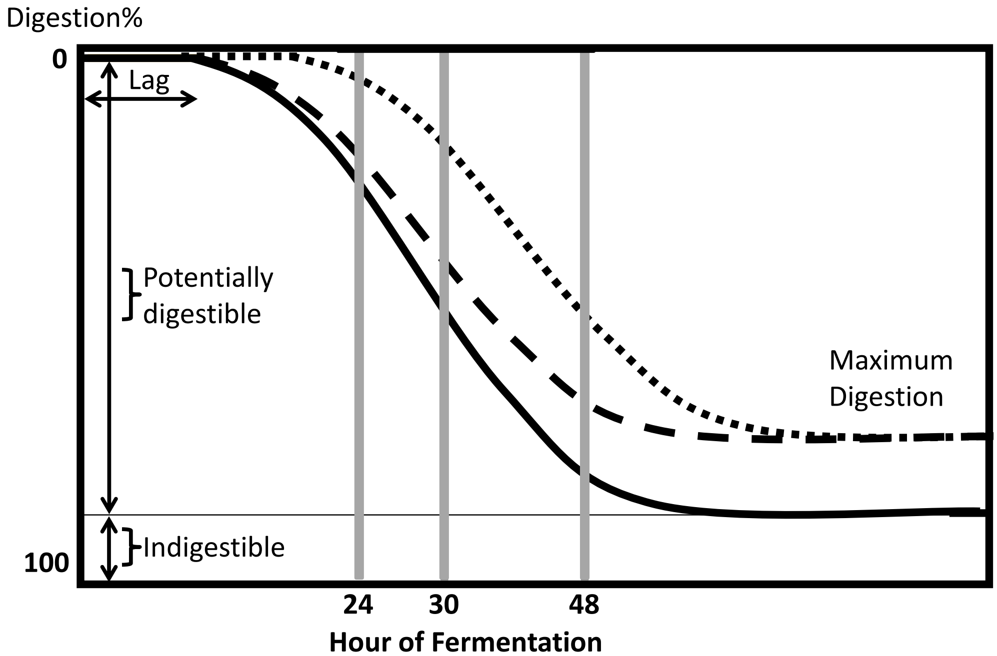


Figure 2. Examples of patterns of NDF digestion over time. "0" = no digestion, "100" = complete digestion, Lag = time before a sample starts fermenting. The dotted line has the longest lag, the solid line has the greatest final NDFD. The dotted and dashed curves have the same fermentation rate, but would differ in NDFD because of differences in lag (Hall, 2014).

the NDF more rapidly, and gradually slowing until they reach the limit of what they can ferment, which is the maximum extent of fermentation. There's debate about what time point to use for NDFD: 24, 30, or 48 hours. The earlier 24 and 30 hour time points may show more differences related to how rapidly the fiber ferments, but are also affected by lag time. They are also sensitive to lab procedures that can create more variability or noise (see Figure 3). As Figure 2 shows, changes in lag time or rate of fermentation translate into differences in NDFD between samples in the earlier hours of fermentation, no matter what their final amount of digestion. The 48 hour value can have less variability and you can detect which forage has a relatively greater extent of digestion than another, but you can't tell the route – lag or rate -- by which it got there.

Labs can differ in the NDFD method that they use, and the methods can give very different results. The 2001 Dairy NRC lists 48 hour NDFD by the Goering and Van Soest method as the one to use for the NEL calculation. More recently, another method that uses different rumen fluid handling procedures has been used (Goeser et al., 2009; Goeser and Combs, 2009), and this method gives lower NDFD values than the Goering and Van Soest method. Since factors that affect the actual NDF digestibility in cows vary by individual cow, and in vitro NDFD is a lab assay, none of the in vitro NDFD are necessarily more “biologically correct” than the others. So, chose one – whatever assay and time point your ration formulation software uses – and use the same lab.

Some labs and research farms may measure an “in sacco” or “in situ” NDFD. This is different from “in vitro” NDFD in that it involves placing ground feed samples in porous nylon bags and placing them in the rumens of ruminally cannulated cows to ferment for varying periods of time. This has the advantage of fermenting feeds under real rumen conditions. Some downsides include variation among cows, higher costs, and longer times required to get results.

How should we interpret NDFD? Fiber digestibility is useful for comparing relative energy values of forages, but it is not a very precise number. This is not because labs are doing a bad job. *All* feed analysis methods have some variability, so you do not get *precisely* the same number with each and every analysis. The NDFD assay combines multiple steps that make the assay more variable than chemical analyses like crude protein. For example, commercial and research labs running 30 hour NDFD assays on 14 forage samples over multiple fermentations showed that, within a given lab, 95% of the results for a given forage sample fall between ± 4.9% NDFD from the average (Figure 3; Hall and Mertens, 2012). Individual labs can vary somewhat from this, but the variation is similar. If a sample is run in different labs, the results fall into a range that is ± 6.6% NDFD from the average. The labs did a good job of ranking forages in order of NDFD, but statistically, you could not separate samples that were closer than 5% NDFD apart. Take home: 1) if NDFD values are closer than 5% NDFD, they may not really be different, 2) for best consistency stick with one lab for NDFD, and 3) pay attention to how feeds rank or change relative to one another as that can reflect differences in energy content.

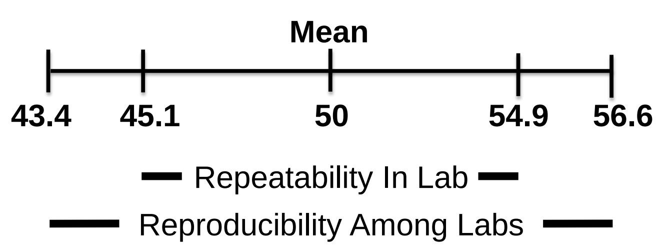


Figure 3. Variation within and among labs in 30 hour NDFD measurements. For a given sample, 95% of the values made in 1 lab will fall within ± 4.9% NDFD of the mean (average); across labs values will fall within ± 6.6%. For example, in a lab, a sample with a 50% NDFD would analyze with real values ranging from 45.1 to 54.9% NDFD.

The NDFD assays may also have other uses: predicting undigested NDF (uNDF). A 240 hour fermentation to give a uNDF 240 is being recommended as a replacement for lignin for predicting how much NDF will be fermented and contribute to NEL (Cotanch et al., 2014). uNDF values are also being suggested as ways to predict how much slowly fermenting, bulky material may limit intake through impact on rumen fill. This is the other side of fiber digestibility: undigested fiber can fill the rumen and reduce dry matter intake. Work is underway now to evaluate how well intake can be predicted based on uNDF measured at 30 (Jones and Siciliano-Jones, 2014) and 240 (Cotanch et al., 2014) hours of fermentation. There is agreement that even with uNDF, the fineness of chop on the forage as well as its fragility will affect how uNDF relates to intake – finer and more fragile material will likely pass more quickly and have less impact on fill.

Starch Digestibility

As with NDFD, digestibility of starch as measured in the lab is designed to give estimates of how it will digest in the cow. In the Dairy NRC, NFC (which includes starch) were estimated to be 98% digestible. That may be largely true of the water-soluble carbohydrates (sugars, oligosaccharides, fructans), but not necessarily for starch. How finely ground, or fermented, or dry a feed is, or how bound the starch is in a protein matrix will affect starch digestion. Starch degradability assays have not yet been directly linked to in vivo digestibilities, but, they can give an index for how rapidly the starch is fermented for consideration in ration formulation, and the assays have been included in ration formulation programs.

Present starch digestibility assays include a 7 hours in vitro fermentation like that used for NDFD but with slightly more coarsely ground samples (to retain the effect of grain structure on starch degradation). The relative differences in how much starch is fermented by 7 hours gives an indication of how rapidly the starch is fermenting. Another assay relates protein composition (prolamin for dry ground corn, or ammonia in high moisture corn) and particle size as an indicator of starch fermentation rate (Hoffman et al., 2012; used in the University of Wisconsin Feed Grain v2.0 Evaluation system to predict energy content of corn grain). Historically, soluble protein measures in high moisture corn have been used in the beef industry as a proxy for starch digestibility. Prolamin describes the part of the protein matrix that interferes with microbial or enzyme access to starch granules in dry corn. Ammonia or soluble protein in high moisture corn describe how much the protein matrix around the granules has broken down and opened access to the starch granules.

Another approach using gas production measurement from in vitro fermentation of starch containing samples gives rates of fermentation. Gas production does not evaluate “starch”, but gives describes more rapidly or slowly fermented fractions of feeds that may be aligned with the NFC (generally more rapidly fermented) and fiber (more slowly fermented).

Take Home

The rate of development and release of new feed analyses has accelerated, at least in part in response to demands from the field. One of our challenges is that it takes time after a new analysis is released to sort out how to use it to improve ration formulation. The new values need to be put into context with all of the other feed information across a large variety of rations so that it can be made reliably reliable. And the values need to be integrated into ration formulation software so that they complement the other feed values with which the programs were developed and calibrated. Assays that are newer than the ration program may not “fit” in that program, so be careful how you use them. Ask the labs and your nutritionist how to interpret the new results. Do not just substitute new methods/values for the “old” analyses unless you have verified that it’s ok to do so. You can also use the “old” assays, but keep the new results in mind when formulating (not all numbers need to go into a software program).

References

Cotanch, K. W., R. J. Grant, M. E. Van Amburgh, A. Zontini, M. Fustini, A. Palmonari, and A. Formigoni. 2014. Applications of uNDF in ration modeling and formulation. Proc. Cornell Nutr. Conf., pp.114-131. Oct. 21-23, 2014, Syracuse, NY.

Goeser, J. P., and D. K. Combs. 2009. An alternative method to assess 24-h ruminal in vitro neutral detergent fiber digestibility. J. Dairy Sci. 92:3833–3841.

Goeser, J. P., P. C. Hoffman, and D. K. Combs. 2009. Modification of a rumen fluid priming technique for measuring in vitro neutral detergent fiber digestibility. J. Dairy Sci. 92:3842–3848

Hall, M. B. 2014. Feed analyses and their interpretation. In Veterinary Clinics of North America: Food Animal Practice, Vol. 30, No. 3,Dairy Nutrition. Ed. R. J. Van Saun. Elsevier, Philadelphia, PA.

Hall, M. B. and D. R. Mertens. 2012. A ring test of in vitro neutral detergent fiber digestibility: Analytical variability and sample ranking. J. Dairy Sci. 95:1992-2003.

Hoffman, R. C., N. M. Esser, R. D. Shaver, W. K. Coblentz, M . P. Scot, A. L. Bodnar, R. J. Schmidt, and R. C. Charley. 2011. Influence of ensiling time and inoculation on alteration of the starch-protein matrix in high-moisture corn. J. Dairy Sci. 94:2465-2474.

Hoffman, P.C., D. R. Mertens, J. Larson, W. K. Coblentz, and R. D. Shaver. 2012. A query for effective mean particle size in dry and high-moisture corns. J. Dairy Sci. 95:3467-3477.

Jones, L. R., and J. Siciliano-Jones. 2014. Forage analysis considers gut fill. Feedstuffs Vol. 86, No. 29, pp. 18-19. July 21, 2014.

National Research Council. 2001. Nutrient requirements of dairy cattle, 7th rev. ed. National Academy Press, Washington, DC.

John F. Smith, age 51, of Oro Valley, Arizona, died March 29, 2013, at his home after a courageous battle with cancer.

John was born on February 2, 1962, in Nevada, Iowa, the son of John and Karen Smith. He grew up in Jefferson, Iowa, where he graduated from high school in 1980. John completed his B.S. in Animal Science in 1984 and his M.S. in 1986 at Northwest Missouri State University in Maryville, Missouri. In 1989, he completed his Ph.D. in Dairy Science at the University of Missouri.

From 1989 to 1995, John was an Extension Dairy Specialist, Associate Professor, at New Mexico State University in Las Cruces, New Mexico. He then continued his career at Kansas State University in Manhattan, Kansas, as an Extension Dairy Specialist, Professor, from 1995 to 2011. In 2011, John moved to Arizona to finish out his career at the University of Arizona in Tucson, Arizona.

In 1993 and 1994, John was awarded the Salt of the Earth Award from the Dairy Producers of New Mexico, In 2000 he was awarded the Midwest Outstanding Young Extension Specialist Award, in 2002 the DeLaval Dairy Extension award, in 2008 he was selected as Western Dairy Business Magazine's Outstanding Dairy Educator/Researcher, and in 2010 John was recognized with the Jefferson Iowa Bell Tower of Fame Award for his efforts in dairy education and research.

John's professional interests and research centered around cow comfort, heat stress, milking parlor performance, and management of expanding dairies. He was a Co-Founder of the Western Dairy Management Conference and High Plains Dairy Management Conference. John worked throughout the United States and internationally assisting producers with the development of efficient dairy operations.

John was a lifelong hunter and fisherman. He experienced hunting or fishing trips with dear friends in Alaska, Canada, South Africa, and many other unique and interesting places. One of his favorite passions was hunting with friends in Missouri, Iowa, and Kansas. John was an avid fan of the Northwest Missouri State University Bearcats and the Kansas State University Wildcats. His greatest love, however, was spending time with his two beautiful daughters.

On August 10, 1985, John married Debbie Schieber. She survives him of the home. Additional survivors include their two daughters: Jordan Smith of Corvallis, Oregon, and Hope Smith of the home; his parents, John and Karen Smith of Jefferson, Iowa; three sisters, Rhonda (Joe) Coffman of Carroll, Iowa, Debbie (Bob) Sees of Lee's Summit, MO, and Diane Smith of Wichita, KS, many dear in-laws, nieces, and nephews.

A scholarship for Animal Science majors at Northwest Missouri State University has been established in memory of John. Memorial contributions may be made to "Northwest Foundation - John F. Smith Memorial Scholarship" and mailed to the Northwest Foundation, 800 University Dr., Maryville, MO 64468.

John Smith Memorial Lecture: New Technologies in Heat Stress Abatement

Joe Harner
Kansas State University
Manhattan, KS
jharner@ksu.edu
With Mike Brouk and J. Zulovich

The impacts of heat stress on milk production, feed efficiency, breeding and cow health have been researched and studied since the 1950's. Numerous studies whether based on environmental chambers or field scale pen studies have demonstrated the economic benefits of reducing heat stress. The payback of fixed and variable cost is minimal however, the long term sustainability of current heat stress recommendations must be considered. Horner and Zulovich (2008) economic analysis of heat abatement show the larger economic incentive producers have to install and manage a cooling system for the dairy herd. Even with increased feed, marketing, utility, and ownership costs of the equipment, the investment in a properly operating cooling system that provides the herd with relief from heat stress is profitable. Their economic analysis did not consider the possible improved animal health with improved milk quality and lower illness and/or death loss.

Nearly all current recommendations are based on utilizing electrical energy for increasing air velocity across the cows back and water either for low pressure feed line sprinkler systems or evaporative cooling rings or pads. As new technologies are explored, systems using less electrical energy and lower water consumption should be explored and considered.

Temperature humidity index (THI) is the most common index used to measure heat stress in dairy cows. The index is calculated using the dry bulb temperature and dew point temperature or relative humidity. The impact of wind velocity or shade is not components of the THI index. Zulovich et al (2008) concept of Cow Heat Stress Hours (CHSH) which quantifies the intensity and duration of heat stress conditions. The CHSH are used to calculate a Cow Heat Balance over 24 hours or other time interval to estimate the effectiveness of heat abatement systems. The Cow Heat Balance considers THI, heat abatement from air movement and direct cooling and air exchanges. L. Zimbelman et al (2006) studied the impact of THI on high performing cows since the origin research was conducted more than 50 year ago. They results showed the physiological and production parameters indicate a new THI threshold for lactating dairy cows producing more than 77 lbs/day should be 68. Buffington et al. (1981) concluded with the Black Globe Humidity Index BGHI there was an increase in the correlations to rectal temperature increases and milk yield decreases compared to THI (Buffington et al., 1981). However, Zimbelman et al (2006) concluded there was no advantage of replacing THI with Black Globe Humidity Index.

Introduction

Hourly weather data was obtained for 21 cities from 1994 to 2013 to evaluate the impact of heat stress. The cities or regions selected are shown in Figure 1. Hourly data (annually 8,760 observations/site) were utilized to calculate hours and days of heat stress. The hourly temperature humidity index (THI) was then calculated to evaluate the impact of annual heat stress. Figure 2 shows the annual days per year when the minimum THI was equal to or greater than 65 and or the average daily THI were greater than or equal to 68. Cities located along the southern tier of states had 140 to 190 days when the THI was above 65 or 68. Cites along the 40 degree latitude had between 89 and 140 days of heat stress and northern regions tend to have less than 80 days of heat stress.

Figure 1. Regions across the US where 20 year average hourly weather data was use to evaluate heat stress.

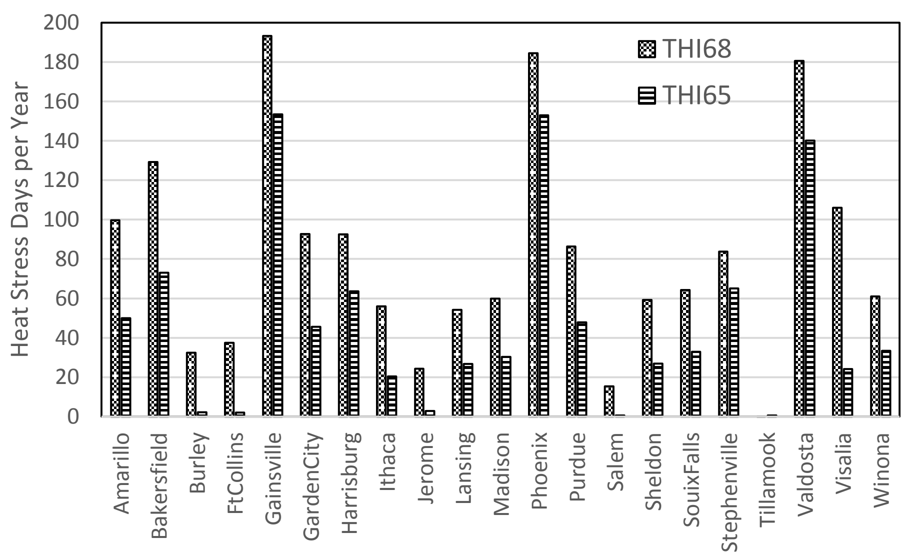


Figure 2. Comparison of days per year when the temperature humidity index averaged 68 for the day or the minimum THI for the day was 65.

Figure 3 plots the average THI and temperature for each of the data sets. Hourly THI or temperature readings of less than 65 or 65 F were excluded from the data set. Across on the United States, the average THI value is 73 to 75 and average temperature is 75 to 78 F.

Figure 4 plots average temperature vs the difference between average temperature and average THI. In general, the THI is 5 to 6 units lower than the average temperature in dry climates with low rainfalls and humidity. This indicates in drier climates the actual THI value could be estimated by assuming the THI value is 5 units below the temperature or if temperatures average is 75, the THI would equal 70 (75 – 5). In wetter climates with higher relative humidity, the difference between average temperature and THI is only 2 to 3 units.

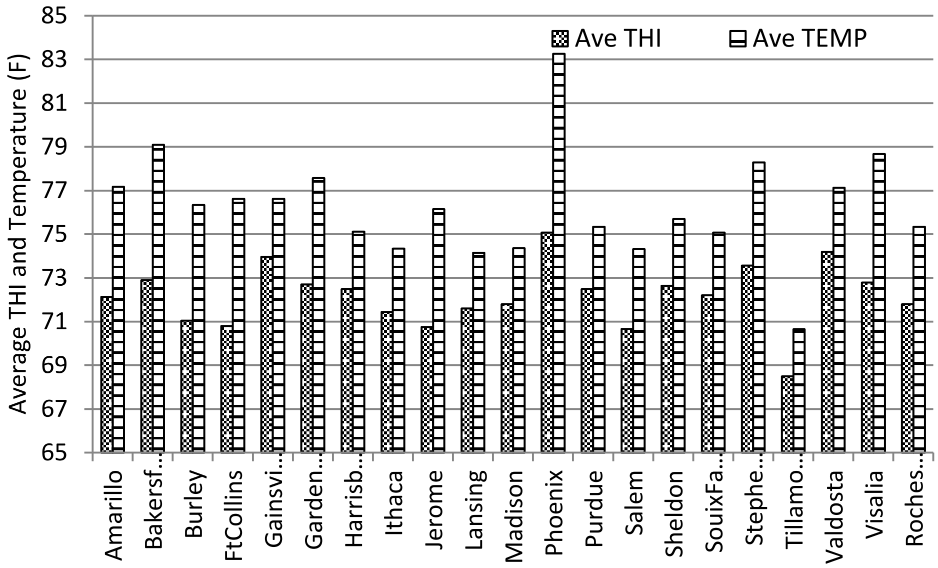


Figure 3. Comparison of the average temperature and temperature humidity index.

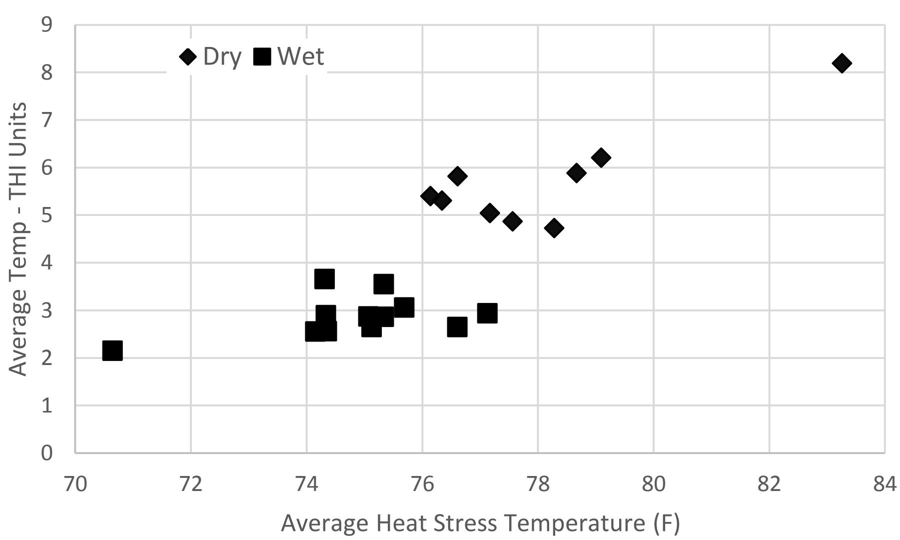


Figure 4. Comparison of average temperature and temperature humidity index in wet and dry areas.

The data sets were used to estimate the number of sprinkler cycles anticipated when using a fence line soaker system based on current recommendations and assuming the soaker systems is turned on either when THI equals to or exceeds 68 or temperature equals or exceeds 68. Figure 5 shows the cycles range from less than 5,000 to more than 40,000 depending on the location of the dairy.

Using 1 gpm nozzles, spaced 8 feet on center, Figure 6 shows the estimated annual water requirements per dairy cow for heat stress abatement. In most regions of the US annual water requirements are between 1,500 and 2,000 gallons per cow. However, in the extremely hot regions and areas where dry lot dairies are utilized the water requirement exceeds 4,000 gallons per cow. These are the regions during the 2009 to 2014 have experienced some of the greatest drought and face water availability issues. Current heat stress abatement is based on temperature controllers; however, as shown in Figure 7 an estimated 30 to 50 % water savings could occur if technology was available to operate the controllers on THI rather than temperature. Development of reliable relative humidity sensors that are accurate in a dusty environment is critical for a THI controller to be accurate.

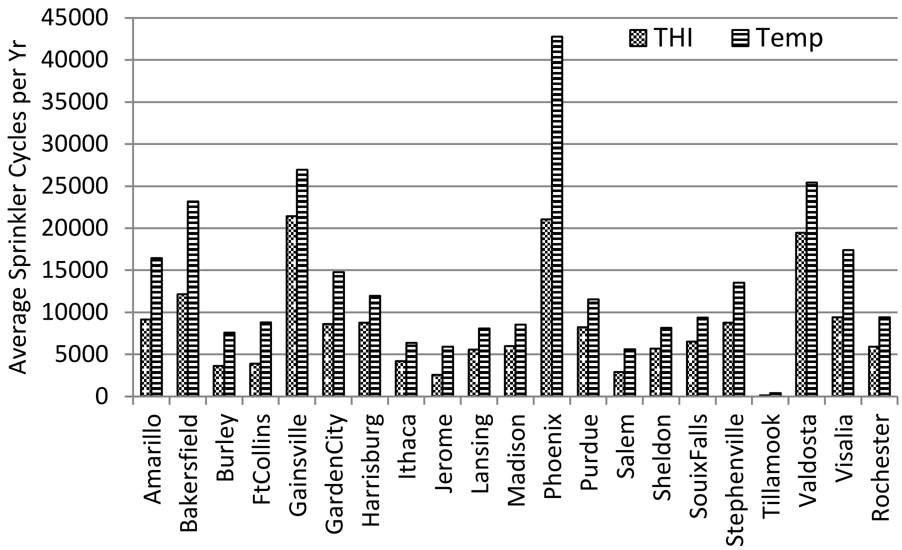


Figure 5. Estimate of the annual on cycles based on current recommendations for low pressure soaker feedline systems.

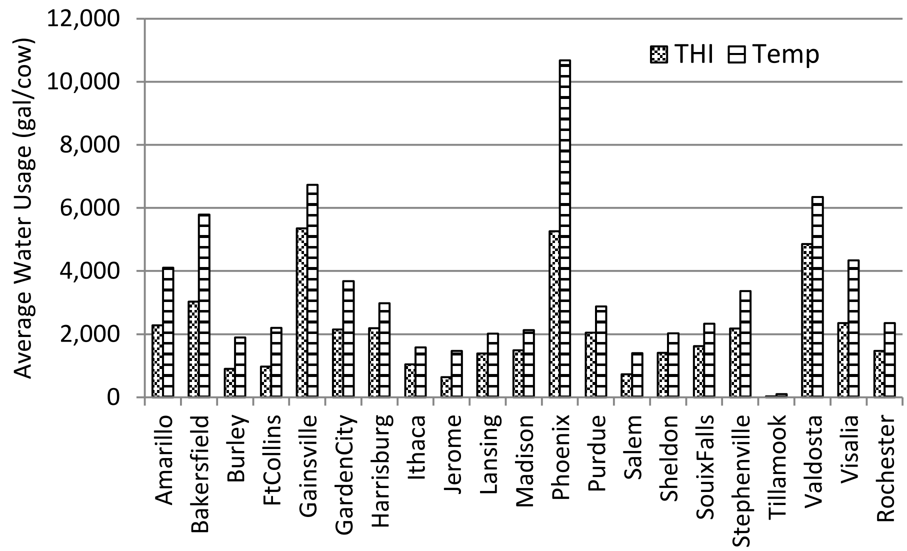


Figure 6. Estimate of the annual water requirements per cow for cooling using a feedline soaker system with 1 gallon per minute nozzle and spaced 8 feet on center.

On option for measuring relative humidity in dusty livestock environments is an aspirated psychrometer. This device raises a wet bulb sensor from a reservoir and into the airstream during aspiration and measures the wet bulb temperature. Use psychometric equations, the dry bulb and wet bulb temperatures can be used to calculate the relative humidity. Costello et al. (1991) reported "in laboratory tests over a wide range of vapor pressures, the root-mean-squared-difference (RMSD) between relative humidity from the psychrometer and a chilled mirror hygrometer was 0.3%. In tests in a commercial broiler house, differences between three psychrometers (RMSD=2.0%) could be traced to experimental uncertainty in temperature measurement. Tests in broiler houses have shown the psychrometer mechanisms to be reliable with minor maintenance required every five to ten days." Barber and Gu (1989) early reported the accuracy and reliability of a shop-built aspirated psychrometer were comparable to a saturated-salt dew point hygrometer, and a mechanical hygrothermograph. The measured relative humidity measurements were within ±5% relative humidity of a reference psychrometer. Dust accumulations did not affect the accuracy of the sensors as much as was expected during an eight week test in a dairy barn.

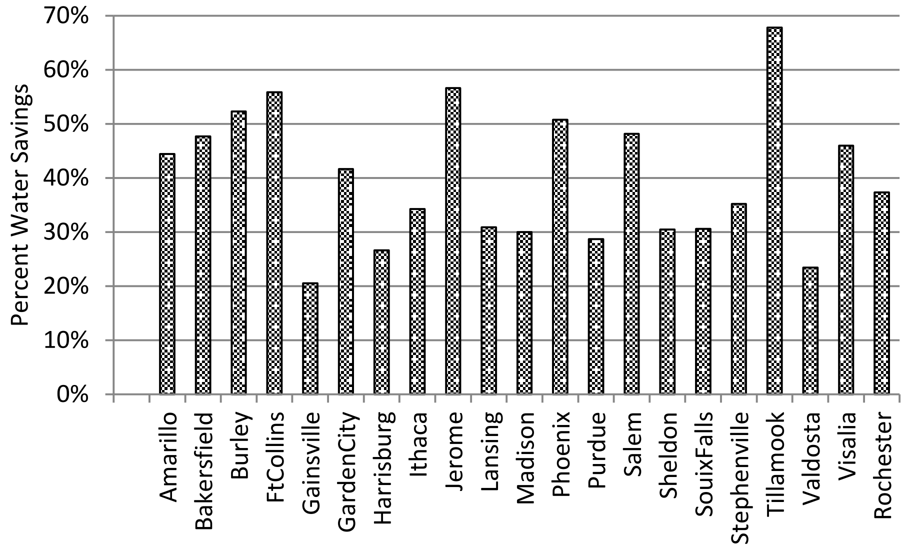


Figure 7. Estimated annual water savings if feedline soaker system was controlled based on THI rather than temperature.

Figure 8 compares the annual electrical energy requirements for heat stress abatement per cow. The estimates assume 1 hp (0.75 kW) of fan capacity per 12 dairy cows which is the common recommendations in a 4-row freestall building with 2-rows of fans per pen. Electrical requirements range from 100 to 250 kWh per cow per year regardless of whether the fans operated based on temperature or THI.

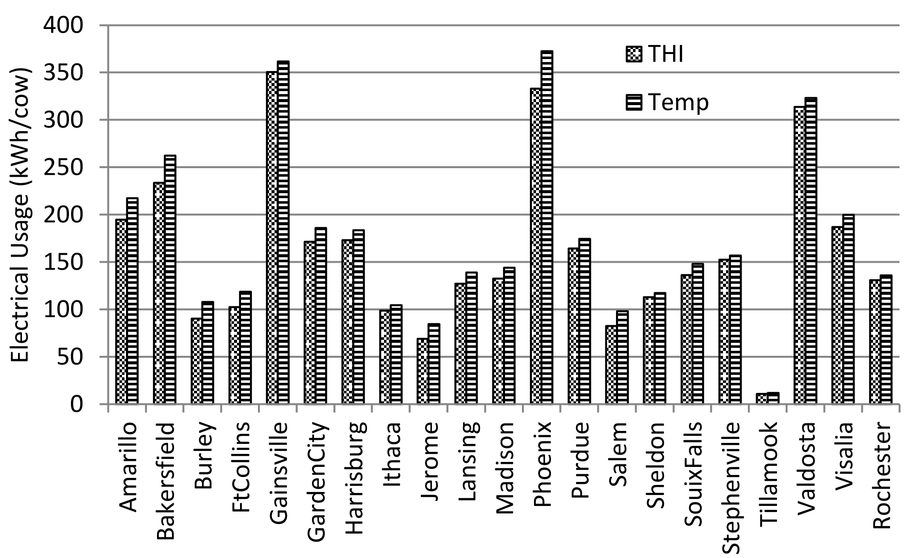


Figure 8. Estimate of electrical energy requirements utilized for heat stress abatement

Figure 9 shows the electrical energy savings if heat abatement were based on THI rather than temperature. Energy savings are 1/3 to 1/5 of the water savings, however, there would still be economical benefits to managing heat stress based on THI.

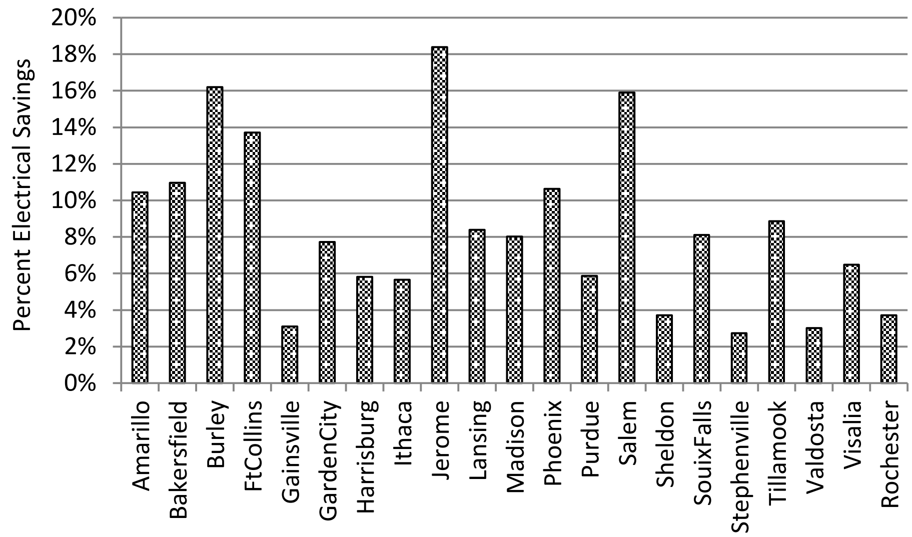


Figure 9. Electrical energy savings if heat abatement ventilation systems were controlled based on temperature humidity index rather than temperature

Figure 10 shows the percent hours of the heat stress period when the THI is between 70 and 74. With the exception of Phoenix, 60 % of the heat stress abatement occurs during periods when the THI is between 70 and 74. Since much of the heat stress in the US occurs with the THI range of 70 to 74 understanding and developing control strategies in this heat stress range is critical in reducing the energy and water footprints necessary to abate heat stress.

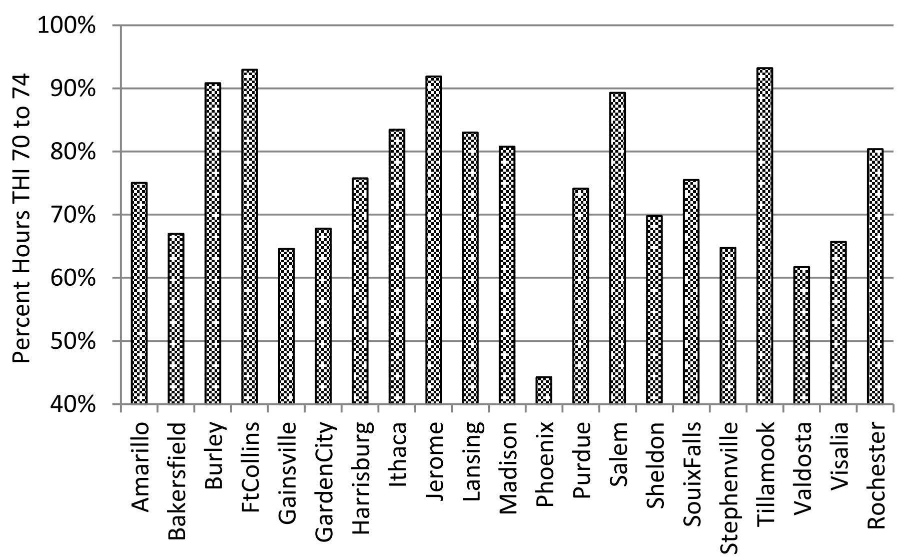


Figure 10. Percent of heat stress occurring between temperature humidity indices of 70 and 74

Energy Ratings of Fans

The fan manufacturing industry has taken the leadership in developing energy efficient fans. Most companies have their fans independently test to verify their performance at Bioenvironmental and Structural Systems Laboratory (BESS Lab at http://bess.illinois.edu/) located at the University of Illinois. This lab independently verifies the performance of ventilation fans used in the livestock industry similar to the test procedures used by the Underwriter's Laboratory. Figure 12 shows the energy efficiency rating(cfm/watt) for five 54 inch diameter and 1.5 hp fans. Tunnel and low profile dairy housing systems often operate at 0.15 inches of static pressure. In viewing Figure 11 at 0.15 inches static pressure the energy efficiency ranges from 15 to 17.8 cfm/watt of electricity. The kWh of electricity utilized per hour for tunnel ventilation of a barn requiring 1,000,000 cfm of air ranges from 56 to 67 kWh. This equates to an 11 kW difference in demand charges and 11 kWh difference in electrical energy charges.

According to the Department of Energy over half of all electrical energy consumed in the United States is used by electric motors. Motors may be classified as standard or energy efficient. Motor efficiency is the ratio of mechanical power output to the electrical power input, usually expressed as a percentage. Dairies with mechanically ventilated housing systems such as tunnel or cross ventilated should consider energy efficient motors. While the initial cost may be higher, there may be energy tax credits available, energy savings and reduced operating costs. Energy-efficient motors are better constructed so they usually have higher service factors, longer insulation and bearing lives, lower waste heat output, and less vibration, all of which increase reliability.

Munter-Aerotech (this is not an endorsement by the authors or the Western Dairy Management Conference of their fans or products) has developed and patented a direct-drive "M" fans. Figure 12 compares the energy efficiency rating of four of Munter-Aerotech 55 inch fans. The 1.5 and 2 hp fans have belt drives and the M drive fans are high efficiency or high output. Using the same example as above, the difference in electrical requirements at 0.15 inches static pressure is from 70 to 92 kW per hour of fan operations. These energy efficient fans do have a higher initial cost but in mechanically ventilated buildings the savings in the electrical demand and electrical energy charges may result in a quick payback. Direct drive fans also result in less maintenance cost since belts do not have to be periodically replaced or tightened. Cleaning of the fans and shutters is required with both types of fans. The test results of the BESS lab are based on a clean environment. Energy efficient declines if dust or dirt accumulates on the fan blades.

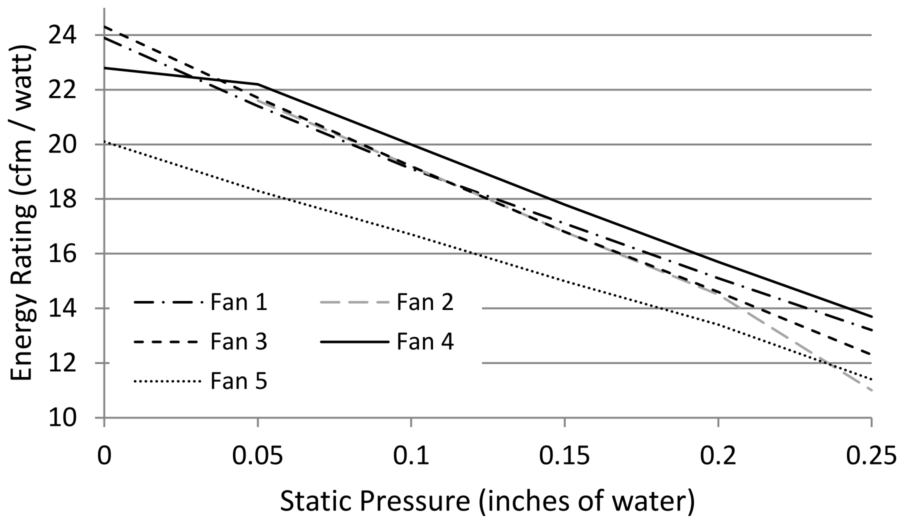


Figure 11. Comparison of energy rating of five different 54 inch fans tested by the BESS Lab

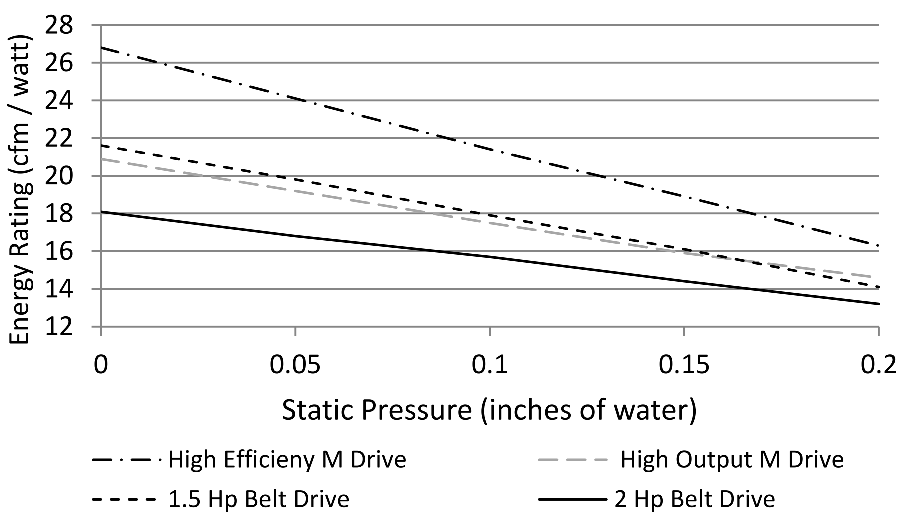


Figure 12. Comparison of Munter-Aerotech's 55 inch direct and belt drive fans

Directional Fans

Manufacturers are increasingly focusing on directional control of the air flow and velocity. Air tends to follow the path of less resistance resulting in higher air velocities in alleys, traffic lanes and head space of freestall. This is occurs in mechanically ventilated buildings such as tunnel or cross ventilated freestall houses. Direction all fans move air that stratifies above the cows back or near the top of the building direct the air back into the cow space. Since the fans are operating at low to zero static pressure, they can direct air at high velocities into the cow space very energy efficient. Most of these fans may be equipped with a high pressure mist or fogging unit and can re-cool the air as the moves the length of the building assuming the air is not saturated with moisture. In tunnel freestalls, the end walls fans are used to create the desired air exchange inside the building and the directional control fans are used to create the velocity in the cow space. This results in a much more energy efficient ventilation system. Other manufacturers are changing the fan blades to increase the throw of cage or basket fans utilized in naturally ventilated freestalls. A 36 inch (~1 m) fan that is normally mounted 24 ft (8 m) on center with redesigned blades the mounting increases to 36 to 40 ft (13 m) since higher velocities can be maintained further distances from the fan.

Water Savings

The authors have received inquiries about turning of the feed line soaker during various portions of the day. Current recommendation is to leave the soaker system on 24 hours per day however cow time budgets indicate cows only spend 5 to 6 hours per day at the bunk or about 25 % of the time. There has been discussion on placing motion or thermal sensors on feedline sprinkler nozzles. The complexity of the system increases and a power source is required at individual nozzle or a bank of nozzles for the sensor and the solenoid. A simpler solution for dairies to experiment with is adding a 2nd soaker line controlled by a 24 hour time in series with the main controller (Figure 13). The main soaker line would remain in place and a timer would turn on the soaker system 30 minutes after the cows were at the milk center and remain on for the next 2 hours. Any time feed was pushed up the main line would be operational for 1 hour. Therefore, when most of the cows were at the feedline, 100 % of the nozzle would be operational. During the other periods of the day the secondary line would be operational. The secondary line would per shorter and only a few nozzles would be turned on. The recommendation is the secondary line length equal 10 % of the number of nozzles along the main line if a 2-row pen and 20 % if a 3-row pen. The nozzle spacing recommended 2x of main line nozzle spacing in order to distribute the cows along the feed line. Assuming the main line is 400 feet long and the pen is 2-row, the secondary line would have 5 nozzles (10% of main line nozzles - 400 ft / 8 ft spacing). The secondary line would be located at the center of the feedline with only 5 nozzles spaced at 16 ft. The potential water savings will vary but using the following assumptions:

- the pen is milked 3X
- feed is pushed once per milking interval
- 4 sprinkler on cycles per hour
- 0.25 gallons per cow per sprinkler on cycle, and
- 16 hours of heat stress
- Nozzle Spacing is 8 ft

The water usage with current recommendations equals 16 gallons per day per cow and installation of a secondary line reduces water usage to 7 gallons per day per cow.

Geo Thermal Heat Exchangers

The University of Arizona and GEA ((mention of trade names is not an endorsement by the authors or the Western Dairy Management Conference of their fans or products) are evaluating the use of heat exchangers placed beneath the bedding in freestall. Cold water passes through the heat exchanger and cools the bedding resulting in heat transferring from the cow as she is resting on the bedding. Oritz et al (2014) reported the results of this study using geo thermal heat exchangers buried 10 inches below the surface as components in a conductive system for cooling cows. Their studies conducted in an environmental chamber with 10 inches of either sand or dried manure between the cows and the heat exchangers. The water temperature through the exchanger was 45 ˚F and three different climates (hot and dry, thermo- neutral, and hot and humid) were evaluated. This studied showed sand bedding remained cooler than dried manure bedding regardless of climate. The cooler beds resulted in a reduction of core body temperatures, respiration rates, rectal temperatures, and skin temperatures for cows housed in the stalls with sand bedding and the heat exchanger operating. They also observed feed intake and milk yield numerically increasing during the bed treatment with sand and water on for all climates. There were no major changes in the lying time of cows or milk protein or fat. They "conclude that use of heat exchangers is a viable adjunct to systems that employ fans, misters, and evaporative cooling methods to mitigate effects of heat stress on dairy cows. Sand was superior to dried manure as a bedding material in combination with heat exchangers."

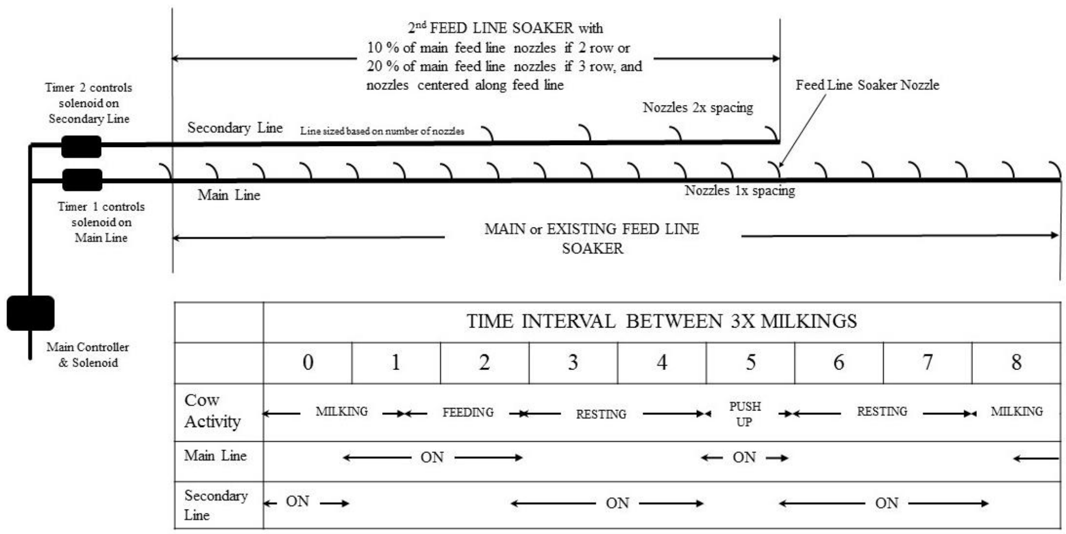


Figure 13. Conceptual idea of adding a secondary soaker line along the feed line and operating schedule

Summary

Technologies are being developed to reduce the energy and water requirements for heat abatement. Electrical energy savings of the fans and energy efficient fans are currently available from equipment suppliers. The geo thermal cooling mats are being evaluated through research trials and efforts are being made to improve the performance. Technologies available for reducing water consumption are currently lacking. There is much interest in water saving technologies utilizing timers, cameras, motion detectors or infrared sensors to determine when cows are at the feed line. Significant electrical and water savings are possible by operating the heat abatement system based on the temperature humidity index rather than temperatures.

References

Barber, E.M., D. Gu. 1989. Performance of an Aspirated Psychrometer and Three Hygrometers in Livestock Barns. *Applied Engineering in Agriculture*. 5(4): 595-600.

Buffington, D. E., A. Collazo-Arocho, G. H. Canton, D. Pitt, W. W. Thatcher and R. J. Collier. 1981. Black globe-humidity index (BGHI) as comfort equation for dairy cows. *Transactions of the ASAE.* 24(3): 711-714.

Costello, T.A., I. L. Berry, R. C. Benz. 1991. A Fan-Actuated Mechanism for Controlled Exposure of a Psychrometer Wet Bulb Sensor to a Dusty Environment. Applied Engineering in Agriculture. 7(4): 473-477

Horner, J. L. and J. M. Zulovich. 2008 Heat Stress on a Commercial Dairy Farm Startup: An Economic Evaluation of Cooling. *Eighth International Livestock Environment Symposium*. ASABE Pub. No. 701P0408. ASABE. St. Joseph, MI.

Ortiz, X. A., J. F. Smith, F. Rojano, C. Y. Choi, J. Bruer, T. Steele, N. Schuring, J. Allen,‖ and R. J. Collier.2014 Evaluation of conductive cooling of lactating dairy cows. under controlled environmental conditions. J. Dairy Sci. TBC:1–13. http://dx.doi.org/10.3168/jds.2014-8583

Zimbelman, R. B., R.P. Rhoads, M.L. Rhoads, G.C. Duff, L. H. Baumgard, and R. J. Collier. Re-Evaluation of the Impact of Temperature Humidity Index (THI) and Black Globe Humidity Index (BGHI) on Milk Production in High Producing Dairy Cows. Pages 158–168 in Proc. Southwest Nutr. Manag. Conf., Tempe, AZ.

Zulovich, J.M., J. T. Tyson, & M. Brugger. 2008. Improving Management of Heat Abatement Systems on US Dairy Farms. *Eighth International Livestock Environment Symposium*. ASABE Pub. No. 701P0408. ASABE. St. Joseph, MI.

Anon. Fact Sheet: Buying an energy-efficient electric motor. Pub. DOE/GO-10096-314. U.S. Department of Energy. (www.motor.doe.gov.)

Notes:

Dr. Donald L. Bath was presented the College of Agricultural and Environmental Sciences Award of Distinction in 1996.

Donald L. Bath, University of California Cooperative Extension specialist emeritus, passed away on Oct. 26, 2013. He was 81.

He earned his B.S. and M.S. in animal husbandry and his Ph.D. in nutrition, all from UC Davis, where he also quarterbacked the Aggie football team and served as president of the Sigma Alpha Epsilon fraternity. In 1963 Bath became a UC Cooperative Extension dairy nutrition specialist based at UC Davis. "Don had a significant impact on my career and my philosophy toward the dairy industry," said Ed DePeters, professor in the Department of Animal Science at UC Davis. "I first met Don when I came to UC Davis in October 1979, as a green Ph.D. from Penn State. It was a meaningful experience for me, because as an undergraduate at Cornell University I used his book, "Dairy Cattle: Principles, Practices, Problems, and Profits "by Foley, Bath, Dickinson, and Tucker in my dairy production class."

During his 30-year career, Bath authored 350 publications, including the widely used textbook. He and his colleagues developed and marketed PC Dairy, one of the first linear programming ration-balancing computer programs. Bath and his UC Davis colleague Vern Marble developed a method for determining total digestible nutrients in alfalfa hay. In 1980, he co-authored "By-products and Unusual Feedstuffs in Livestock Rations," which summarized the scientific literature on the chemical composition of more than 200 by-product feeds, and which remains a reference guide. In the 1980s, when cottonseed meal was commonly used in feed, Bath and DePeters conducted research that demonstrated that canola meal was equivalent to cottonseed meal and opened the California market to canola meal. Canola meal is a common feed ingredient in commodity barns and is widely used in dairy rations on California dairy farms. Bath retired in 1993. "The facts that PC Dairy and the Alfalfa Hay Testing Program each still plays a role in the dairy industry and that canola meal is a primary protein supplement in California demonstrates the significance of Don's science to the dairy industry," said DePeters.

Bath is survived by his wife Gloria, their sons Robert and Daniel, five granddaughters and his sister Darlyn. Gifts in Bath's memory may be made to the "Donald Bath Animal Science Student Award," payable to the UC Davis Foundation, UC Davis, CAES Dean's Office, One Shields Ave., Davis, CA 95616.

Don Bath Memorial Lecture: The Future of Alfalfa in the West = Water!

Seth Hoyt
Hay Marketing Consultant
Publisher of "The Hoyt Report"
Ione, California 95640
209-274-9945

Abstract

With drought conditions in some areas of the west in 2014, including extreme drought in California and resulting record high alfalfa hay prices early in the season, one could ask the question "what is the future of alfalfa hay production in the West?" This question has more significance in the central and northern valley of California where permanent crops, particularly almonds and other tree crops that use less water have replaced acres that were once used for alfalfa hay production. In some other western States such as Idaho and Utah, alfalfa hay acres and production seem to be more impacted by prices on corn, wheat, and potatoes. While irrigation water availability impacted alfalfa hay acres and production in 2014, one thing that was evident in the west but particularly in central California was the significant increase in groundwater usage during a period of reduced surface water availability. This will be a bigger issue during drought conditions in the future with new groundwater management legislation in California in 2014. Some States are already involved in groundwater management. There are a growing number of crops in the central and northern valley of California that use drip irrigation which is a big factor during periods of tight irrigation water supplies. Another thing discovered during the severe drought in California in 2014 and the record high prices on milk cow quality alfalfa hay – hay will move from throughout the west to central California if there is enough spread between FOB and delivered prices. This will be a bigger issue in the future as all signs point to fewer acres of land available in California for alfalfa hay production in the years ahead.

2014 - A Year with Many Dynamics in Alfalfa Hay Production and Usage

While the seven western States experienced abnormally dry to extreme drought conditions in 2014, California by far had the worst drought conditions of any State in the nation. However, in October, alfalfa hay production in the seven western States in 2014 was forecast by USDA to be up 8 percent from 2013. I disagreed with USDA on their forecast for alfalfa hay production in California for 2014 after I surveyed 25 bigger alfalfa hay growers in California representing nearly 63,000 acres. These growers reported alfalfa hay production to be down 7 percent from 2013 compared to the 8 percent higher production reported for California by USDA. While I believe alfalfa hay production was down in California in 2014 it would have been down much further had it not been for an increased amount of groundwater used for alfalfa hay production. Conversely, a survey I conducted of bigger alfalfa hay growers in Idaho showed alfalfa production to be up 8 percent from 2013, close to USDA's forecast of 9 percent higher alfalfa hay production for the State of Idaho in 2014. Groundwater was a bigger factor in alfalfa hay production in other areas of the west besides central and northern California. In Nevada, alfalfa hay production in Lovelock was down dramatically due to very low supplies of surface water from Rye patch Reservoir while alfalfa hay production in other areas such as Diamond Valley were normal due to groundwater usage.

One thing evident in 2014 was the above normal movement of alfalfa hay and straw from western States into central and north central California for dairy cows. With the largest concentration of dairy cows in the U.S. located in central California (1.3 million dairy cows between Kern and Stanislaus Counties with nearly 40% of those in Tulare County), there was strong demand for alfalfa hay and other forages. Normally, California receives very little alfalfa hay from Idaho but that was not the case in 2014 according to industry contacts (because of budget cuts, the California border stations are no longer furnishing in-shipped alfalfa hay data from western States to me). You rarely see wheat straw shipped from out-of-State into California but in 2014 a large amount of straw shipped into central California from throughout the west as dairymen were using straw with other by-product feeds to lower the cost of feeding dry cows. This included ryegrass straw shipped from Oregon and Washington. Delivered prices on straw reached record high levels. This pushed the delivered market on dry cow alfalfa hay in central California lower from July through the fall as demand declined.

The story was much different on higher quality milk cow alfalfa hay in most areas of the west. Due to tight supplies of Premium and Supreme quality alfalfa hay, the market stayed strong through the season in many areas with prices slipping late in the fall due softer milk prices. As a result of the strong market on Premium and Supreme alfalfa hay, dairymen throughout the west reduced the pounds of alfalfa hay fed to milk cows. In California, pounds of alfalfa hay fed per head/per day in 2014 dropped from 9.44 pounds in the first quarter to 7.97 pounds in the third quarter, according to the California Department of Food and Agriculture. Supreme alfalfa hay delivered to central California dairies ranged from $330 to $370 per ton through the season compared to a rolled corn delivered price in a range of $198 to $250. There were several reasons for the tighter supplies of higher quality alfalfa hay in the west in 2014, including an increased amount of rain damaged hay, particularly in Idaho and Utah, disappointing tests on non-rain damaged alfalfa hay in some areas, alfalfa growers in some areas such as central and northern California that shifted to longer cutting cycles earlier in the season than normal due to uncertain irrigation water supplies. As previously mentioned, the market slipped late in the year on higher quality alfalfa hay due to declining milk prices but the drop was nothing like what was seen in the low to middle quality alfalfa hay markets. Indications are pointing to a bigger carryover of alfalfa hay in the west into 2015 but much of it is low to middle quality.

Alfalfa Hay Production in the West in Future Years – Where are we headed?

With drought conditions spurring record high delivered prices on alfalfa hay in Central California in 2014, particularly on Premium and Supreme qualities, and reduced feeding of alfalfa hay by dairies the question could be asked, "What is the future of alfalfa hay in the West?" While dairies in the west reduced the pounds of alfalfa hay fed to milk cows and some dairies stopped feeding alfalfa hay, a few dairy nutritionists that I spoke with in central California in early January 2015 still believe that alfalfa hay, even fewer pounds than last year, has value in milk cow rations. One nutritionist said that he keeps alfalfa hay in milk cow rations because it is an effective fiber with protein and compared to costs of other protein feeds it has value. His comment "normally when prices are very high, like in 2014, prices will come down the following year." Drought has changed this on the short term but historically he is correct. Another nutritionist said he keeps alfalfa hay in the ration for "intrinsic value." He also mentioned that high quality alfalfa hay helps milk production, particularly in central California during the hotter months of July through September.

While irrigation water is a critical element in growing alfalfa hay, there will be dry years when irrigation water in the west will be less than normal and there will be years when rainfall and snowpack will be normal to above normal. Unfortunately, in California there has been two years of drought with 2014 being the driest on record. California voters passed a bond measure in the fall of 2014 that will spend billions of dollars to build more water storage in California to capture water in those years when rainfall and snowpack are more plentiful. In the Sierra Nevada's on December 30, 2014, snowpack was around 50 percent of normal. While there is still time in the winter for more snow in the mountains and rain in the valley, another year of below normal snow and rain in California would be a hardship on the State, particularly agriculture. With the outlook for fewer acres of land available for alfalfa hay production in California in the coming years due to competing crops, such as tree crops, alfalfa will need to try to compete as a more efficient user of water in the future. This could increase the use of drip irrigation on alfalfa hay. One of my contacts in Central California who is a hay dealer and a dairyman has had success using drip irrigation on alfalfa hay this past year and wants me to look at his fields when I am at the World Ag. Expo in Tulare in early February. I will report this in my presentation on March 3 at the Western Dairy Management Conference. Drip irrigation has been tried before in central California with mixed success but I think it is something that needs to be looked at again and build on successes of those that are making it work. We are in an era of competing crops and the efficient use of water will become a bigger factor when it comes to decisions of what farmers will plant, particularly in the central valley where the largest amount of alfalfa hay is grown in California.

In the years ahead when there is below normal production of milk cow quality alfalfa hay in central California due to drought, the hay will come from other States. Even with the outlook for fewer acres of alfalfa hay in California in the years ahead due to competing crops, particularly tree crops, some of this shortfall in alfalfa hay production will be made up from hay from the southern desert (including Arizona), Idaho, Utah, Nevada, Oregon, and at times from Washington, Colorado and Montana. With the prospect of lower freight rates in 2015, hay could ship from Midwestern states. There was dry cow alfalfa hay delivered to central California from Canada in 2014. If there is demand and enough spread between the fob and delivered price, the hay will come. Early estimates are that alfalfa hay acres will increase in Idaho, Utah, and Washington in 2015. The jury is still out for California but with a 7 percent decline in alfalfa hay acres in the Imperial Valley due to increased Durum wheat plantings and with some growers holding back on fall plantings in the central valley due to irrigation water uncertainties, I'm not sure that alfalfa hay acres in California will be up at all in 2015. The key will be winter and early spring plantings in central California.

An interesting thing happened in the fall of 2014 in central Utah that may not occur when we get into new crop 2015 alfalfa hay when there is more volume of hay on the market but non-GMO alfalfa hay in a barn sold for more money to export buyers than the same quality GMO (Genetically Modified Organism) alfalfa hay would bring from dairies on the domestic market. The reason is that there is strong demand for non-GMO alfalfa hay to export to China. Currently, the leading export market for alfalfa hay from the west coast is China and it appears they will be strong buyers in 2015. In July of last year, China announced a zero tolerance for GMO alfalfa hay (Round-Up Ready) and with new testing procedures they are not accepting alfalfa hay that is GMO. In late 2014 China accepted a strain of GMO corn from the U.S. so it appears that they will eventually accept GMO alfalfa hay.

Conclusion

While much of the seven western States had dry conditions in 2014, alfalfa hay production reported by USDA in October was still up 8 percent from 2013. Groundwater played a bigger role in alfalfa hay production in 2014 and will be a bigger part of alfalfa hay production in dry years in the future. Groundwater management will impact growers in areas where there is demand for water from urban and agricultural users. While wet and dry cycles will continue in the west in the future, there are efforts to increase water storage in California and drip irrigation may be used more in some areas, particularly in central California to make alfalfa more competitive with crops currently using drip irrigation. In future years when alfalfa hay production in California is impacted by drought, the large dairy industry in the central valley will draw alfalfa hay from other States, even from States that rarely export alfalfa hay to California. This will also hold true with Idaho or other dairy States in the West.

World Dairy Competion- Jostling for Position

Tim Hunt

Short bio:
Tim Hunt is the Global Dairy Strategist for Rabobank's Food & Agribusiness Research and Advisory team.

Rabobank is the world's leading Food & Agribusiness bank, serving farmers, processors, traders and users of food and fiber in more than 45 countries around the world, including Canada.

The bank's research team, comprised of 70 analysts based in key food and agri markets around the world, is charged with analyzing developments in food and agricultural markets and industries, and advising the bank and its clients on the strategic implications for their businesses.

Based in New York, Tim leads a team of 12 dairy analysts located in the world's major dairy regions.

He is responsible for analyzing and forecasting developments in the North American and global dairy markets, advising the bank on its engagement with the dairy industry, and providing strategic counsel to clients involved in the global dairy sector.

Tim's 20 years of experience in the food and agribusiness sector was gained through his work with leading financial institutions and consultancies in Australia, England and the United States.

Notes:

Group Feeding Calves with Autofeeders

Robert James
175 West Campus Drive
Dept. of Dairy Science
Virginia Tech
Blacksburg, VA 24061-0315
jamesre@vt.edu

Two challenges exist in feeding the preweaned dairy calf – providing sufficient nutrients for "biologically normal" rates of gain and managing labor. Research has shown that calves cannot meet their maintenance requirements when fed only two quarts of milk or milk replacer twice daily at temperatures below 50° F. However, feeding more milk with twice a day feeding is a challenge due to the large volume of milk involved. Uneven intervals between feeding may limit intake during the afternoon feeding when larger volumes are fed. Calf feeding and care is a labor intensive operation involving feeding and cleaning of buckets and bottles as well as other chores with health care. More frequent feeding is problematic as it increases labor requirements and involves a late night feeding.

Several manufacturers are producing equipment that has shown to be effective in feeding calves and providing valuable management information. Desirable features of autofeeders include:

- Identification of calves using standard RFID tags.
- Development of individual calf feeding plans
  - Gradual daily increase of milk or milk replacer allocation during early life.
  - Minimum and maximum meal sizes - According to their daily allocation established in the feeding plan, calves must "earn" enough credits as time passes to reach a minimum meal size. (Eg. If calves are allocated 8 liters of milk replacer per day they must wait a little over 2 hours to earn the right to consume 1 liter of milk since their last meal). Maximum meal sizes are established to avoid "slug" feeding of large volumes of milk at one visit to the feeding station. Milk or milk replacer is delivered in .5 L batches. If the calf has a remaining allocation for a given feeder visit, additional batches will be mixed until the calf consumes their maximum meal size.
  - Weaning can be tailored as desired to gradually reduce milk or milk replacer allocation over 3 to 14 days to encourage less stressful weaning.
- Monitors – Autofeeders automatically provide information to the manager describing feeding behavior of the calf which might indicate impending illness.
  - Daily intake relative to previous days
  - Drinking speed - Although calves may consume their daily allocation, declines in the rate of intake appear to be a useful indicator of impending disease.

- Breaks - The calf leaving the stall before the delivered volume of milk is consumed.
    - Managers can specify multiple measures which will trigger an alarm notification for a calf that has not achieved desired feed behavior.
- Feeders can deliver whole milk or milk replacer at a specified temperature and solids level in the case of milk replacer. Milk replacer and milk can be blended to achieve desired nutrient levels. This is especially beneficial when there is an inadequate supply of unsaleable milk.
- Additives can be delivered in precise amounts to individual calves
- Equipment is sanitized automatically, much the same as milking equipment.

The benefits of automatic calf feeders allow greater daily volumes of milk or milk replacer to be delivered in smaller meals which should be less stressful to the calf. Significant amounts of information are reliably provided to the manager to assist in detection of calf disease. Since dairy animals are “herd” animals, group housing appears to be less stressful to calves from a social viewpoint. Movement of calves in to the post weaning pen is also less stressful.

However, it is important to note that there are challenges to the adoption of systems using autofeeders in group housing. Calves are usually housed and managed individually in hutches or individual pens for the first 3 to 10 days of life. Facilities must be carefully designed to assure adequate positive pressure ventilation and provision of dry, well bedded resting areas. Calf managers in these systems must have excellent observation skills of young calves and be somewhat mechanically inclined to service and maintain the autofeeders. They should be data oriented individuals as well.

The panel members represent a variety of situations and environments across the U.S. We have asked them to share information about their operations as well as how they adapted to the management challenges of calf autofeeder systems. We greatly appreciate their traveling to Reno to share their experiences with you.

Laura Flory
Hillside Farm
6486 Cleburne Blvd.
Dublin, VA 24084
loflory@gmail.com
(540) 320-5169

Laura is one of 4 family owner/managers at Hillside Farm located in Dublin, VA. She received a B.S. in Dairy Science from Virginia Tech in 2009 and has spent the past five years working with her family to promote efficiency and animal health on their 200 cow dairy. During 2014 the farm transitioned into new facilities including an automated calf feeder barn with a Lely Calm calf feeder with two milk feeding stalls. The barn has two nursing pens which are equipped to house up to 60

nursing calves, divided into age groups of newborn to 30 days and 31 days to weaning. The nursing half is 76' x 45' and has a full concrete floor. All pens provide resting areas bedded with straw and have free choice access to 22% protein calf starter.
Key features of the calf rearing system are:

- **Building design**

-New construction (156' x 45' with 14'eave height) equipped with top drop curtain system, positive pressure ventilation tubes, and full concrete floors for ease of cleaning.

- Weaned calves are housed within the same barn which allows for easier transition.

- **Rigid risk management protocols for disease prevention**

-All calves are treated with equal attention at birth including a full 1 gallon portion of high quality colostrum within the first 6 hours, a preventative dose of a serum antibody within 12 hours and a dose of Inforce 3 upon introduction to the group pen.

- Boot sanitization is required upon entering and exiting the barn.

- **Attention to detail in the environment**

-The floor around the feeder area is hosed clean a minimum of once daily, calves have deep bed straw at all times and calf jackets are utilized in temperatures under 50 degrees F.

Jeanne Wormuth
CY Farms
5327 Watson Road
Elba, NY 14058
Jeanne@cyfarms.com
585-356-2395

Jeanne Wormuth is the Manager of CY Heifer Farm, LLC. Located in Elba, New York the facility custom raises 4,000 dairy heifers for customers ranging in size from 100 cows to several thousand. Ten very dedicated and long-term employees raise heifers from shortly after birth to about 2 months pre-calving. Calf raising has evolved from individual pens and hutches to converting in 2007 to group housing and automatic feeders. Jeanne also oversees Provitello Farms, LLC a 1,200 head milk fed veal facility that is co-located with the heifer farm that also group houses calves and machine feeds milk.

C. A. Russell
CDFD-Exum and Yosemite Dairy
P.O. Box 1089
Hilmar, CA 95324
carussell@prodigy.net

CDF DAIRY TEXAS with locations in Hartley and Exum, TX. C.A. and his wife Kirsten Clauss Russell are partners with Kirsten's two sisters, Karen Tate and Kimberly Jorritsma, in CDF Dairy. The dairy began operations in November of 2011 and is currently milking 3500 in Hartley, TX. Construction is in progress on the Exum milking facility that will expand the herd to 6000 milking. The Texas operations have all grown out of the partner's California dairies. (Yosemite Jersey Dairy, Clauss Dairy and Sunwest Jersey Dairy).

We made the decision to move to automatic feeders with the desire to:

- Provide calves with a controlled environment to minimize harsh weather conditions of the High Plains
  - Develop a more consistent milk delivery system
  - Improve labor efficiency
  - Obtain information to assist us with management decisions

The design for the EXUM calf operation came from touring installations in Iowa, Minnesota and South Dakota. The facilities we visited ranged from converted chicken and hog barns to ones designed specifically for dairy calves. We noticed that regardless of the design, the calves in each facility were thriving. Working with our contractor we designed the Exum facility incorporating the things we liked best about the operations we toured.

The barn currently has 12 Automatic feeders each with two feed stations. Each feed station services 26 calves. The pens are designed with 21 square feet per calf. Pens are bedded once a week with wood chips and chopped straw. The pens are sloped to drain to an underground fresh water flume that is flushed each hour. Radiant heated floors are in the nesting area in each pen. The barn itself runs east and west with triple curtains on each side. The barn has 12 ridge fans on top of the barn. Ventilation tubes run over each pen and we have installed circulation fans in each pen. All of the fans and curtains are designed to run on a computer-controlled program based on current weather conditions

The calves are born at the Hartley dairy and transported 26 miles to Exum. They are housed in individual pens for 4 to 5 days, where they are bottle-fed. Next they enter the group feeding and the feeding program is up to 8 liters a day with the weaning process starting at 45 days and complete at 60 days. Calves are moved to outside bedded pens at 70 days.

Results have not reached our expectations. Ventilation has been challenge number one. With all the fans we have in place as well as the curtains we can open and the natural wind in the High Plains I would think that it would be the last issue we would struggle with. If we had to do it over again I would make the investment in a ventilation engineer for the project. We have totally reworked the ventilation system in the past year.

The second challenge has been developing protocols for cleaning and maintaining the auto feeders that work for our situation. Our third challenge has been developing systems and protocols for handling group feeding. This includes monitoring the barn, detecting sick calves, vaccination and treatment protocols. The calf facility continues to be a work in progress. We believe we can develop it to reach our original objectives.

Notes:

Turning Manure Nutrients from a Liability to an Asset

Dana M. Kirk, Ph.D., P.E.
Michigan State University
Biosystems and Agricultural Engineering Department
Anaerobic Digestion Research & Education Center
524 S. Shaw Lane
East Lansing, MI 48824
P: 517.432.6530
E: kirkdana@msu.edu

Introduction

With fertilizer costs still near record prices, dairy farms should expect to reap some reward for the nutrients contained in dairy manure. However, manure continues to be viewed at as a liability by most farms. Many farms continue to seek nutrient recovery systems that concentrate nutrients, produce low nutrient effluent and reduce manure odors during storage and application. Nutrient recovery technologies range from basic solid-liquid separation, systems targeting phosphorus or nitrogen or technology combinations that generate multiple fertilizers streams and potable quality water. As farms consider nutrient recovery technologies, they must weigh the current cost and benefits of their manure management practices and their management goals against the opportunities and drawbacks of innovative nutrient recovery systems.

Record Fertilizer Prices and Mounting Environmental Concerns

Even with fertilizer costs still near record levels, manure as a fertilizer source is often undervalued. Figure 1 shows the change in value of elemental nutrients since 2000.

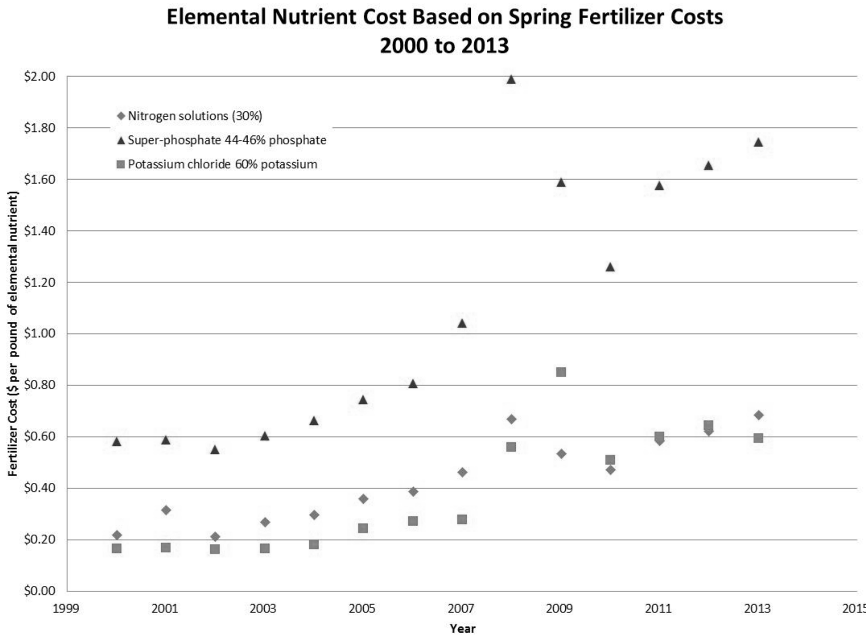


Figure 1: Elemental Nutrient Cost Based on Spring Fertilizer Prices 2000 to 2013 (USDA-NASS, 2014)

In the last 10 years, the cost of N-P-K fertilizers has increased on average 236%, compared to a very low and stable, prices from 1980 and 2004 (average increase of only 122%). The drastic increase in fertilizer cost has been driven by high oil prices and increasing demand caused by record corn and grain prices.

When viewed as a fertilizer, dairy manure provides a mix of nutrients and carbon necessary to maintain good soil health and high crop yields. Table 1 summarizes the annual production and nutrient content of manure from a single dairy cow.

Table 1: Annual Manure and Nutrient Production for a Lactating Dairy Cow (ASABE, 2005)

Manure Production			**Moisture Content**	**Nutrients**			**Solids**	
				N	**P**	**K**	**Total**	**Volatile**
ton/yr	*ft^3/yr*	*gal/yr*	*%*	*lb/yr*	*lb/yr*	*lb/yr*	*ton/yr*	*ton/yr*
27	876	6,552	87	361	62	84	4	3

Based on 2013 commercial fertilizer prices, the value of manure nutrients (N-P-K) for a single lactating cow is approximately $400 per year. This valuation does not include the value of carbon or micronutrients that are contained in the manure.

Manure as a fertilizer source, however, is often undervalued or not valued at all. As a commercial fertilizer replacement, manure is a challenge due to a number of factors including the dilute nature of nutrients, nutrient availability, and uneven nutrient distribution. Based on the ASABE (2005) dairy manure as excreted contains 55, 9, and 13 pounds of N-P-K per 1,000 gallons of manure, respectively. Factoring in dilution water added to manure, the N-P-K value drops to 33, 6, and 8 pounds per 1,000 gallons of manure. Due to the low nutrient content, manure applications rates of

5,000 to 12,000 gallons per acre are not uncommon to satisfy crop requirements. Because of a large portion of the manure nutrients are in the organic form, mineralization must occur before the nutrients become plant available. Organic nitrogen availability in the year manure is applied can range from 30% to 50%, due to decomposition of organic matter, year 2 nitrogen availability will be roughly 10 to 25% (Russelle et al., 2013 & Leikam & Lamond, 2003). Balancing the nitrogen availability with nitrogen credits from previous manure applications requires careful attention and planning to ensure that crop needs are met.

Other factors that contribute to the undervaluing of manure include the application cost, potential for soil compaction as well as social and environmental concerns such as runoff and odor. Nationally, manure application costs range from $0.005 to $0.031 per gallon of liquid manure applied (Gray et al., 2014). The wide range of application cost is influenced by application type (irrigation, dragline, injection, etc.), equipment used, fuel cost and distance from farm to field. Given the average cost of manure application at $0.014 gallon (Gray et al., 2014), the annual cost to land apply as-excreted manure is just under $90 per cow. Factoring in dilution water plus manure, the average annual application cost is closer to $148 per cow. If proper application equipment and tillage practices are not employed, manure application can contribute to soil compaction. The density of manure as excreted is close to that of water (62 lb/ft^3). Adding bedding does change the manure density. Sawdust, shavings and straw will lower the density (to as low as 25 lb/ft^3) whereas sand bedding can cause manure density to increase to over 90 lb/ft^3. Considering the fact that a 7,500 gallon manure tank containing sand laden dairy manure can weigh 15 tons or more than the same tank hauling just dairy manure should provide some perspective on the importance of manure density.

Social and environmental concerns associated with land application of manure are well documented, ranging from runoff to surface waters contributing to eutrophication, algal blooms and fish kills, to high pathogen and nitrite/nitrate levels due to leaching to groundwater, to nuisance odors and road damage during transfer from the farm to the field. In August of 2014, the issue of agricultural nutrient management was again brought to the forefront of the national conversation due to a toxic, microcystis algal bloom in Lake Erie that contaminated the freshwater supply of Toledo, OH, causing 500,000 people to seek out alternative sources of freshwater (Henry, T., 2014). Lake Erie has suffered numerous algal outbreaks over the past decade with the largest recorded algal bloom occurring in 2011, covering more than 1,900 mi^2 according to the International Joint Commission (IJC) (2014). The commission noted that 44% of the total phosphorus entering Lake Erie is attributed to agricultural activities. The Ohio Environmental Protection Agency (OEPA) has looked closely at phosphorus sources in the Lake Erie basin and determined that agricultural phosphorus sources are either commercial fertilizer (84%) or manure application (16%) (OEPA, 2013). The OEPA study infers two key points; 1) livestock and dairy farms are doing a good job at minimizing the environmental impact of manure nutrients and 2) more emphasis needs to be place on utilizing manure nutrients in lieu of commercial fertilizers.

Recovering Nutrients

To address these issues with manure and to realize the market value of manure nutrients, many dairy farms are investigating nutrient recovery technologies (manure treatment systems). Nutrient recovery technologies can be broadly grouped into three categories including systems to address solid-liquid separation, phosphorus recovery and nitrogen removal (stripping). In most cases, nutrient recovery systems will employ combinations of technologies to address the farm specific manure management concerns.

Solid-Liquid Separation. Solid-liquid separation, in this context, is the physical process by which solids are separated from liquid manure (water). For dairy manure, solid-liquid separation is commonly achieved by mechanical separation; however sedimentation can be successfully managed under certain conditions.

Sedimentation. Sedimentation or natural settling occurs due to density differences between manure particles and water. Denser (heavier) particles will tend to drop out of suspension provided the material is diluted and agitated before entering the settling basin. Without dilution and agitation, very little separation will occur. Most dairy farms will observe sedimentation in long term manure storages. The challenge with sedimentation is that separation of solids and nutrients is highly dependent on environmental conditions, requires significant time (months) for fine solids and is difficult to predict. In addition, the settled sludge is generally loose and easily resuspended with minor agitation or pumping. To overcome these challenges, farms that have successfully used sedimentation for nutrient recovery, typically construct multiple manure storages in series with gravity overflow to ensure a long retention time and minimal disturbance. It has been reported that sedimentation is capable of removing 50% of all solids and effective for fine solids (NCSU).

Mechanical Separation. Mechanical solid-liquid separation systems are commonly used by dairy farms to reduce issues with pipe clogging, sludge accumulation in storages and crust formation. Separation of solids is reported to also reduce odor potential during liquid manure storage. Liquid with coarse solids removed is generally easier to land apply, requiring less agitation and a reduced likelihood of clogging equipment. Common mechanical separators include stationary screens, screw press separators, rotary drum thickeners, centrifuges and hydrocyclones. Separation efficiency is influenced by manure type, screen size, flow rate, and the solids concentration liquid.

Most mechanical separators rely on particle size and shape as the basis for separation. Mechanical separators can be effective down to particle diameters of 1 micron, however most system target slightly larger sizes. Centrifuge separators rely on density differences between the solid and liquid fractions, in addition to particle size. Belt press thickeners and dissolved air flotation (DAF) are mechanical system capable of removing finer particle sizes, but they rely on chemical treatment of manure to be effective.

Solid separator technologies vary widely in separation efficiency and the characteristics of the fiber removed. Basic mechanical separator, the static screen, can achieve solid separation efficiencies in the range of 10 to 25% with the moisture content of the solids removed in the range of 80 to 90%. Screw press separators on the other hand provide more process control and can achieve separation efficiencies in the range of 25 to 40%, with the moisture content of the solids typically less than 75%. Using multiple separators in series with decrease screen pore size can result in solids removal rates as high as 50%. Even good solids removal, solid-liquid separation as a nutrient recovery technology is relatively ineffective achieving roughly 10-20% reduction of nitrogen and a 5 to 20% reduction of phosphorus contained in the liquid filtrate (Frear & Dvorak, 2012). Most of the nutrient removal will be in the organic form, tied to the manure fibers, while fine particulate and dissolved solids remains in the liquid.

Ultrafiltration. Ultrafiltration (UF) is a form of solid-liquid separation, but due to the unique nature of this technology it requires special consideration. The basis for UF is the application of high pressure on one side of a membrane to create a pressure gradient across the membrane. The pressure gradient tends to drive water and dissolved solids through the membrane pores to the low pressure side of the membrane. Normal operating pressures for UF are in the range of 50 to 150 psi. Permeate is the mix of water and low-molecular weight dissolved solids which passes out of the membrane. The mix of solids and water remaining inside the membrane is termed retentate. Ultrafiltration is most effective at removing solids (solutes) with molecular weights greater than 1,000 or particle sizes greater than 0.01 micron. For nutrient recovery, UF is commonly used to concentrated fine particulate, dissolved solids and phosphorus in the retentate. Ultrafiltration is also effective at removing bacteria, protozoa and some viruses from the liquid. Membrane technologies like UF are often capital intensive to install and have relatively high operating costs due to energy required to achieve the input pressures of the UF. Operation of a membrane system does also require a trained operator and regular monitoring to ensure proper operation.

Reverse Osmosis. Osmosis is the natural process by which water (the solvent) migrates across a semipermeable membrane to equalize solute concentrations differences on each side of the membrane. Typically the solvent migration is in the direction of the high solute concentration. In reverse osmosis (RO), high pressure is applied to the high solute concentration side of the membrane to force the solvent flow in the direction of the low solute concentration, hence reversing the natural tendency. Similar to UF, RO can occur over a wide range of pressures (30 to 1,200 psi) depending on solute makeup and concentration. Reverse osmosis is capable of retain virtually all particles, germs and organics remaining in the liquid, resulting in an effluent that is essentially pure water. Reverse osmosis is commonly used to desalinate sea water to produce drinking water.

From a nutrient recovery standpoint, RO is typically used as the polishing step. Potassium is the key fertilizer component recovered using RO. For RO to be effective, the input liquid needs to be free of all particulate. Pretreatment including solid-liquid separation, phosphorus removal and ammonia removal should precede RO. Similar to UF, the key challenge with RO is maintaining clean, consistent input to minimize fouling or clogging of the membrane. Reverse osmosis systems are generally capital intensive and require significant power to maintain the high operating pressure of the system.

Phosphorus Recovery

Two phosphorus nutrient recovery technologies that have been explored and applied at commercial scale in the United States are chemical phosphorus removal and struvite production.

Chemical Phosphorus Removal. Chemical phosphorus removal by coagulation and flocculation of phosphorus using metal salts and polymers has been successfully used to achieve phosphorus reduction of 80% or more in liquid dairy manure. Phosphorus in manure is generally dissolved or in a colloidal form, making it difficult to separate using physical means. Coagulation, the process of thickening the colloidal phosphorus, is initiated by the addition of lime or a metal salt, typically iron or aluminum. Coagulation works by charge neutralization, phosphate carries a negative charge while the salts (coagulants) carry positive charges, thus causing an attraction and creating a larger, denser molecules (O'Melia, 1970). Once the phosphorus is coagulated, a polymer is added to the manure to bind together coagulated molecules into a larger particle.


Figure 2: Belt Press Separator Outlet and Press "Cake"

Flocculated particles are rather easy to separate using a using a belt press separator and dissolved air flotation (DAF). Belt presses use a combination of gravity thickening, porous belts and pressure to dewater the flocculated material. The resulting solid material, "cake", contains the separated phosphorus and solids. Typically, the solid content of the cake is in the range of 25 to 35% and can be land applied as a solid or composted. Dissolved air flotation works by releasing small air bubbles into the bottom of a flotation tank. As the bubbles rise through the water column, they adhere to suspended solids, causing the solids to float to the surface where they are removed by a skimmer. Dense solids will settle to the bottom of the flotation tank and are removed as a sludge material. The skimmed solids and sludge can be mechanical dewatered to produce a stackable manure solid similar to the belt press cake. Liquid effluent from chemical separation is typically less than 1% solids, contains low levels of phosphorus, has minimal odor and is high in ammonia and potassium.

While chemical separation is very effective at recovering phosphorus and commercially available, the equipment, chemicals and labor are costly. Also, the chemical balance of the system is sensitive to small changes in pH, temperature and manure characteristics (lactating versus dry cow manure) resulting in continual monitoring to maintain efficient performance. Farms using chemical phosphorus removal have benefitted installing anaerobic digesters prior phosphorus removal system. In addition to providing a homogenous and warm input to the phosphorus removal system, digestion also increases the mineralized phosphorus level through the breakdown of organic material.

Struvite Production. Struvite is a white to brownish-white, crystalline solid containing equal molar parts magnesium, ammonium and phosphate (chemical formula $NH_4M_gPO_4 \cdot 6H_2O$). Analysis of the pure form of struvite provides an N-P-K formulation of 6-29-0 (Hotaling & Hamkins, 2006). Natural formation of struvite requires high concentrations of the soluble forms of magnesium, nitrogen and phosphorus, alkaline or increasing pH levels, and temperatures in the range of 60 to 95^{o}F (Hanhoun et al., 2011). High turbulence areas, such as pipe elbows or pumps, are common locations where formations begin. In the municipal wastewater treatment industry, struvite formation has long been a problem, causing restrictions on pipe flow to complete clogging of pipes, pumps and other process equipment. The nutrient balance of struvite as well as its granular nature makes it an appealing nutrient recovery technology for dairy manure.

Figure 3: Struvite Crystals (Dangaran)

Commercial struvite reactors are typically designed as fluidized beds using fine particles to "seed" the crystal formation. Magnesium salts are generally added to the manure as it flows into the reactor to ensure adequate levels for struvite formation. Mixing is achieved by the addition of air in the bottom of the reactor or by the turbulence caused by the fluidized bed. Denser crystals (seed material coated with struvite) tend to settle to the bottom of the reactor and are periodically funneled out through a cone bottom. Struvite crystals drain of moisture easily, creating a dry, solid granular fertilizer. Effluent from the reactor typically flows out the top of the system.

Struvite production is not without challenges. Production from dairy manure is pretreatment intensive, requiring solid-liquid separation, denitrification and potentially anaerobic digestion, to maintain stable struvite production. Highlighting the importance of pretreatment, research has indicated that total suspended solids levels exceeding 0.1% adversely impact precipitation of struvite (Hotaling & Hamkins, 2006). Elevated calcium levels in the manure may also interfere with struvite production and resulting in the formation of calcium phosphate minerals. Similar to chemical phosphorus removal, struvite production does require a steady input of materials to balance the system chemistry and maintain separation efficiency.

Nitrogen using Ammonia Stripping

Ammonia stripping is simple chemical process that allows ammonia to be removed from liquid manure and converted to a marketable fertilizer. The stripping process has been developed and used in the wastewater industry for years as a means for cost effectively lowering the ammonia levels of wastewater (USEPA, 2000). According to the EPA (US2000), stripping is best suited for fluids containing 10 to 100 ppm of ammonia.

In order to strip ammonia from manure, the pH of the liquid must first be adjusted to a range of 10.8 to 11.5 using lime or caustic. The pH adjustment is necessary to convert ammonium to ammonia. Depending on the level of pH adjustment, the temperature of the manure should be in the range of 68 to 120^{o}F (higher temper for lower pH). Using a countercurrent system shown in Figure 4, after pH adjustment, the liquid is introduced into the top of a packed bed tower. The packing material helps to distribute the downward flow of water. Ambient air is drawn into the bottom of the tower, creating the countercurrent flow of liquid moving downward from the top while air is moving upward from the bottom. Free ammonia is stripped from the falling water droplets and carried out of the tower with the air. To create a marketable fertilizer, the exhaust air from the stripper is directed into an absorber (another packed bed tower) where sulfuric acid used to condense the ammonia into ammonium sulfate. The exhaust from the absorber can than become the inlet air to the stripper, creating a closed loop system. Ammonia free water is discharged from the bottom of the tower.

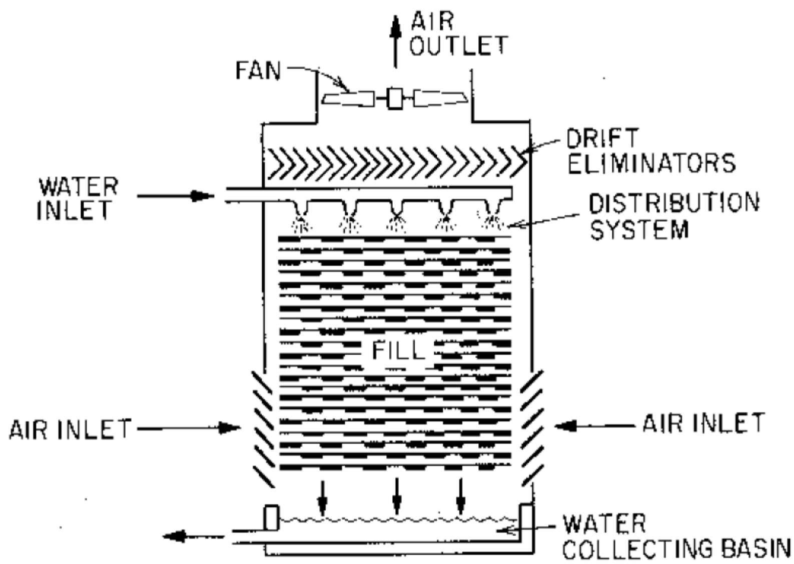


Figure 4: Countercurrent Ammonia Stripper (USEPA, 2000)

To avoid fouling of the stripper, pretreatment is necessary. In most commercial applications coarse solid-liquid separation is used as well as ultrafiltration or a similar fine solid removal system to create a relatively clean input. Without proper solids removal, clogging of the filter media is a major concern.

Complete Nutrient Recovery Systems

Combining various nutrient recovery technologies to achieve a desired outcome, concentrated phosphorus solids or discharge quality water for examples, has gained momentum over the past several years. With a complete system, manure is typically broken down into several nutrient rich fractions including; a concentrated organic solids containing phosphorus and organic nitrogen, ammonium sulfate, a potassium concentrate, and clean water. The exact nutrient fractions and composition will depend on the technologies implemented, site specific conditions, and the management goals. Depending on the goals, systems can be tailored to remove only solids, to remove solids and some phosphorus (20% to 99%), to remove solids, phosphorus and nitrogen or to remove all water contaminants. Creating a system tailored to the farm needs and management goals allows a producer to a treatment train that addresses the agronomic balance between manure nutrient and crop needs, while minimizing the capital and operational costs. The benefits complete nutrient removal are that clean water that can be used as irrigation with minimal oversight and no odor and concentrated nutrient sources that can be used in a manner similar to commercial fertilizers.

Nonetheless, the decision to installing a complete nutrient recovery system does require careful consideration to ensure that the correct technologies is implemented and that the system is financial viable. To start, the farm management should closely evaluate the current and future needs and costs of nutrient management including manure application and regulatory compliance to determine the exact nutrient recovery needs. During this evaluation, a reasonable unit treatment cost can also be determined based on current practices, necessary site modifications, and future fertilizer values. As discussed earlier, the capital cost of such systems is generally very high with equally challenging operational costs due to the labor, energy and chemical requirements. Successful operation of a system requires well trained operators. To maximize the value, nutrient removal products should be storage and managed separately. However, conventional manure storage designs may not meet the storage requirements for some fertilizer products. A plan on how to market the "new" fertilizers should also be developed. Questions should be asked to assess if a market exists? And how would potential users value the manure based nutrients compared to commercial fertilizers? In addition, dairy farms should consult local permitting authorities to determine how the installation and operation of a nutrient recovery system impacts environmental permits.

With proper planning, these traditional and innovative nutrient recovery systems can successful be integrated in to the farm, reducing environmental concerns and helping the farm to realize the true economic value of manure.

Conclusions

The nutrient value of dairy manure is real and has measurable value. However, minimizing the negative attributes of manure and the stigma that it is not a valuable fertilizer is still a challenge. Nutrient recovery offers the opportunity to partition nutrients into concentrated products, while reducing odor potential and producing clean water for irrigation or discharge. Adopting individual nutrient recovery technologies like solid-liquid separation or chemical phosphorus removal allow the producer to address manure application or agronomic issues relatively easily and potentially cost effectively. If the goal is to maximize the value of nutrients or to reduce the volume of liquid manure applied to fields, the farm may need to look to a complete nutrient removal system capable of producing clean water. Due to the potential for high capital and operation costs, farms must be diligent in their assessment of technologies and review of pro forma financial models carefully. Complete nutrient removal systems provide an opportunity to create real value from manure and address environmental and social concerns by creating stable, easily managed renewable fertilizers.

References

American Society of Agricultural and Biological Engineers (ASABE). 2005. Manure Production and Characteristics Standard. ASAE D384.2 MAR2005. St. Joseph, MI.

Dangaran, K. Accessed 2015. Manure Processing Technologies, 3.5 Phosphorus Recovery. Ohio Agricultural Research and Development Center. Ohio State University. http://www.oardc.ohio-state.edu/ocamm/images/MPT_3.5_P_recovery.pdf

Frear, C. and S. Dvorak. 2012. Anaerobic Digestion and Nutrient Recovery. AgStar National Conference. Syracuse, NY. http://www.epa.gov/agstar/documents/conf12/10b_Dvorak-Frear.pdf

Gray, C.W., L. Chen, M.E. de Haro-Marti, M. Chahine, & H. Neibling. 2014. Costs of Liquid-Manure Application Systems. University of Idaho Extension. Bulletin 888. http://www.cals.uidaho.edu/edComm/pdf/BUL/BUL888.pdf

Hanhoun, M., L. Montastruc, C. Azzaro-Pantel, B. Biscans, M. Freche, and L. Pibouleau. 2011. Temperature impact assessment on Struvite solubility product: A thermodynamic modeling approach. Chemical Engineering Journal. 167 (1): 50-58.

Henry, T. 2014. Water crisis grips hundreds of thousands in Toledo area, state of emergency declared. The Blade. www.toledoblade.com/local/2014/08/03/Water-crisis-grips-area.html#JTJIWOmyJMmeCOzS.99

Hotaling, J. and M. Hamkins. 2006. Struvite Recovery from Digested Dairy Manure and Regional Manure Anaerobic Digestion Study. New York State Energy Research and Development Authority (NYSERDA). NYSERDA 6740.

International Joint Commission (IJC). 2014. A Balanced Diet for Lake Erie; Reducing Phosphorus Loadings and Harmful Algal Blooms. Report of the Lake Erie Ecosystem Priority. http://www.ijc.org/files/publications/2014%20IJC%20LEEP%20REPORT.pdf

Leikam, D.F. and R.E. Lamond. 2003. Estimating Manure Nutrient Availability. Kansas State University Agricultural Experiment Station and Cooperative Extension Service. MF-2562. http://www.ksre.ksu.edu/bookstore/pubs/MF2562.pdf

North Carolina State University (NCSU). 2015 (accessed). Separating Manure Solids. https://www.bae.ncsu.edu/topic/animal-waste-mgmt/program/lagoon/lagoon-technologies/solidseperation.pdf

Ohio Environmental Protection Agency (OEPA). 2013. Ohio Lake Erie Phosphorus Task Force II Final Report. http://www.epa.state.oh.us/portals/35/lakeerie/ptaskforce2/Task_Force_Report_October_2013.pdf

O'Melia, C.R. 1970. Water Quality Improvement by Physical and Chemical Processes; Coagulation in Water and Wastewater Treatment. Chapel Hill, NC. University of Texas Press.

Russelle, M., K. Blanchet, G. Randall and L. Everett. 2013. Nitrogen Availability from Liquid Swine and Dairy Manure: Results of On-Farm Trials in Minnesota. University of Minnesota Extension. http://www.extension.umn.edu/agriculture/nutrient-management/nitrogen/nitrogen-availability-from-liquid-swine-and-dairy-manure/

United States Department of Agriculture – National Agricultural Statistics Service (USDA-NASS). 2014. Table 7. Average U.S. farm prices of selected fertilizers. Washington, DC. http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx#26727

United States Environmental Protection Agency (USEPA). 2000. Wastewater Technology Fact Sheet: Ammonia Stripping. EPA 832-F-000019.

Dairy Forages: What's New in Genetics and Management?

Bill Mahanna, Ph.D., Dipl. ACAN,
Global Nutritional Sciences Manager, DuPont Pioneer,
6900 NW 62nd Avenue, POB 256, Johnston, Iowa 50131.
Cell: 515.229.3409,
e-mail: bill.mahanna@pioneer.com

Introduction

It is clear that both seed genetics and producer management affects forage quality and potential dietary inclusion levels along with impacting daily feed cost and intangible factors such as rumen health and function. However, the relative contribution of genetics versus management (environment) must be considered. In our cow populations, genetics establish the base for milk production potential while environment (feed, housing) dictates the absolute yield. This is also true for forages where growing environment and harvest management often trumps genetics when it comes to yield and quality. High quality forage does not ensure high milk production (cow comfort is equally important) but low quality forage almost certainly will guarantee low milk production (or very expensive rations). Pennsylvania State University research (Buza et al., 2014) refutes the importance of feed cost per cow per day, with data showing that profit margins are affected more by the quality rather than the cost of the feed. That said, once forage genetics are chosen and planted, there are four major areas over which dairy producers have some control in optimizing quality: (1) harvest maturity/moisture, (2) particle size, (3) storage/feedout and (4) nutritional profiling.

The amount of forage in the dairy diet today is primarily dictated by the need to maintain rumen health (and milk components) and the economics of forage production (influenced by yield and cost for harvest, storage and transportation logistics) compared to the availability of other non-forage, co-product fiber sources. It is not unusual today to find diets containing 55-70% forage on a dry matter basis. Much of what has allowed this to happen is improvement in forage genetics, producer management of those genetics and a better understanding of how to analyze and feed high-forage diets.

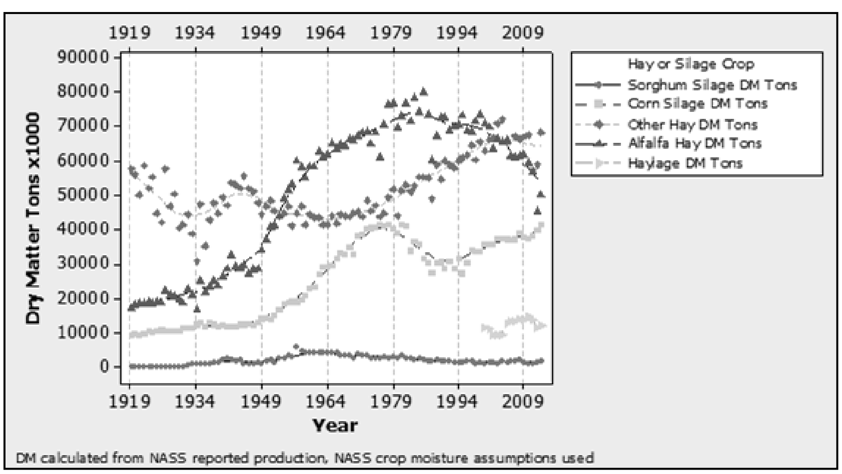
The quantity of forage that can be consumed by a dairy cow depends on the interactions among bodyweight, level of intake, rumen fill, passage rate, specific gravity (buoyancy), neutral detergent fiber (NDF) content, particle size, particle fragility/tensile strength and the pool size and digestion rates of potentially digestible NDF (pdNDF) versus indigestible NDF (iNDF) fractions. Improvements in forage genetics (e.g. BMR corn, reduced-lignin alfalfa, drought-tolerant corn), coupled with improved rumen models (e.g. NDS, CPM) and forage analyses (e.g. Fermentrics™, uNDF240,) are helping provide higher quality forages and the understanding of how to capture their full value in the diet.

High-forage intakes are possible by producing and feeding higher-quality, lower-NDF (and iNDF) forages. The classic multi-forage meta-analysis by Oba and Allen (1999) suggests that a one-percentage point increase in NDF digestibility can increase daily dry matter intake by 0.37 lb., resulting in a daily increase of 0.55 lb. of 4% fat-corrected milk. Chase and Grant (2013) offered these guidelines for herds considering higher forage rations: 1) strive for consistent quality because variations in forage quality will have more effect on milk production as the level of forage in the diet increases, 2) closely monitor forage inventory and considerations for required changes in the cropping (or sourcing) program, 3) allocate the highest-quality forage to appropriate animal groups, 4) frequently analyze forages (including particle size and digestibility) to keep the feeding program on target, 5) monitor rations closely to determine if adjustments are needed based on frequent forage test results (including dry matter), 6) target forage management, including silage face management, aerobic stability and palatability, feed delivery and the need for pushups and 7) track the need for more mixes per day or the need for a larger mixer given that high-forage rations will be bulkier and not as dense (pounds per cubic foot).

Shifts in forage production

It is interesting to note that the top 10 forage production states in 2013 (WI,CA,NY,TX, PA,MN,ID,IA,MI,SD) also represent 8 of the top 10 dairy production states (CA,WI,ID, NY,PA, TX,MN,MI, NM, WA) (Progressive Dairyman, 2014). Forage production in the United States has increased dramatically over the past century (Figure 1) with the major trend of reduced alfalfa production and increased corn silage production. The benefits of high dry matter yields, high starch, consistent fiber digestibility, a single harvest time and the ability to utilize manure has driven higher corn silage inclusion rates responsible for the current corn silage trend.

Figure 1. US Forage Dry Matter Production 1919-2013 (Newell, 2014)



The current alfalfa trend started in the 1990's, partly due to the corn silage shift, and accelerated downward due to increased corn acres for ethanol production under the Renewable Fuels Standard created under the Energy Policy Act of 2005. Alfalfa production was also affected by the broad regional droughts in 2011 and 2012 which led to declining hay production and shortages that drove up hay prices and increased hauling distances for hay. In response, acres devoted to alfalfa increased in some Western states where corn is less prevalent, but not enough to offset the overall loss of alfalfa acres. The Upper Midwest remained in alfalfa deficit through 2013 due to winter damage and stand loss. 2013 alfalfa production was below trend, and hay market prices continue to remain somewhat elevated. The increase in availability of distillers grains as a mid-protein source replacing alfalfa-protein is also a key factor in alfalfa production and utilization trends. There may be a rebound in alfalfa seedings over the next few years if competing crop prices decline or alfalfa prices stay relatively elevated but total acres could remain stagnant, because average stand age has grown excessively long in some regions where producers delayed new seedings in favor of grain crops. If a higher stand replacement rate unfolds, a younger average stand age could help support a production rebound (Newell, 2014).

Other hay in NASS reports includes warm-season grasses like bahiagrass, bermudagrass, sudangrass and teff, several species of clovers and other legumes, and cool season grasses of many species. Hay species in this large category are often grown for their adaptability in geographies not suitable for row crops and as such, their acres should continue providing substantial hay production (Newell, 2014).

Sorghum and sorghum-sudangrass silages are often more successful than corn under heat and drought stress where rainfall and/or irrigation is limited. Their use is relatively minor from a broad US perspective, but can be locally important, particularly in the semi-arid plains and in the southwest (Newell, 2014).

Corn silage

Since the 1926 commercialization of hybrid corn (*Zea mays*), steady advances in grain yield per acre have occurred. DuPont Pioneer periodically conducts “decade (grain) studies” using saved seed representative of the corn genetics of every decade from the 1930’s to today. In DuPont Pioneer era studies conducted since 1972, corn yields showed no signs of plateauing and it is corn grain that contributes over 60% of the energy in corn silage. In these “decade” studies, genetic gains averaged about 1.5 bu/acre per year since 1963 (the “single-cross” era) in normal growing conditions, and 1.0 bu/acre per year under drought conditions. Genetic gains accounted for about 70-75% of total yield gains. Today’s hybrids have improved stress tolerance, a higher grain-to-stover ratio, less silk delay and barrenness, better stalks and roots, smaller tassels, more upright leaves, better staygreen, and deeper roots than older hybrids. Corn yield gains show no signs of slowing. Growers can expect future gains to continue if corn research is supported at historic or higher levels (Butzen and Smith, 2014).

A corn silage version of DuPont Pioneer decade (grain) studies has been conducted at the University of Wisconsin (Coors et al., 2001; Lauer et al., 2001). This UW corn silage “era research” shows that as corn genetics have advanced, dry matter yield of both stover and whole plant have increased. Grain production has been the greatest driver of yields resulting in whole plant yields increasing faster than stover yield. Over time, cell walls (neutral detergent fiber, NDF) have comprised less and less of the whole plant, because of the dilution effect of higher grain yields. Stover, per se, has not changed significantly in percentage of NDF or in in vitro digestibility. In fact, unpublished work by DuPont Pioneer (Owens, 2011) indicates that a summary of published literature and DuPont Pioneer plot data shows that in newer genetics possessing improved late-season plant health, NDFD declined minimally over the maturity range of 30-40% dry matter, while starch increased at the rate of almost 1% unit per day (Owens, 2010).

Much of what has contributed to corn yield improvements has been improved stress tolerance allowing plants to respond better to higher planting populations (Wikner, 1996; Paszkiewicz and Butzen, 2001). Hybrid corn in the 1930’s was typically planted at densities of 4-5,000 plants per acre; whereas today, hybrids can routinely withstand the population stress of over 35,000 plants per acre. Improved late-season plant health and kernel weight (grams per kernel) have also increased steadily since the 1950’s. When these same modern genetics are exposed to moisture-stress, there is less improvement in yield, kernel weight, and staygreen. This fact, along with depleting agricultural water supplies, is driving seed companies to actively research mechanisms and genes controlling drought tolerance.

Corn Moisture Requirements: Estimates are that about 15% of the U.S. corn acres are irrigated. This means that 80-85% of the acres are at the mercy of Mother Nature. Corn has relatively high water use efficiency (dry matter produced per quantity of water used) compared to alfalfa, but because it produces more total dry matter, it can requires more total moisture. A high-yielding corn crop requires between 20-24 inches of water and upwards of 28-30 inches in the more arid West. One inch of water per acre is about 27,000 gallons. A corn crop requiring 24 inches of moisture would require about 648,000 gallons of water. If that crop yielded a national average of 175 bu, each bushed would require about 3700 gallons of water. At some point during the growing season, 85% of all corn acres will experience some level of water deficit (Warner, 2011). Knowledge of the relationships between plants and their environment is vital to successful irrigation management (Kranz et al., 2008). Soil characteristics important to irrigation management include water holding capacity, water intake rate, and restrictive soil layers that might limit root penetration and/or water movement. Plant factors include crop development characteristics, rooting depth, and daily and total seasonal crop water use. Atmospheric factors are solar radiation, air temperature, relative humidity, and wind. Total available seasonal water supply is also important (Shanahan and Groeteke, 2011).

Irrigated corn grain yields are about 30% higher than non-irrigated yields attributing to irrigated corn accounting for nearly 20% of total U.S. corn production while occupying only 15% of acres (USDA, 2007). Much of the irrigated corn is cultivated in the semi-arid Great Plains region (Musick and

Dusek, 1980) of the U.S., with corn occupying more irrigated acres in this area than any other crop (Norwood, 2000). However, recent concerns have been raised regarding declining surface and groundwater supplies (Clark et al., 2002) and increased pumping costs (Norwood and Dumler, 2002) in this region. For this reason, improving management practices under declining water supplies is critical for sustaining irrigation water resources (Shanahan and Groeteke, 2011).

Figure 2. Long-term daily average (black line) and individual year (green line) corn water use by growth stage in Nebraska (adapted from Kranz et al., 2008)

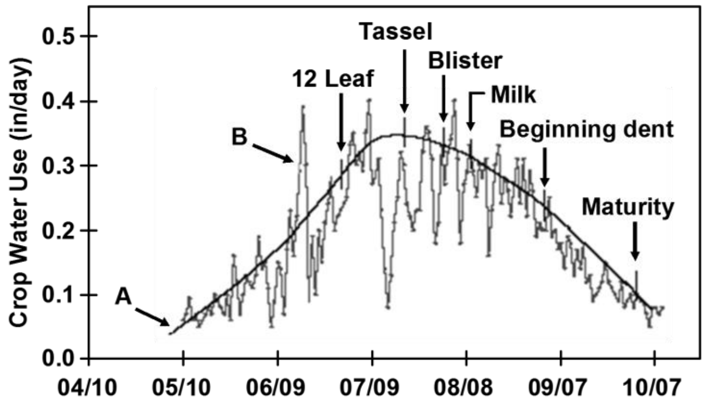
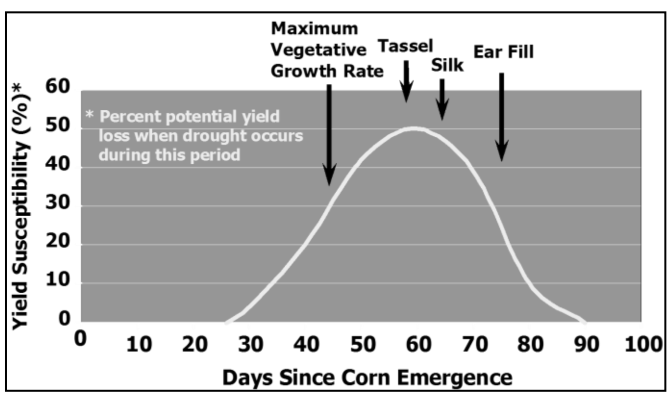


Figure 3. Yield susceptibility to water stress for corn (adapted from Sudar et al., 1981)



Corn production uses water through evapotranspiration (ET). In this process, water is removed directly from the soil surface to the atmosphere by evaporation and through the plant by transpiration. Plant transpiration is evaporation of water from leaf and other plant surfaces. For corn, evaporation often accounts for 20-30% and transpiration accounting for the remaining 70-80% of total ET over the course of a growing season. Transpiration involves a continuous flow of water from the soil profile, into the plant roots, through plant stems and leaves, and into the atmosphere. This serves to cool the crop canopy and prevent leaf tissues from reaching lethal temperatures. Additionally, water from transpiration provides positive pressure inside cells that gives plants much of their structure and ability to stand. Finally, the transpiration stream carries water-soluble nutrients like nitrate and potassium from the soil into the plant, providing essential nourishment for plant growth (Shanahan and Groeteke, 2011).

Both evaporation and transpiration are driven by a tremendous drying force the atmosphere exerts on soil or plant surfaces. Hence the magnitude of daily ET will vary with atmospheric conditions. For example, high solar radiation and air temperatures, low humidity, clear skies and high wind increase ET, while cloudy, cool and calm days reduce ET. Seasonal water use is also affected by growth stage, length of growing season, soil fertility, water availability and the interaction of these factors. Although the amount of daily water use by the crop will vary from season to season and location to location, it will generally follow the pattern shown in Figure 2.

When water supplies do not fully compensate for crop ET, grain yields are reduced compared to fully irrigated corn. To maximize yields and returns under limited water supplies, growers must understand how corn responds to water, and how changes in irrigation and agronomic practices can influence water needs depending on growth stage, irrigation timing, crop residue, hybrid genetics and plant populations. The impact of water stress on corn grain yield varies with crop growth stage (Figure 3). During the vegetative growth of the corn plant, it is relatively drought tolerant and can survive on upward of 60% soil water depletion in the root zones without a significant impact on grain yield. However, silage yields will be reduced due to shorter plants when moisture-stressed during vegetative growth stages. The corn plant needs the most moisture from about silking through the blister stage (Figure 2). After blister stage, the plant is again fairly immune to water deficiency and irrigation can be termination when the kernel milk line is at about 50% (Figure 2). Growers may be able to delay the first irrigation as late as tasseling in years of lower evaporative demand provided soil water reserves are ample at planting and irrigation systems have the capacity to rapidly correct soil water deficits (Shanahan and Groeteke, 2011).

In recent years, the seed industry has been actively engaged in utilizing advanced genetic tools to mine and advance native drought resistance in pursuit of more drought-tolerant hybrids. Several of these products are now on the market and demonstrate upwards of a 5% average grain yield advantage over leading commercial hybrids when water was limited during flowering or grain fill to less than 66% of optimum crop moisture (Warner, 2011). Transgenic approaches to drought tolerance are also being actively pursued by several seed companies but regulatory hurdles must be met before they will reach the marketplace. In general, the tremendous research dollars spent on corn breeding and research compared to any other crop, along with the introduction of biotechnology traits, has been the key driver in the continuous improvement in agronomics and yield of corn.

Climatic Effects: Weather patterns, if trending toward either warmer/colder or wetter/dryer have potential to impact corn yields over time. Increased weather variability within single seasons could also affect yield trend. Using the DuPont Pioneer propriety software, EnClass®, Pioneer breeders were able to evaluate historic weather patterns and model their expected impacts on yield from 1950-2011. This analysis of weather records determined that the effects of weather on yield was minimal, contributing an upward bias of only 0.02 bu/acre per year during the period studied (Butzen and Smith, 2014).

Crop Management Advances: In addition to genetic and technology trait gains, corn yields have benefitted from improvements in cropping practices. Those most beneficial and widely adopted by growers include: 1) earlier planting, which reduces moisture stress during pollination and ear fill, and lengthens the growing season; 2) Use of seed treatments that contain a fungicide and insecticide, and may also include a nematicide, growth promoter, or other active ingredient, 3) increasing use of foliar fungicides to limit leaf diseases, 4) use of improved planters to achieve more consistent depth and coverage of seed, more equal plant-to-plant spacing to reduce competitive effects among plants, more timely planting of a higher percentage of corn acres at higher ground speeds, 5) improvements in irrigation practices and number of acres of irrigated production, 6) improved fertility practices, including higher rates of nitrogen fertilizer, 7) variable-rate technologies that allows growers to plant specific hybrids and place fertilizer where most beneficial, 8) narrower row spacing and 9) increase in systematic tiling (Butzen and Smith, 2014).

BMR: Some nutritionists question if breeding for improved agronomic traits, such as standability, has negatively impacted corn stover (cell wall) nutritional composition and digestibility. In conventional corn hybrids, there is no obvious association between either fiber or lignin concentration and stalk lodging. Distribution of structural material may be as important, or more important, than concentration of structural components, per se (Allen et al., 2003). The University of Wisconsin Departments of Agronomy and Dairy Science jointly led a 1991-95 UW Corn Silage Consortium that was jointly funded by all the major seed companies. A review of their findings (Coors, 1996) indicates there was genetic variation for nutritive value among adapted U.S. corn hybrids with both silage yield and grain yield potential and that forage quality and agronomic traits were not highly correlated.

The heritability of fiber digestibility in conventional corn silage hybrids is quite high; however, the genetic variation to apply selection pressure against is relatively narrow in high yielding corn genetics. The introduction of brown mid-rib (BMR) corn as a non-GMO, recessive gene trait to improve fiber digestibility in corn silage is testament to the fact that significant improvements in fiber digestibility could not be achieved by traditional selection methods. Corn hybrids with BMR mutants have less lignin and a lower proportion of iNDF than isogenic conventional corn silages. Research conducted at the Miner Institute (Grant and Cotanch, 2011) indicate that, presumably, the more fragile fiber in BMR is what drives higher intakes in early lactation cows who lack the ability to satisfy energy needs from typical dry matter intakes. Rations need to be balanced differently when using BMR corn silage, particularly in terms of starch supplementation, total NDF and physically-effective fiber levels. Despite the lower lignin in BMR resulting in higher fiber digestibility, BMR genetics are also at the mercy of Mother Nature just like conventional silage genetics. Excessively wet growing conditions prior to silking (vegetative stages) typically increases plant height and reduces fiber digestibility, while growing conditions after silking appeared to only exert an effect on grain yield (Mertens, 2002). Bolinger (2010) summarized data from Michigan State University silage plots harvested in a relatively wet growing season (2006) compared to the same hybrids harvested from the same plot in a relatively dry growing season (2007). Hybrids averaged 6.5 points higher in 24-hour NDFD in the drought year. It was interesting to note that, as expected, the highest NDFD in both seasons was a BMR hybrid, but the BMR fiber digestibility was also reduced in the wet growing season (Mahanna, 2010). It has been proposed that with irrigated crops, silage growers might stress the crop for water during pre-tasseling to increase NDFD (without reducing plant height too much) and applying the conserved water more liberally during kernel starch filling periods of plant growth. More research is definitely warranted as to when to irrigate the corn plant to manipulate both silage yield and nutritional value.

Corn silage harvest and feeding advances

High-chopping: High-chopping is a management option to potentially increase fiber digestibility and concentrate more starch in corn silage. In a review of high-chop research by Wu and Roth (2004) at Pennsylvania State University, they found an average increase of 6.7% in NDFD and a 5.9% increase in starch content when comparing 19 inch versus 7 inch chop heights. Leaving the less digestible, lower stalk internodes in the field resulted in an average dry matter loss per acre of 7.4%. There does appear to be a significant genetics-by-growing season interaction suggesting that hybrids need to be analyzed for NDFD at various chop heights just prior to harvest because not all hybrids respond the same to specific growing environments. Several lactation studies with high-chop corn silage indicate higher milk production and but reduced milk fat content. This is likely the result of researchers not reducing the starch level in the high-chop treatments; unlike what field nutritionists would do when recognizing the increased starch level from high-chopped corn silage.

Changing Starch Digestibility: Several research studies have put credence to field experience that starch and protein degradability increase over time in corn silage. However, the effects of fermentation should not be viewed as an acceptable alternative to adequate pericarp damage from proper kernel processing at harvest. Using newly available starch digestibility laboratory methods (e.g. 7-hour starch digestibility or Fermentrics™) or tracking water-soluble nitrogen levels correlated to increasing starch digestion, can help nutritionists monitor these changes and make appropriate ration adjustments. Understanding these changes can help nutritionists better formulate cost effective rations as well as prevent potential sub-acute acidosis problems caused by longer-fermented silages (Mahanna, 2007).

More Mature Kernel Harvest: As the late-season plant health of the corn plant continues to improve from both genetic advancements and management practices (e.g. foliar fungicides), it allows producers the ability to delay harvest and obtain more starch from advancing kernel maturities without sacrificing significant declines in NDFD. A recent study by Seglar et al., (2014) showed that as kernels matured from the half milk line to black layer, kernel weight increased an average of 24% and starch by 27%, suggesting that premature harvest of corn silage dramatically reduces starch content.

Floury endosperm: There has been recent interest in the endosperm type (e.g. floury versus vitreous) of kernels found in corn silage. Harder texture kernels typically have more vitreous endosperm accompanied by higher levels of zein proteins (prolamin) surrounding the starch granules. Despite some of the marketing claims by some seed companies about the improved ruminal starch digestibility of floury endosperm hybrids, a study (Seglar et al., 2014) of commercial corn hybrids grown in different years at two different locations and harvested at three maturities indicated that neither the kernel density, prolamin content nor prolamin:starch ratio of kernels reliably predicted seven-hour ruminal starch digestibility.

Advocates of floury genetics often show kernel texture data on fully mature dry corn, lacking data on hybrid vitreousness levels at corn silage maturities (half to three quarter milk line). It is further misleading to promote university starch digestibility studies comparing genetic extremes (e.g. 3-66%) in vitreousness (Mahanna, 2013). These comparisons make sense for researchers investigating the mode of action of starch digestion. However, vitreous ranges this wide simply do not exist in commercially viable North American corn hybrids that typically exhibit a range in vitreousness of 50-70% in fully mature kernels and even less of a range in kernels at silage harvest maturity.

University of Wisconsin researchers (Hoffman et al., 2012) have developed an integrated analytical approach to starch digestibility called Feed Grain V2.0 that is available at select laboratories. This approach reinforces the relative importance of: 1) kernel particle size, 2) extent and length of fermentation and finally, 3) endosperm differences (vitreousness or hard kernels). In Feed Grain V2.0, starch digestibility in fermented samples are based on particle size and ammonia content (more ammonia, the longer the fermentation). Starch digestibility in unfermented, dry corn grain is based on particle size and prolamin content. The prolamin content is not considered in high-moisture corn, snaplage or corn silage starch digestibility calculations because of the small variation and minimal effect vitreousness (kernel texture) has on grain harvested at relatively early kernel maturities (pre-black layer).

The inclusion of vitreousness or kernel texture for dry corn grain is consistent with a review by Firkins (2006) indicating that vitreousness of corn grain in silages (fermented grains) was of relatively little value, whereas vitreousness of dry corn grain should be considered, particularly to help users know when to grind corn more finely. At the same particle size, starch digestion is similar for soft and hard corn. More vitreous (hard) corn simply yields larger, more slowly digested particles than softer corn, particularly if it is ground. Research from France (Ramos, 2009) with relatively high-vitreous (flinty) corn compared to North American hybrids showed that grinding removes most of the negative influence of vitreousness in dry corn. The body of research to dates suggests it makes more sense for producers and nutritionists to focus attention on corn yield, agronomic strengths/weaknesses, particle size and fermentation quality rather than the minor effects of kernel texture, especially in silage hybrids (Mahanna, 2013).

Kernel processing advances: Laboratory methods now exist (e.g., corn silage processing scores [CSPS]) which allow nutritionists a better understand of the particle size distribution of kernels in corn silage. Mining laboratory data on how well kernels were processed in submitted corn silage samples indicates upwards of 40% are significantly under-processed. At the same time, producers often desire even longer corn silage fiber particle size in high corn silage diets in an attempt to improve effective fiber and avoid the necessity of adding long fiber such as hay or straw to help establish a rumen mat to stimulate rumination to help buffer the rumen environment. The commercial release of Shredlage® processors in 2010 allowed for excellent kernel damage even when chopping at upwards of 26-30mm (compared to standard 19mm). The design of the teeth on the Shredlage rolls rip and tear rather than smashing kernels apart like conventional rolls. Shredlage rolls also have more grooves on one roll then the other which adds even more differential without changing the speed of the rolls more than the 30% differential set at the factory (Olson, 2013). Two lactation studies by Shaver and co-workers have proven the merits of this alternative approach to processing corn silage (Mahanna, 2014, 2012). It is very encouraging that chopper manufacturers like John Deere and Claas are now also offering unique roller mill designs or modification kits to speed up roll differentials, to finally give dairy producers both effective fiber and kernel damage needed in high corn silage diets.

Choppers with NIRS: It is entirely possible in the near future to "dial-in" desired NDFD or starch content of corn silage with choppers outfitted with on-board Near Infrared Reflectance Spectroscopy (NIRS). As silage is exiting the chopper spout, it could be analyzed for important constituents and the cutter head tied into this information forcing the head up or down to modify either NDFD or starch content of the silage being harvested.

Alfalfa

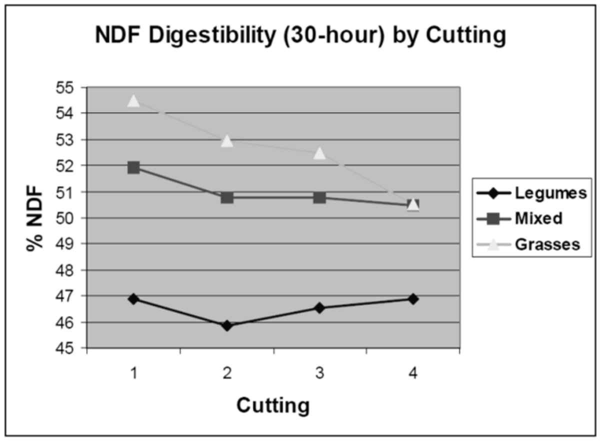
Alfalfa is arguably one of the most variable feeds on many dairies. This is due to field-by-field variations in the age of stand (grass content), harvest maturity/moisture, fiber digestibility affected by the growing environment and issues around fermentation and palatability. It is well documented that environmental factors have a smaller effect on quality than on yield and that most factors that limit plant development (e.g. lack of water, cold weather, plant diseases) tend to promote higher quality because of their effect on altering leaf: stem ratios (Van Soest, 1996). Many nutritionists would rather that producers delay alfalfa silage harvest and deal with lowered digestibility than suffer with feeding rained-on, poorly fermented silages. Field experience has also conditioned producers to target ideal moisture levels at around 60% to reduce protein degradation and the potential for clostridial alfalfa silages. This does bring up a dietary issue regarding need for supplemental soluble protein (SP) in many high corn silage diets due to the fact that less SP is being supplied in the diet from reduced levels of drier (hence less SP) alfalfa silages.

Nothing influences the nutritional quality of alfalfa more than growing environment and harvest maturity. Fiber digestibility is higher under cooler temperatures (Figure 4) with 1st and 4th cuttings having the highest NDFD; and 2nd and 3rd cuttings typically grown under higher heat units, displaying the lowest NDFD. The biggest environmental factors influencing alfalfa quality are temperature, water deficiency, solar radiation and a distant fourth, soil fertility. Growing conditions that promote the highest alfalfa quality exhibit long day lengths, cool nights and moderately dry weather. Warm, wet weather results in the poorest-quality alfalfa. Cool, wet growing conditions produce high-quality alfalfa due to low neutral detergent fiber (NDF) and low lignification (Van Soest, 1996). However, getting a hay crop harvested in these conditions can be problematic, with harvest delays resulting in maturity issues, in addition to potential for higher respiration, leaching or fermentation/spoilage losses from increased exposure to soil-borne fungi and bacteria. Solar radiation (light) is the only environmental factor promoting both yield and quality. Light promotes carbohydrate production with every hour increase in day length increasing digestibility by about 0.2 percentage units (Van Soest, 1996).

The shortening photoperiod in the fall has a negative effect on alfalfa digestibility but is somewhat offset by cooler temperatures. Cloudy weather reduces photosynthesis, causing low sugar and mobilization of nutrients, which results in higher proteins; both of which can be problematic for silage production (Van Soest, 1996). There are also more pentose (5 carbon) sugars in fall-harvested alfalfa, further contributing to fermentation challenges. Drought conditions reduce yield, but the resulting stunted, yet leafy plants, are generally higher in protein and digestibility due to the higher leaf:stem ratio. The digestibility advantages would be greater if they weren't somewhat offset by increased lignification from high temperatures which typically accompany drought conditions. Temperature accelerates plant development and warm weather accelerates NDF development and lignification. Every 1°C increase in temperature will generally decrease the digestibility of forages 0.3-0.7% units (Van Soest, 1996). This is one reason why forages produced in northern latitudes or higher elevations (cooler nights) tend to be higher quality. In the spring, light and temperature are positively correlated until June 21- when maximum day length and light occur - after which light decreases and temperature increases (bad for quality) until the fall, characterized by declining temperatures and decreasing day length and light (good for quality) (Van Soest, 1996).

Alfalfa Silage in a Day: This harvesting approach involves mowing alfalfa into a wide swath to facilitate faster drying followed by merging and chopping all within 24 hours. The most important factors to accelerate the drying of alfalfa are the amount of sunlight hitting the swath (swath density), wind velocity, relative humidity and ground moisture. Being able to harvest more quickly reduces the soluble protein degradation and conserves sugars for use during fermentation or by rumen bacteria. Research from the Northeast has suggested that use of conditioners at cutting time are of no benefit when wide swathing because it interferes with moisture transmission from the leaf stomata. Research from the University of Wisconsin clarified that most of the moisture loss is through stomata openings from fresh cut down to about 70% moisture. For moisture loss to continue beyond that, conditioning of the stem is essential. In that producers are targeting closer to 60% moisture alfalfa silage, most producers continue to condition alfalfa at harvest.

Figure 4. 30-hour NDFD data from legumes (13261 samples), mixed grass/legumes (10158 samples), and grasses (2407 samples) analyzed by NIR at Cumberland Valley Analytical Services (Ward and de Ondarza, 2007).



Seed Coating: Many seed companies sell heavy-coated seed with the most common coating being 33% limestone. Heavy coat is usually less expensive per pound but more expensive on a basis of pure live seed. There is mixed research on the value of limestone-coated alfalfa seed varying from providing a more suitable micro-environment for seed germination to claims that limestone-coated seed has no advantage in cloddy or dry soil conditions and may actually slow water uptake under moderate to dry soils. Despite the research contradictions, alfalfa growers need to understand how heavy-coating affects both the cost and seeding rate in terms of the number of live seed sown per acre. For example, it takes 21 pounds of 33% limestone coated seed, to equal the same number of seeds per square foot as typical 9% coated seed sown at 15 pounds per acre. When a grower purchases heavy-coated seed without increasing seeding rate, they take on a higher risk of thin stands, stand establishment failure, more weeds during the seeding year and risk that yield over the life of the stand will be reduced.

Lodging Resistant Varieties: Lodged alfalfa is more difficult to harvest. Every inch of uncut stem equates to 0.13-0.15 tons per acre of lost hay yield. Uncut stems left in the field can turn 'woody' and lower the forage quality of subsequent cuttings. One of the more recent innovations in alfalfa genetics is the commercialization of lodging-resistant varieties. These varieties have much improved standability when exposed to wind and rain events due to a more upright stem and crown architecture. Research also shows that more vertical plant architecture has no effect on lowering fiber digestibility.

Alfalfa Fungicides: There is a definite lack of consistent and statistically significant results from small-plot university research on the use of fungicides on alfalfa, yet farmer testimonials seem to suggest a positive response to fungicide application. General recommendations are to apply fungicides prior to first cutting when alfalfa is 6-8-inches tall. It only requires about 0.1- 0.2 tons per acre of added yield to justify the price of fungicide and application when the crop is selling for upwards of $200 to $250 per ton. Producer testimonials and company literature suggest early application to prevent fungal growth rather than assuming later maturity applications will eliminate disease problems after they have become established. The required yield improvement necessary to justify fungicide use is also less if growers are adding it to tank mixes of insecticide that they are already applying to control leafhoppers.

Positive grower observations may be the result of greater variability in their production-sized fields compared to smaller, replicated research plot studies in terms of canopy humidity levels, fungal loads, trash content and less than optimum soil environments (low pH, low fertility, poorly drained soils) across their larger acreages. More research is certainly needed on the effectiveness of other chemistries given the potential concern of resistant fungal populations. The good news is that, as growers continue to drive this market, more fungicides will likely add alfalfa to their approval list. As more research and producer experience is accumulated, there will likely be improved diagnostics as to when fungicides make the most sense such as in wet springs or on older stands. From a scientific, published literature perspective, the jury is leaning against the economics of alfalfa fungicides. However, fungicides would be expected to be most beneficial in growing conditions conducive to the development of stem and leaf diseases. Wet growing conditions coupled with a heavy crop should theoretically respond to a greater degree to fungicide application. Application in the fall may improve plant health to help stands weather the winter. Fungicides should also be more beneficial in stands which are harvested at later stages of maturity (e.g. lower lignin varieties) which are more susceptible to increased leaf drop (Mahanna and Thomas, 2014).

RFV versus RFQ: Relative Feed Value (RFV) was developed over a quarter century ago as a standard for comparing alfalfa quality based on voluntary animal intake of digestible dry matter. A RFV of 100 describes full bloom alfalfa hay containing 41% ADF, 54% NDF and digestible dry matter of 1.29% of body weight. Relative Forage Quality (RFQ) is an improvement on RFV in that it includes NDF digestibility in the calculation. If sellers and buyers of alfalfa would agree on the same reputable lab and base value on RFQ, there would likely be fewer situations where two lots of hay have the same fiber levels but considerably different results in lactating rations. Producers should remember that when using a RFQ target to stage harvest, it is not uncommon to lose 20 RFQ points during harvest and ensiling.

Cutting Height: Lowering the cutter bar obviously results in higher yields of alfalfa. Research shows that alfalfa can be cut as short as 1.5 in. and that each inch above this will result in a half-ton-per-acre reduction in annual yields (Undersander, 2009). However, increased yields must be balanced against the tendency for disc mowers to vacuum soil (which contributes to ash values) into the crop, resulting in lowered digestibility and the potential for increased soil-borne clostridia.

AM versus PM Cutting: The time of day to harvest alfalfa (morning versus afternoon) has research results that fall on both sides of the debate. The basic idea is that cutting later in the day allows the crop to lay down more sugars to improve palatability or aid in silage fermentation. Much of the positive research has been conducted on alfalfa hay harvested in western states. Although morning versus afternoon forages differ in initial composition, these differences don't always exist after drying and/or fermentation because cell respiration reduces sugar levels at night and in sections of the windrow not receiving sunlight.

Research in Wisconsin (Undersander, 2003) showed that 11 of 14 Wisconsin farm samplings had higher sugars with afternoon-cut alfalfa, yet only one of the 14 had higher sugar levels in stored forage. There also appear to be adequate sugars to support fermentation when alfalfa is harvested at typical North American moistures/maturities compared to wetter European forages (Nasser et al., 2006). A Miner Institute study (Thomas, 2001, 2007) showed no statistical difference in plant sugars, starch, NDF or *in vitro* digestibility between am and pm harvested alfalfa. While afternoon-harvested alfalfa was numerically higher in sugar and starch, the small differences either decreased or disappeared entirely by the time the forage was 40% dry matter. Alfalfa mowed in the morning was ready for silage harvest in about nine hours, while alfalfa mowed in the late afternoon was not harvestable until after noon on the following day. Many researchers in the Midwest or East believe it makes more sense to cut early in the day to maximize the hours of drying from solar radiation rather than expose the crop to delayed drying or increased weather risk.

Reduced Lignin Alfalfa: The October 2014 World Dairy Expo in Madison Wisconsin was the launch site of two new alfalfa technologies; a genetically-modified reduced lignin alfalfa (HarvXtra™) by Forage Genetics International (FGI) that will be licensed to a number of seed brands and the other being lower-lignin alfalfa from Alforex Seeds developed through conventional plant breeding. The Alforex Seed products (Hi-Gest 360 and Hi-Gest 660) are reported by the company to have 7-10% less lignin and will be available in 34%-coated, non-Glyphosate-tolerant varieties on a limited basis for spring 2015 planting season (Jaynes, 2014).

HarvXtra was developed through a strategic partnership between FGI, The Samuel Roberts Noble Foundation and the U.S. Dairy Forage Research Center in conjunction with Monsanto. There are several steps in the process of lignin synthesis in alfalfa with the lignin biosynthetic pathway involving twelve different enzymes. Each is required for a specific step in the pathway. Noble Foundation scientists identified and suppressed several "lignin genes" that code for specific pathway enzymes. FGI scientists generated and evaluated biotechnology-derived plants with suppression of a specific lignin gene resulting in 10-15% decrease in lignin content, 10-15% increase in NDFD and RFQ when compared to related lines without the HarvXtra™ trait. HarvXtra™ alfalfa also displays a slower change in quality with advancing maturity compared with conventional varieties yet maintains alfalfa's important agronomic characteristics, including lodging potential equal to most commercial varieties harvested at the same time. HarvXtra™ alfalfa will be sold in a trait stack with Genuity® Roundup Ready® alfalfa. A petition to deregulate is currently under review by the USDA with anticipated limited commercial introduction in 2016 to allow growers the opportunity to realize the benefits of the technology, with 2017 as the first year of a wide-scale commercial launch (Fanta, 2014).

These technologies should provide alfalfa producers with greater harvest flexibility when either adhering to current harvest schedules and harvesting higher RFQ alfalfa or by delaying harvest to capture more yield yet maintaining desirable forage quality. In geographies that typically take four harvests, there is opportunity to improve yields upwards of 15-20% by harvesting only three times, and obtaining the same or better quality compared to lower-yielding late-bud harvest. The improved fiber digestibility of these varieties will likely provide the most benefits in transition and early-lactation diets where dry matter intake is of most concern. Research will be needed to determine desirable physically-effective fiber levels in rations containing low-lignin alfalfa, especially if it is coupled with BMR corn silage (Mahanna and Thomas, 2013b).

Condensed Tannin Alfalfa: Researchers at the U.S. Dairy Forage Research Center are conducting studies with condensed tannins (CT) which are compounds found in forages such as birdsfoot trefoil that have the ability to bind proteins to reduce protein degradation during the ensiling process. Researchers are investigating new methods of assaying CT in forages and characterizing alfalfa bioengineered to produce CT. The practical utility of this technology will depend on the need for reducing protein degradation in alfalfa silage, which may not be desirable in high corn silage diets (Zeller et al., 2014).

Grass

Interest in cool-season forage grasses exists because not all soils are suited to growing alfalfa. In the Northeast, it is not uncommon for producers to plant alfalfa with a cool-season grass such as timothy, orchardgrass, or tall fescue in proportions of alfalfa: grass of 2:1 to 3:1 (depending on the grass species), with a total seeding rate of about 20 pounds per acre. The best alfalfa-growing soils are deep, well-drained loams that permit alfalfa taproots to penetrate far into the soil profile. Some soils have fertile topsoil with much less desirable subsoil, including high acidity and/or a fragipan that limits good drainage. Grasses have dense, fibrous root systems that don’t penetrate nearly as deep into the soil making them more suitable for tough soils (Thomas and Mahanna, 2012).

Alfalfa tap roots store nutrients needed for the next crop and do not regrow from the cut stems but rather from crown buds. Grasses do not have tap roots and regrow from the cut stems. Nutrients for the following crop are stored in the bottom few inches of grasses, so cutting height can impact both regrowth and stand life. The trend toward disc mowers (versus sickle bar mowers) has resulted in lower stubble heights because disc knives are less apt to be damaged from scalping the soil surface or hitting rocks. Reduced grass stand life can be caused by short stubble height due to grass not having enough nutrients in the remaining stubble for normal regrowth. While it may be acceptable to mow alfalfa to a 2-inch stubble height, many agronomists now recommend a 4-inch stubble height for cool-season forage grasses (Thomas and Mahanna, 2011).

Grass species differ in their tolerance to soil drainage and seasonal growing conditions. Reed canarygrass will tolerate very wet soils, while orchardgrass will not. Orchardgrass and tall fescue will produce well under typical summer growing conditions, while timothy grow well in the spring but will become somewhat dormant during the heat of the summer. Orchardgrass is high-yielding but requires aggressive management and is more susceptible to winter damage, particularly ice sheets.

Forage quality also differs among grass species. Cornell University research reported somewhat higher forage quality for tall fescue versus reed canarygrass when both were harvested at the boot stage. If establishing a pure stand of grass it is best to use one species because there are considerable differences in heading date among cool-season grasses and also between varieties. In recent years, the cool-season grass species generating the most interest is endophyte-free tall fescue. There are dozens of tall fescue varieties on the market, most which head at about the same calendar date as do the latest-maturing orchardgrass varieties (Thomas and Mahanna, 2015). There can also be large differences in maturity within the species. For example, early maturity varieties of timothy and orchardgrass head out at least 10 days earlier than late-maturity varieties of the same species. There is somewhat less varietal difference in the heading dates of reed canarygrass, tall fescue, and bromegrass. Within a species, there is little difference in forage quality when the varieties are harvested at the same stage of maturity. However, there are significant differences in varietal yield within a species, so variety selection is important (Thomas and Mahanna, 2011).

Research at the University of Minnesota found that tall fescue and orchardgrass had higher yield and quality than did alfalfa, and forage analyses predicted that both milk per acre and milk per ton would be higher for the two grasses. However, even though the neutral detergent fiber (NDF) in grass is more highly digestible than alfalfa NDF, the digestion rate is slower which may limit the amount of grass that can be fed to high-producing dairy cows. The farms that have the most success feeding grass put a high priority on harvesting any grass that will be fed to high-producing cows when it’s still in the boot stage (Thomas and Mahanna, 2015).

Sorghum

There has been renewed interest in forage sorghum and sorghum-sudangrass attributable to the 2012 drought and declining water in the Ogallala Aquifer (South Dakota to Texas). The advantage of these forages is their adaptability to high temperatures and requiring about 33% less water than corn. Sorghums are diverse cultivars ranging from shorter (3-5 feet) grain (milo) sorghums to taller (8-13 feet), higher-tonnage forage sorghums that have stems and leaves similar to corn. Forage sorghums have varying grain-to-stover ratios, ranging from no grain with male sterile to upwards of 40% grain depending upon variety. Sudangrass grows 4-7 feet, has much smaller leaves and stem diameter and can be harvested as early as 45 days after planting. The smaller stems allow for faster drying than other sorghums for those interested in harvesting as hay. Sorghum-sudangrass hybrids are intermediate between forage sorghum and sudangrass, with leaf-to-stem ratios driving their nutritive value and regrowth contributing to total yield potential. There are also brown midrib (BMR) versions of forage sorghums, sudangrass and sorghum-sudangrass hybrids which have reduced lignin in both the stem and leaves, resulting in higher fiber digestibility. However, similar to corn, there is a slight yield drag (10%) in BMR genetics compared to conventional genetics (Mahanna and Thomas, 2013).

Forage sorghums are typically harvested for silage when grain is about mid-dough maturity to optimize yield, quality, berry starch digestibility and adequate plant dry matter for ensiling. Non-heading varieties usually require a killing frost for the plant to reach adequate dry matter to prevent excessive levels of effluent. Post-frost harvesting can result in lower yield and quality due to leaf loss and lodging. Sudangrass and sorghum-sudangrass are harvested before reaching 3 feet tall, allowing for two to three cuttings per year. These crops must be field wilted to achieve proper ensiling moisture.

There are several published research studies with sorghum silages claiming similar milk production when dairy cows are fed a ration containing BMR sorghum silage versus a ration containing corn silage. However, the cows in these studies are typically late-lactation and/or low-producing cows (57-75 pounds per day). In one short-term study, cows fed the BMR forage sorghum silage consumed 2 pounds more dry matter per day than those fed corn silage, yet the cows on the corn silage treatment gained 7.5 pounds more body weight. This would indicate more energy among the corn silage treatment despite similar milk production. The other issue is that the corn silage in these trials didn't represent typical fiber and starch content levels. In one study, the corn silage contained 55% NDF, which was similar to the level of NDF in the BMR forage sorghum. Obviously, there was little starch in the corn silage to dilute the NDF. Similarly, another trial comparing BMR forage sorghum to corn silage used corn silage containing 46% NDF and only 20% starch. These trial details may help put in perspective the claims that BMR forage sorghum has 85-100% the feeding value of corn silage. Perhaps this is true for the poorest corn silage, but certainly not compared to typical corn silage. Research has yet to be conducted comparing BMR sorghum to BMR corn silage. In the end, it is not just who wins in milk production, but which forage yields the most starch and digestible fiber resulting in the highest income over feed cost which, unfortunately, is not reported in most studies. Despite advances in sorghum breeding, the variability in plant height (yield), dry matter, standability, starch content and starch digestibility has held back wider adoption of sorghum silage. However, for producers dealing with dwindling water supplies, BMR forage sorghum may have a place, especially for heifers, dry and late-lactation cows which have lower nutrient requirements (Mahanna and Thomas, 2013).

Cereal forages

Small grain silages, such as wheat, oat, rye, barley or triticale (wheat-rye hybrid), used in double cropping programs are becoming increasingly popular as a forage source, especially for young stock. In general, cereals should be harvested in the milk-to-soft dough stage if the goal is to maximize the yield of energy per acre. As small grains mature from flag to boot to head to flower to milk to dough stages, the protein level drops while yield and energy value typically increase. Dairy producers can maximize protein content by harvesting small grains in the late flag leaf to early boot stage. While the boot stage of maturity produces the highest "bite for bite" nutrient value, dry matter yields are considerably reduced. Producers desiring the highest quality forage are cutting at this stage of maturity. The milk stage is less desirable than the early dough stage as it is less palatable and studies indicate animal performance may be reduced. The early dough stage of maturity produces maximum energy per acre and is the most common maturity for harvest.

If considerable acres of small grain are to be harvested, it is recommended to begin harvest at milk stage to avoid harvesting past the dough stage of maturity. The following guidelines are commonly used as to when to harvest specific cereals: 1) wheat and barley - soft dough stage (direct chop), 2) oats - boot to early heading (wilted), 3) rye - boot stage (wilted) and 4) triticale - flag leaf fully emerged but no head (wilted) (Kilcer, 2010). Moisture levels in the range of 60-70% are best for ensiling small grain silage. Small grain silages with less than 60% moisture are difficult to pack, and excessive heating and nutrient losses can occur. Recommended length of cut is ¼-3/8 inch to facilitate packing and reduce oxygen being carried in with hollow stems in later harvested cereals.

Forage environmental implications

One potential concern with high-forage diets is an increase in methane emissions. There is little that can be done to changes this biological fact and methane may simply be the price for balancing “starch for humans” versus “fiber for ruminants”. Manure accounts for about 25% of dairy farm methane emissions, with the remaining 75% from enteric emissions, representing between 6% and 10% of the total gross energy intake of lactating cows (Chase 2010). In December 2009, the U.S. Department of Agriculture and the Innovation Center for U.S. Dairy signed a memorandum of understanding to work jointly in support of the goal to reduce dairy industry greenhouse gas emissions 25% over the next decade (Bauman and Capper, 2011). The areas they have identified that directly affect methane emissions are: (1) rumen function (including microbial genomics/ecology) and modifiers, (2) enhancing feed quality and ingredient usage to improve feed efficiency, (3) genetic approaches to increase individual cow productivity, (4) management practices to increase individual cow productivity and (5) management of the herd structure to reduce the number of non-productive cow-days (Tricarico, 2012).

The U.S. dairy industry has had a remarkable record of advances in productive efficiency and environmental stewardship over the last half-century, with annual milk production per cow increasing by more than 400% with a corresponding two-thirds reduction in the carbon footprint per unit of milk (Bauman and Capper, 2011). It is also important to maintain a global perspective on the goal of reducing methane emissions. The U.S. provides about 16% of the world's total milk production but only about 8% of total greenhouse gas emissions (Chase, 2010). North America and Europe currently have the lowest greenhouse gas emissions per unit of fat-protein-corrected milk. The highest level is in sub-Saharan Africa and the majority of the increase in global livestock production over the next 35 years will occur in the developing world (Mitloehner, 2010).

Research from Wageningen University (Dijkstra, 2013) suggests that improving feed efficiency and reducing methane output required an interdisciplinary, fundamental approach and that direct methane inhibition through the use of dietary lipids, nitrates or tannins typically does not improve feed efficiency. They advised approach to improve feed efficiency and reduce methane emission intensity is to increase milk production levels and improve forage quality

Conclusion

As concluding "food for thought", listed below are field comments the author has solicited from DuPont Pioneer colleagues and interactions with consulting nutritionists when they were asked about the important forage-related areas dairy producers should keep in mind: 1) reduce fermentation and feed-out losses as a way to improve water utilization, 2) have someone in the operation who makes a priority of managing the agronomics and harvesting of forage crops, 3) optimize locally grown energy sources – anchor the diet with corn silage and reasonable levels of alfalfa, 4) consider all factors if switching from corn to sorghum due to water limitations - shorter maturity hybrids planted a lower populations may provide more energy per acre than sorghum, 5) focus on ration consistency and reducing variation in forage inventories, 6) be mindful of the huge varietal differences in sorghums and decide at what production level sorghum in the diet makes economic sense, 7) focus on economics of growing versus purchasing forages, 8) establish legal contracts for purchased forages with clear incentives around quality parameters (starch, kernel processing), 9) investigate ways to feed cows with less alfalfa by using alternative forage sources, 10) look closely at new silage technologies to improve forage feeding such as enzyme-producing inoculants, oxygen-barrier film, facers, rumination monitors and on-farm NIRS, 11) remember that forage quality cannot drive economical production without consistency and cow comfort, 12) consult with trusted academic and industry specialists to help separate "fact from fiction" when it comes to new forage technologies, 13) utilize new forage analysis methods to proactively predict the associative effects of combining various forage and supplements into a lactating diet and 14) keep abreast of agronomic advances allowing for prediction of yield, quality and harvest timing of forages as the growing season advances.

Literature cited

Allen, M.S., J.G. Coors, and G.W. Roth. 2003. Corn Silage. Silage Science and Technology. In: Buxton, D.R., R.E. Muck, and J.H. Harrison, ed. Agronomy Monograph No. 42. p. 547-608.

Bauman, D.E. and J.L. Capper. 2011. Sustainability and dairy production: challenges and opportunities. Proc. Cornell Nutr. Conf., Syracuse, NY.

Bolinger, D. 2010. Personal communication. Dann.bolinger@pioneer.com

Butzen, S. and Stephen Smith. 2014. Corn yield gains due to genetic and management improvements. DuPont Pioneer Crop Insights. Vol. 24. No. 12.

Buza, M.H., L.A. Holden, R.A. White and V.A. Ishler. 2014. Evaluating the effect of ration composition on income over feed cost and milk yield. J. Dairy Sci. 97:3073-3080.

Chase, L.E., and R.J. Grant. 2013. High forage rations - What do we know. Proc. Cornell Nutr. Conf., Syracuse, N.Y.

Chase, L.E. 2010. How much gas do cows produce. Proc. Cornell Nutr. Conf., Syracuse, NY.

Clark, J. S., E. C. Grimm, J.J. Donocan, S.C. Fritz, D.R. Engstrom, and J.E. Almendinger. 2002. Drought cycles and landscape responses to past aridity on prairies of the Northern Great Plains, USA. Ecol. 83:595-301.

Coors, J., J. Lauer, P. Flannery, and D. Eilert. 2001. How have hybrids changed for silage yield and quality over the decades? University of Wisconsin Corn Breeding Website. Available: http://uwsilagebreeding.agronomy.wisc.edu/.

Coors, J. G. 1996. Findings of the Wisconsin corn silage symposium. In: Proceedings Cornell Nutr Conf. Rochester, NY.

Dijkstra, J. 2013. Nutrient losses during digestion and metabolism. Proceedings of International Dairy Nutrition Symposium on Feed Efficiency in Dairy Cattle. Nov. 21. Wageningen, Netherlands. p. 43-52.

Fanta, M. 2014. Forage Genetics International. Personal communication.

Firkins, J.L. 2006. Starch digestibility of corn – Silage and grain. Proc. Tri-State Dairy Nutrition Conference. April 25-26.

Grant, R. and K. Contach. 2011. Feeding high forage diets: Miner experiences with BMR corn silage Miner Institute Crop Congress , Chazy, N.Y. February 15, 2011.

Hoffman. P.C., R.D. Shaver and D.R. Mertens. 2012. Feed Grain V2.0 – Background and development guide. UW Extension. http://www.uwex.edu/ces/dairynutrition/documents/Background-DevelopmentGuidev2.0b.pdf

Jaynes, L. 2014. Lower lignin alfalfa: What this means to growers. Progressive Forage Grower. October 14, 2014.Kilcer. 2010. Winter Triticale Forage Information 2010. http://www.cceoneida.com/assets/Agriculture-Files/Crops-files/Forage-crops/fact-sheet-triticale2010-v2.pdf

Kranz, W.L, S. Irmak, S.J. van Donk, C.D. Yonts, and D.L Martin. 2008. Irrigation management for corn. NebGuide G1850.

Lauer, J.G., J.G. Coors, and P.J. Flannery. 2001. Forage yield and quality of corn cultivars developed in different eras. Crop Sci. 41:1449-1455**.**

Mahanna, B. 2014. Corn silage research from joint meetings reviewed. Feedstuffs. August 11, 2014

Mahanna, B. 2013. Growing conditions alter feeding value of corn. Feedstuffs. October 14, 2013

Mahanna. B. 2012. Lactation trial propels interest in shredlage Feedstuffs, August 13, 2012

Mahanna, B. 2010. Growing conditions affect silage quality. Feedstuffs. Vol. 82, No. 24, June 14, 2010

Mahanna, B. 2007. Watch for changing starch digestibility. Feedstuffs. Vol. 79, No. 24. June 11, 2007.

Mahanna, B., and E. Thomas. 2014. A mixed review for fungicides in alfalfa. Hoards Dairyman. February 10, 2014.

Mahanna B and E. Thomas. 2013. Where does sorghum fit? Hoards Dairyman. September 10, 2013

Mahanna, B. and E. Thomas. 2013b. Reduced-lignin trait could revolutionize alfalfa. Hoards Dairyman. Nov. 2013

Mitloehner, F.M. 2010. Clearing the air on livestock and climate change. Proc. Cornell Nutr. Conf., Syracuse, NY.

Mertens, D.R. 2002. Fiber: Measuring, modeling and feeding. In: Proceedings of the Cornell Nutr. Conf. East Syracuse, N.Y.

Musick, J.T. and D.A. Dusek. 1980. Irrigated corn yield response to water. Trans. Am. Soc. Agric. Eng. 23: 92-98.

Nasser, S. Al-Ghumaiz, Leep, R.H and T.S. Dietz. 2006. Influence of cutting time on alfalfal (Medicago sativa) sugar content and silage fermentation. PMN International. http://www.plantmanagementnetwork.org/pub/fg/research/2006/cutting/

Newell. R. 2014. Forage Trends and Prognostication. Progressive Forage Grower. March 6, 2014.

Norwood, C.A. and T.J. Dumler. 2002. Transition to dryland agriculture: Limited irrigated vs. dryland corn. Agron. J. 94: 310-320.

Oba, M and M. S. Allen. 1999. Evaluation of the importance of the digestibility of neutral detergent fiber from forage: effects on dry matter intake and milk yield of dairy cows. J Dairy Sci 82:589–596

Olson, R. 2013. Personal communication. Roger.olson@zinpro.com

Owens, F.N. 2011. Personal communication. fred.owens@pioneeer.com

Owens, F.N. 2010. Personal communication. fred.owens@pioneeer.com

Paszkiewicz, S., and S. Butzen. 2001. Corn hybrid response to plant populations. Pioneer Crop Insights. Vol. 11, No. 6.

Seglar, W.J., M. Pauli, A. Patterson, L. Nuzback and F.N. Owens. 2013. Influence of maize kernel maturity on chemical characteristics, prolamin content and in vitro starch digestion. J. Anim. Sci. Vol. 91, E-Suppl. 2/J. Dairy Sci. Vol. 96, Poster T88, E-Suppl. 1, p 32. Progressive Dairyman. 2014. http://www.progressivedairy.com/home/us-dairy-and-industry-stats

Shanahan, J. and J. Groeteke. 2011. Irrigation and agronomic management for corn grown under limited water supplies. Pioneer Crop Insights. Vol 21, No 1. January, 2011.

Ramos, B.M.O., M. Champion, C. Poncet, I.Y. Mizubuti and P. Noziere. Effects of vitreousness and particle size of maize grain on ruminal and intestinal in sacco degradation of dry matter, starch and nitrogen. Anim. Feed Sci.Technol. 148: 253-266.

Sudar, R.A., K.E. Saxton, and R.G. Spomer. 1981. A predictive model of water stress in corn and soybeans. Transactions of ASAE, 24:97-102.

Thomas, E. 2007. AM vs. PM alfalfa harvest. Miner Institute Farm Report. August, 2007.

Thomas, E. 2001. AM vs. PM alfalfa harvest. Miner Institute Farm Report. January, 2001.

Thomas, E. and B. Mahanna. 2015. Choosing and using pure stands of grasses. Hoards Dairyman. January 10, 2015.

Thomas, E. and B. Mahanna. 2012. Straight alfalfa or alfalfa-grass mixes. Hoards Dairyman. January 10, 2012.

Thomas, E. and B. Mahanna. 2011. Grass is finding newfound respect. Hoards Dairyman. April 10, 2011.

Tricarico, J.M. 2012. Cow of the future: the enteric methane reduction project supporting the U.S. dairy industry sustainability commitment. Proc. Cornell Nutr. Conf., Syracuse, NY.

Undersander, D. 2009. Watch your ash. Midwest Forage Association - Forage Focus. May, 2009

Undersander, D. 2003. AM vs. PM harvested alfalfa - hay or haylage. Personal communication. djunders@facstaff.wisc.edu

United States Department of Agriculture-National Agricultural Statistics Service. 2007 Census of Agriculture at: http://www.agcensus.usda.gov/Publications/2007/Full_Report/usv1.pdf (Verified 19 November. 2010).

Van Soest, P.J. 1996. Environment and forage quality. In: Proceedings Cornell Nutrition Conference for Feed Manufacturers. 22-24 Oct. 1996. Rochester, NY.Ward, R and M.B. de Ondarza. 2007. How does NDF digestibility vary with cutting? Cumberland Valley Analytical Services, Inc. November 13, 2007

Warner, D. 2011. A new wave in managing water stress. Pioneer Growing Point Magazine. Vol. 10, N0.4, February, 2011 pg. 10-11.

Wikner, I. 1996. Reflecting on 30 years of corn production practices. Pioneer Crop Insights. Vol.3, No.44.

Wu, Z. and G. Roth. 2004. Considerations in Managing Cutting Height of Corn Silage. DAS 03-72. http://extension.psu.edu/animals/dairy/nutrition/forages/silage/considerations-in-managing-cutting-height-of-corn-silage

Zeller, W. and J. Grabber. 2014. Researching ways to improve nitrogen-use efficiency on dairies through the use of condensed tannin-containing forages. Midwest Forage Association Newsletter. September, 2014.

Notes:

‘Shrink’ in Corn Silage Piles. What are the Real Losses?

P.H. Robinson[1], N. Swanepoel[1], J. Heguy[2], D. Meyer[1]
[1]Department of Animal Science and [2]UCCE Stanislaus, San Joaquin & Merced Counties
University of California, Davis, CA, USA 95616

Abstract

Silage shrink, or losses of weight between ensiling and feedout, represent a loss of nutrients to the dairy producer, as well as the potential to degrade air quality if that loss is volatile carbon compounds, or to degrade water quality due to weepage to surface water – or seepage to subsurface aquifers. Thus numerous Federal and State agencies are concerned about defining and minimizing silage shrink, even though virtually no research has documented the extent of silage shrink in large commercial silos or documented impacts of the mitigations designed (in some cases required) to minimize it, especially in the silage piles commonly used in the Southwest USA. Indeed the term ‘shrink’ is generally undefined, and can be expressed as loses of wet weight (WW), oven dry weight (oDM), and oDM corrected for volatiles lost in the oven (vcoDM) weight, which can all be expressed with or without wastage (i.e., silage recovered but not fed). Using 8 corn silage piles (2 rollover, 1 bunker, 5 wedge) ranging in size from 1052 to 13470 tons (as built), on concrete (5), dirt (2) and a combination base (1), on 4 dairy farms, in 2 areas of the San Joaquin Valley, all covered within 48 h by professional crews with an oxygen barrier inner film and black/white outer plastic weighted with tire chains, fed out by professional crews using a silage tracking system, and from the 2013 crop year; total shrink losses as well as the phase of the process where those losses occurred were measured. Total WW, oDM and vcoDM losses (not including wastage) were 8.4 +/- 1.59, 6.8 +/- 1.82 and 2.8 +/- 2.08 %, suggesting that much of what is measured as WW shrink is water and what is measured as oDM shrink contains a lot of volatiles driven off during oven drying. The largest part of shrink occurred in the silage mass prior to face exposure, with losses from the exposed face, as well as between face removal and the mixer, being small. Other (undefined) losses were quantitatively similar to losses in the mass. These losses could be evaporation of water during pile building, plant respiration of CO_2 prior to pile covering, small losses of fresh chop and silage during transit to and from the pile, as well as weepage and seepage. While the number of piles were insufficient to examine many mitigations, pile bulk density, face management, rate of face use and face orientation did not have obvious impacts on shrink. The only factor which seemed to impact shrink was the average temperature during pile feedout (higher temperatures related to higher shrink losses), but mainly for WW shrink. Real shrink losses (i.e., vcoDM) of well managed corn silages piles are much lower than has been generally assumed, the exposed face is a small portion of those losses, and many of the proposed mitigations may not be effective in

reducing shrink, possibly because it is quantitatively so small in large well manged silage structures.

[1] P.H. Robinson (phrobinson@ucdavis.edu), UCCE Dairy Specialist, Dept. of Animal Science, UC Davis, Davis, CA. In: Proc. 2015 Western Dairy Management Conference, Reno, NV. 3-5 March.

Introduction

Corn silage has been an important silage crop for a very long time in America. And in today's America, of over 350 million people and a resulting high requirement for dairy products leading to large commercial dairy enterprises, corn silage is far and away the most important ensiled crop in virtually all US dairy areas. As in most aspects of life, where we want to receive all of whatever it is that we pay for, losses of corn silage post-harvest during the ensiling period represent an economic loss to the dairy industry. Generally referred to as 'shrink', although seldom clearly defined, it is the proportion of the fresh crop weight that is not recovered from the pile as feedable, or sometimes expressed as total, silage. Shrink can refer to wet weight (WW) recovery of silage or as oven dry weight (oDW) recovery. But, however you express it, shrink could be costly. For example, 10% WW shrink on a 15,000 ton corn silage pile represents a loss of $90,000 if WW corn silage is valued at $60/ton WW. In addition to an economic loss to a dairy farmer, shrink can represent a loss of carbon compounds to waterways as weepage from the pile, or to aquifers as seepage, or to the atmosphere as gases. As such, these silage loses have attracted the attention of various US regulatory agencies, especially water and air districts in California which are tasked with reducing environmental impacts of farming as a way to create cleaner water and air. These regulatory efforts have, in some cases, resulted in semi-mandatory mitigations to dairy farmers to reduce silage shrink; mitigations (based upon limited data of questionable relevance to large commercial silage piles), which may or may not actually reduce silage shrink which itself may or may not be a problem of a magnitude equal to that assumed by the regulatory agencies. As with many governmentally regulated areas in our society, nothing is simple.

Nevertheless reducing shrink is important. So what is an achievable corn silage shrink loss and what factors impact it? Shrink numbers in the commercial literature are commonly in the 5 to 20% range, and numerous management strategies have been suggested to reduce it. These include practices such as use of an inoculant at chopping, building piles on a concrete base, creating high pack density at silage pile building, use of a plastic cover, rapid covering of the mass with that plastic cover, use of an inner plastic film, use of an inner film with enhanced oxygen barrier characteristics, use of weights on the plastic, sealing the periphery of the pile with dirt or weights, minimizing exposed face at feedout, removing the maximum possible depth of silage at feedout, maintaining a 'smooth' silage face, using moveable weight lines along the cut surface of the plastic, only removing as much silage as is immediately needed, use of mechanical defacers, use of block cutter defacers, and leaving no overnight piles of loose silage. Quite an extensive list – some simple and some not so simple. The common feature of all of these potential mitigations is that they will increase dairy costs, while the telling feature of the combined list is that it would take a team of 20 scientists about 10 years to investigate the efficacy of each individually. Let's not consider the time and cost of investigating their efficacy if used concurrently. And that is the pickle – lots of costly suggested mitigations of silage shrink with no guarantee that any of them are cost effective – in fact there is little evidence for many that they are efficacious in reducing shrink at all. Thus, in general, common silage-sense and experience are the bulk of what dairy farmers have to go on. Not a great situation, especially when it is recognized that the actual extent of the base 'problem' that the mitigations are designed to address - that silage shrink is substantive economically and environmentally – has little or no supporting data in real world corn silage piles.

Defining 'Shrink'

Shrink losses of corn silage can be defined in many ways. However the most common definition is the proportion of the WW fresh crop which is packed into a silo structure (including a pile) and is later placed into a TMR mixer. Under this definition, spoilage which is removed by hand (in most cases) and disposed of by land application or feeding to heifers counts as shrink. However shrink as defined by air and water boards typically includes wastage since this material is actually recovered (and not 'lost'). The interpretive limitation of WW shrink is that much of it will be water, which has no substantive economic or environmental impact. Thus some dairy producers and regulatory boards also measure shrink on an oDM basis.

To convert WW shrink to oDW shrink it is necessary to collect many samples of fresh cut crop at ensiling, as well as collect many samples of the silage that is put into the TMR mixer. This is a time consuming chore which involves collecting and pooling many samples over the period of silo structure building, as well as many samples over the often long feedout period, in order to create pooled samples representative of the crop ensiled and of the silage fed out. Both of these tasks are prone to poor practices and creation of samples which are not representative of the fresh cut crop ensiled and/or the silage placed into the TMR mixer. While these issues can be dealt with by using defined sample collection protocols, a serious structural issue is that this oDW shrink estimation procedure will <u>always</u> overestimate real DW shrink by adding volatile carbon compounds lost during oven drying to the shrink estimate.

The base problem with oDW shrink is that drying fresh chopped corn crop in an oven will almost exclusively drive off water, since very few volatile carbon compounds are in a fresh chop corn crop, but drying corn silage in an oven will drive off volatile carbon compounds, most of which will actually be fed to the cows, as well as water. Examples of volatile carbon compounds commonly found in corn silage include the volatile fatty acids (VFA) acetic, propionic and butyric, the alcohols ethanol, 1,2 propanediol and 2,3 propanediol, as well as a host of minor volatile carbon compounds. Even lactic acid, always found in corn silage, will be lost to some extent during oven drying – and the 'oven volatility' of all of these compounds differs, and also differs within compound in the range of normal oven drying temperatures. As a group, potentially volatile compounds in corn silage typically make up 2 to 5% of the fresh weight and, depending upon their proportions in the silage, up to 60% of them could be lost during oven drying. Thus 'oDW shrink', where the DW is determined by oven drying, could overestimate actual DW shrink (i.e., volatile corrected DM shrink; vcoDM Shrink) by up to 5 % units. In other words, an oDW shrink of 10% might only be ~5% when corrected for the volatiles lost during oven drying.

Silage Sources (Areas) of 'Srink'

Shrink losses of corn silage originate from many facets of the ensiling process such as during pile building after the fresh chop material is weighed but prior to plastic covering, from the mass while it is ensiled, from the silo 'face' at (or near) its exposure to air, during the defacing operation, after silage has been defaced but before it is moved to the TMR mixer and, finally, during transport to the TMR mixer – which is typically where the amount of fed out silage is measured.

Losses During Pile Building. Once the fresh chop corn crop is weighed in the trucks, small quantities of it could be lost on the way to the pile due to wind, or simply by falling off the trucks. However this is unlikely to be substantial during the life of a pile building operation. A more likely loss of weight is evaporation of moisture (water) from the fresh chop material once it is placed on the pile since, typically, piles are built on pleasant sunny days when solar radiation levels are high. Of course such losses will impact WW shrink to a much greater extent than oDW shrink since there is little opportunity for non-water compounds to evaporate because their levels in a freshly chopped corn crop are very low. Another likely source of oDM shrink is from plant respiration because the plants are not really dead when they are delivered to the pile. Until the plants are fully dead, due to creation of an acidic environment and/or heat and/or they run out of sugars in their biomass, the plants will continue to be metabolically active and, once they are no longer in the sun and photosynthesizing, they will utilize stored sugars to meet their energy requirements which will result in creation of CO_2 which will largely be released to the atmosphere. Such CO_2 losses would be measured as WW, oDW and vcoDW shrink since the carbon atoms are coming from metabolized sugars. Unlike water losses, carbon losses as CO_2 impact the total nutritional value of the silage pile, but would have no air quality impact in most regulated air districts at this time (i.e., CO_2 is a greenhouse gas (GHG), but not a volatile carbon compound which impacts air quality).

Losses From the Silage Mass. Once the fresh chop corn crop is packed and covered it will go through a fermentation cycle which starts with aerobic bacteria (which create heat) and finishes with anaerobic bacteria, which create the alcohols and acids, primarily lactic, acetic and propionic, which drives down the pH to create a 'stable' silage mass. This silage mass, if protected from oxygen penetration, should be unchanging for prolonged periods of time. However it is possible that due to the long period of ensiling, >12 months in some cases, and low level penetration of oxygen through and around the plastic cover (as well as into the face once it is exposed) that some losses of gases, and vaporized water, could occur. Indeed as most silage piles have the plastic peeled back up to 8 feet from the exposed face, evaporative losses of water and volatilization of carbon based compounds (i.e., the surface dries out) could occur from the exposed silage area. Of course if this exposed material is rained on, the losses could turn into weight gains, but only as WW. A silage weight loss which could be negligible or substantive is weepage and seepage of low DM fluid from the silage mass. The extent of this loss will be impacted by the moisture content of the fresh cut crop as well as its pack density which, logically, will be positively correlated (i.e., it is hard to obtain high pack density of a low moisture crop no matter how much packing pressure is applied).

Losses from the Silage 'Face' at (or near) its Exposure to Air. This is an area of high interest from regulatory agencies as it seems intuitive that losses of silage weight occur from silo face areas once they are exposed to air. Such losses could be water, but there must be losses of some alcohols and volatile acids since such compounds are easily detected by simply smelling a freshly exposed corn silage face. Such losses would likely be impacted by factors such as the orientation of the exposed face (south faces in the northern hemisphere having higher losses than north faces due to their being sun exposed), temperature and relative humidity during face exposure (higher temperatures being associated with higher losses), smoothness of the exposed face (rough surfaces creating more real surface area to emit volatiles than smooth surfaces), wind (the higher the wind speed over the face the higher the losses) and perhaps time of exposure of the face (emissions/unit area declining with time of exposure).

Losses from Silage During Defacing. In all silage face removal systems there are likely to be losses of water and volatiles as the silage collapses into a pile after defacing. Such losses would likely be impacted by the violence of the defacing process. For example mechanical rotating defacers are relatively violent, front end loader buckets intermediate and block cutters relatively benignly violent silage removal methods. A greater extent of silage disturbance during defacing could increase immediate losses of volatiles and water, as well as create the potential for higher losses of volatiles and water while it is in the 'drop down pile' awaiting transport to the TMR mixer.

Losses from Silage After Defacing. In all systems where silage is left on the ground for a period of time between defacing and being placed in a TMR mixer (i.e., in the drop down pile), there are likely to be losses of water and volatiles as the silage waits for removal and loading into a

TMR mixer. Such losses would likely be impacted by the length of the delay between defacing and placement in the TMR mixer (for example overnight delays might be expected to maximize losses), the size of the drop down pile (larger piles emitting less per unit weight) as well as the environmental conditions during that wait, as were discussed earlier for losses from the face. Weight 'losses' during this period could even be small weight gains for silage structures on dirt bases if some dirt is picked up by the loader operator with the silage.

Losses of Silage During Transport to the TMR Mixer. Such losses include silage which is never picked up from the ground or falls off the load while it is being transported to the TMR mixer. However it could also result in a weight gain for silage piles on dirt bases if some of that dirt is picked up with the silage. In total, these losses are unlikely to be substantial.

Overall, there are a number or areas of the ensiling process where silage weight, as fresh or dry material, can be lost (or gained in a few cases) between the time that the fresh material is weighed into the pile until the silage is weighed into a TMR mixer. But we had questions. The first questions addressed the issue of the extent of corn silage shrink as WW, oDW and vcoDW, because that focuses on the extent of the silage shrink 'problem' from the perspectives of dairy farm economics as well as potential impacts on air and water quality. The second questions addressed the issue of where in the entire process (as outlined above) shrink is occurring because that suggests where mitigations should be focused to reduce it. Finally, the third questions addressed the issue of which ensiling practices and characteristics exacerbate or mitigate shrink, and where that mitigation occurs in the entire ensiling process, because that suggests where mitigations would likely be more or less efficacious in terms of reducing shrink.

First Questions: Measuring Total Silage 'Shrink' Losses

Silage piles can be very large – 15,000 ton piles are not uncommon – and can be fed out over periods in excess of 12 months. This makes measuring shrink a challenging task, and identification of where that shrink occurs even more challenging. While it is not difficult to measure shrink in mini- or model silos of a few pounds to a few hundred pounds, it is unlikely that such models can be expected to fully represent a 10,000 ton silage pile. However total shrink losses in commercial silage piles can be measured by recording the total WW of fresh cut corn crop delivered to a silage pile at building relative to the amount of WW corn silage measured as being placed into the TMR mixer at feed out. We used 8 corn silage piles (2 rollover, 1 bunker, 5 wedge) ranging in size from 1052 to 13470 tons (as built), on concrete (5), dirt (2) and a combination base (1), on 4 dairy farms, in 2 areas of the San Joaquin Valley, all covered within 48 h by professional crews with an oxygen barrier inner film and black/white outer plastic weighted with tire chains and fed out by professional crews using a silage tracking system, and all from the 2013 crop year. On these 8 piles, average WW shrink losses (i.e., where silage recovered, but not fed, is <u>not</u> classified as shrink) were 8.4 +/- 1.59 %, a number within the range suggested by many persons working on silage issues.

Conversion of WW loss calculations to oDW losses occurs by creating pooled samples of the incoming fresh cut corn crop and fed out corn silage which are both oven dried at 105°C. These pooled samples are then assayed in both their 'as sampled' and 'oven dried' forms, and then arithmetically adding them back to recovered oDM the amount of volatile compounds lost during oven drying. Using this approach, oDW losses were 6.8 +/- 1.82 % (*n*=7) and vcoDM losses were 2.8 +/- 2.08 % (*n*=7), confirming that a lot of measured WW shrink is really water, and some of what is measured as oDM shrink is actually volatile compounds driven off in the drying oven.

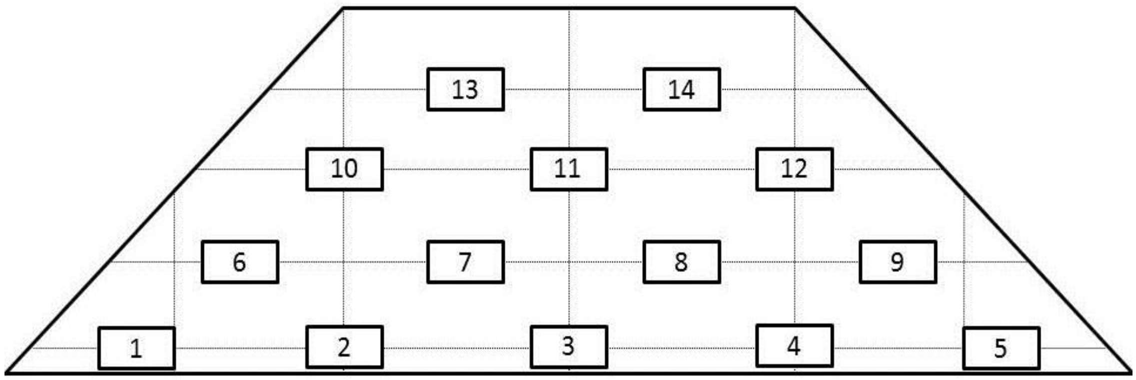
Second Question: Measuring Where Silage 'Shrink' Losses Occur

While it is critical to know total shrink losses for silage piles, as this effects environmental impacts and farm economics, it is as interesting to know where, in the entire silage creation and feedout process, which those losses occur since this suggests where mitigation efforts should be directed.

Losses From the Silage Mass. Once the fresh chop corn crop is packed and plastic covered it goes through a fermentation process that starts with aerobic bacteria (which create heat) and finishes with anaerobic bacteria. The anaerobes are the bacteria which create the alcohols and acids, mainly lactic, acetic and propionic, which drive down the pH to create a 'stable' silage mass. If protected from oxygen penetration, this mass should be relatively unchanging for prolonged periods of time. The extent of this loss was measured by burying Dacron mesh bags of fresh crop in the pile at filling and recovering them from the face at silage removal (Figure 1). We utilized a grid of 14 bags (Figure 2) in each of 4 corn silage piles. Data from these bags suggests that the WW, oDW and vcoDW losses from the mass were 3.9 +/- 2.40, 7.2 +/- 1.12 and 3.5 +/- 1.27 %, respectively. As with total pile shrink losses, as noted above, a lot of what is measured as oDM shrink actually contains a lot of volatile compounds driven off in the drying oven, and not actually lost from the pile.

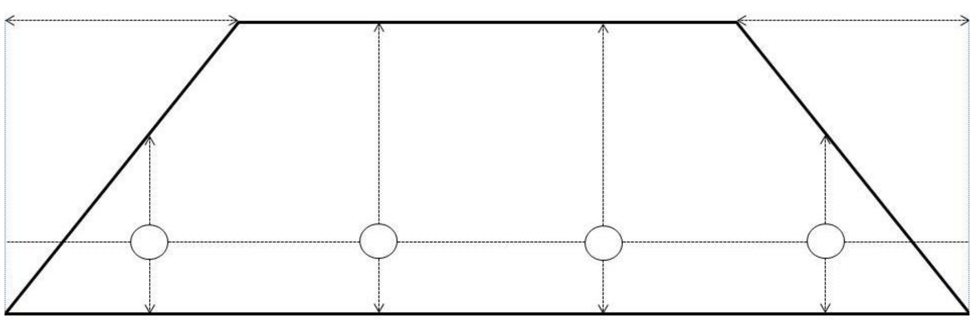
Figure 1. Buried bags prior to burying and after recovery.

Figure 2. The 14 Buried Bag Grid



Losses from the Silage 'Face' at (or near) its Exposure to Air. This is an area of interest to regulatory agencies as it seems intuitive that losses of silage weight will occur as volatile compounds and water are lost from silo faces once they are exposed to air. The extent of this loss was measured by coring each silage pile on two occasions in a 4 core grid (Figure 3), to 20 inches of depth from a freshly exposed face (new face) and from a face exposed for ~20 h (old face) at ~5 ft above grade. WW, oDW and vcoDW losses from the face were 1.3 +/- 1.16, -0.6 +/- 1.55 and 0.1 +/- 1.40 % respectively. Although these values are very low overall, they confirm suggestions that most of the weight loss from the face is water.

Figure 3. The 4 Location Face Coring Grid (samples cored to 20 in depth 5 feet above grade).



Losses from Silage During and After Defacing. In all silage face removal systems there are likely to be losses of water and volatiles as the silage collapses into a pile after defacing, and while it awaits transport to the TMR mixer. The extent of this loss can be estimated by comparing the composition of the silage in the 'new face' with the composition of the silage in the drop down pile that is loaded into the TMR mixer. These WW, oDW and vcoDW losses from the drop down piles were 0.9 +/- 0.54, -0.6 +/- 2.27 and -1.5 +/- 2.17 respectively.

Other Losses. Such losses include fresh chop crop which is weighed but never makes it to the pile, evaporative losses from the pile surface during building, continued plant respiration in the pile as

CO_2, weepage and seepage, and silage which is never picked up from the ground or falls off the loader in transport to the TMR mixer. Unaccounted losses (i.e., those calculated by difference) for WW, oDW and vcoDW were 4.6 +/- 2.50, 2.7 +/- 1.57 and 2.6 +/- 1.66.

In general, shrink losses are highest when measured as WW, intermediate as oDM losses and lowest as vcoDM losses, are measureable from most phases of the ensiling process, and occur at relatively low levels. However percentage losses from the face are, quantitatively, far from the most important shrink losses, which are summarized in Figure 4 below.

Total losses are not the sum of individual losses since the bars represent different numbers of piles (i.e., n= 4-8/bar)

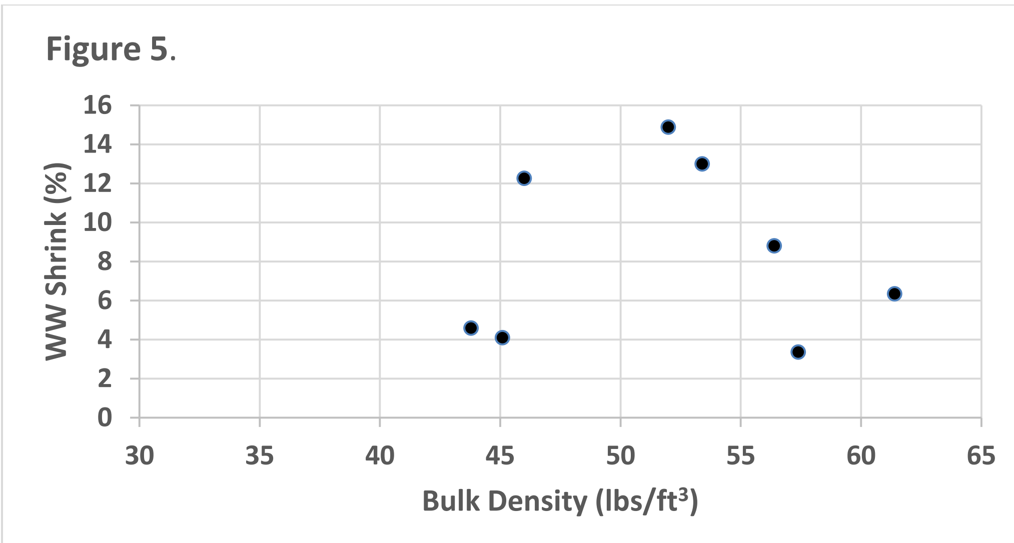
Third Question: Factors Impacting Silage 'Shrink' Losses

As already discussed, there are numerous factors which could impact total shrink losses from corn silage piles. In fact many of these factors can be controlled (i.e., they are chosen) by the operator, at least to some degree. For example, pile orientation (S, N, E, W) and its base (dirt or concrete), use of a thin underlay film with or without enhanced oxygen barrier characteristics, chop length of the crop, use rate (i.e., inches/day) of the pile and face management can be virtually fully controlled. However factors such as the moisture level of the crop, pack density and environmental conditions during feedout can only be partially controlled (or anticipated) by the operator.

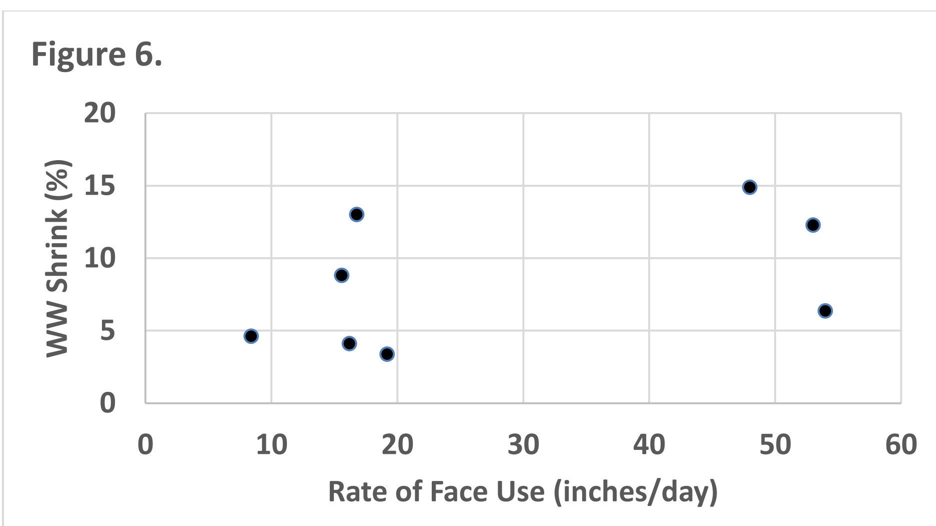
With only 8 silage piles, where each pile differed from all other piles in many ways, while being the same in many ways, it is difficult to assess the efficacy of individual mitigations. For example as all piles had an oxygen barrier underlay, were harvested and packed by professional crews, were rapidly covered (within 48 h) with an inner oxygen barrier film and black/white outer plastic, were weighted with tire chains, and were opened and fed out by professional crews, none of these ensiling practices can be evaluated. However some practices can, although the data requires care in interpretation.

The relationships (below) are shown as WW shrink since they are quantitatively higher than oDW and vcoDW shrink and thus more likely to show impacts of practices/mitigations.

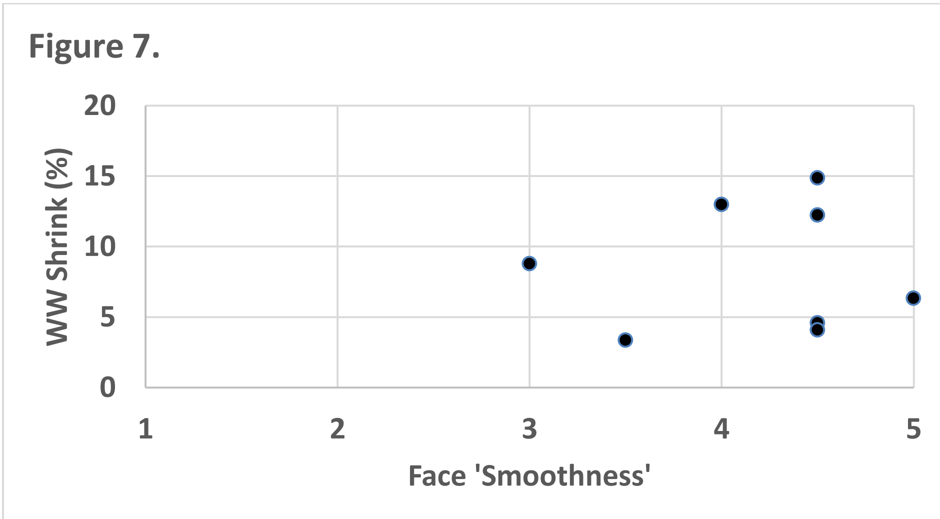
Shrink Losses and Silage Density. This is an area of interest to regulatory agencies as it seems intuitive that losses of silage weight would be reduced if the silage was packed more densely. However in our corn silage piles there was no apparent relationship of bulk density and WW shrink (Figure 5).



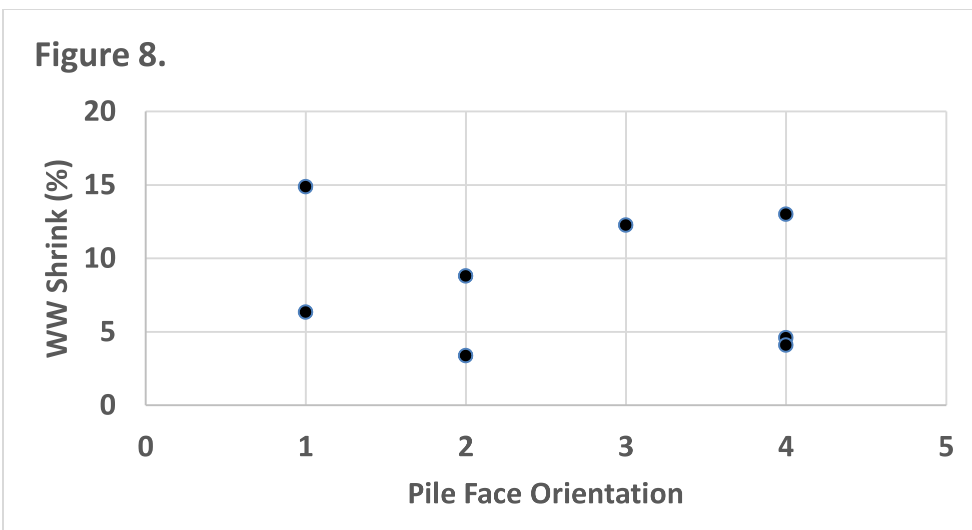
Shrink Losses and Speed of Face Use. This is also an area of interest from regulatory agencies as it also seems intuitive that losses of silage weight would be reduced if the silage was fed out more quickly. However in our piles there was no apparent relationship between the speed of feedout and WW shrink (Figure 6), possibly because face losses were very low overall.



Shrink Losses and 'Smoothness' of the Face. This is also an area of interest to regulatory agencies as it seems sensible that losses of silage would be reduced if the silage face was left 'smooth' at the end of the day. To assess this possibility, faces were scored subjectively on a scale of 1 (really rough) to 5 (really smooth). In our piles, there was no relationship of face 'smoothness' and WW shrink (Figure 7).

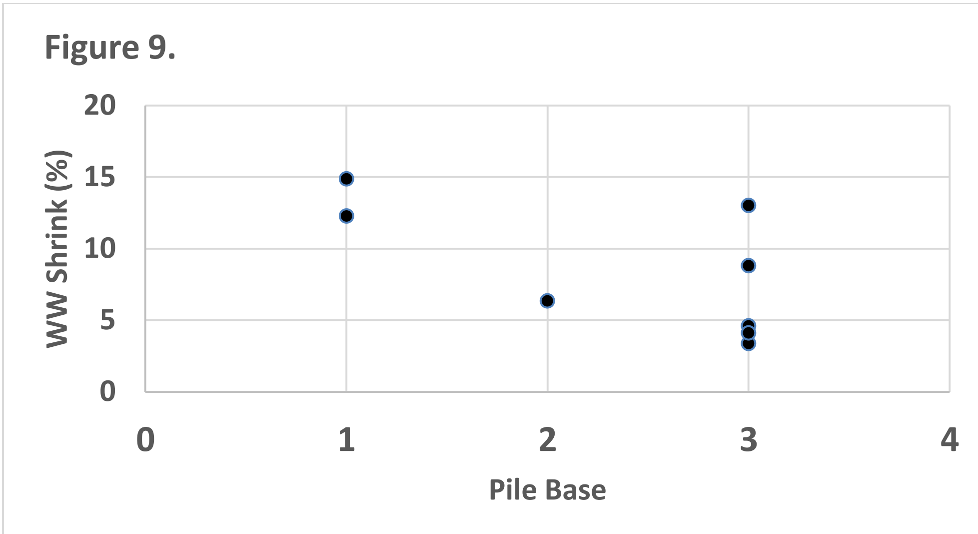


Shrink Losses and Face Orientation. This is a practice which could, at least theoretically, be changed on-farm – certainly on the long term. However in our piles there was no relationship of pile face orientation and WW shrink (Figure 8; *1=W, 2=E, 3=S, 4=N*).

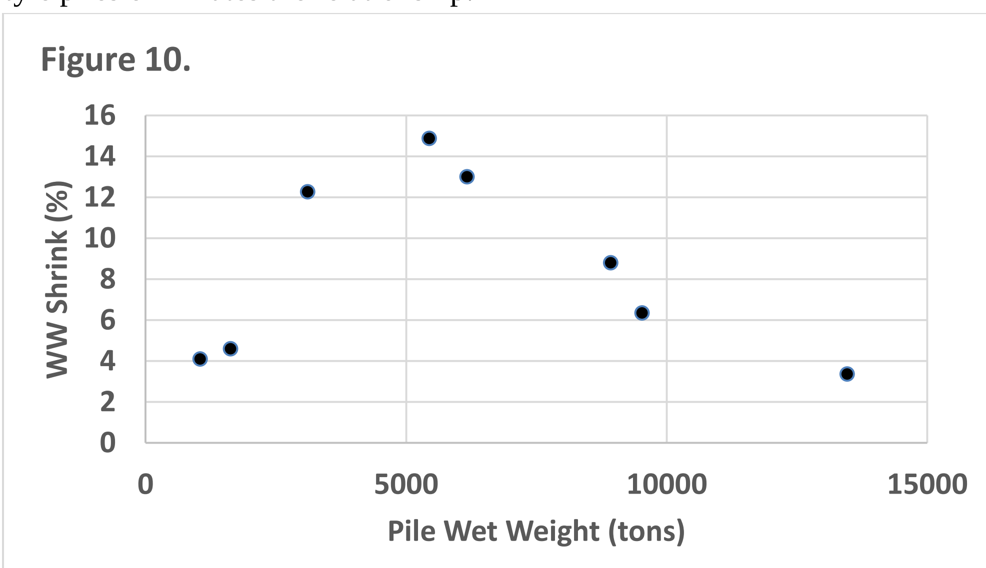


Shrink Losses and Pile base, and Style of Pile. Pile base (i.e., concrete *vs.* dirt) is a practice which could, also theoretically, be changed on-farm, and it seems sensible that a concrete base would reduce leaching losses. In our piles there seemed to be a relationship of pile base and WW shrink

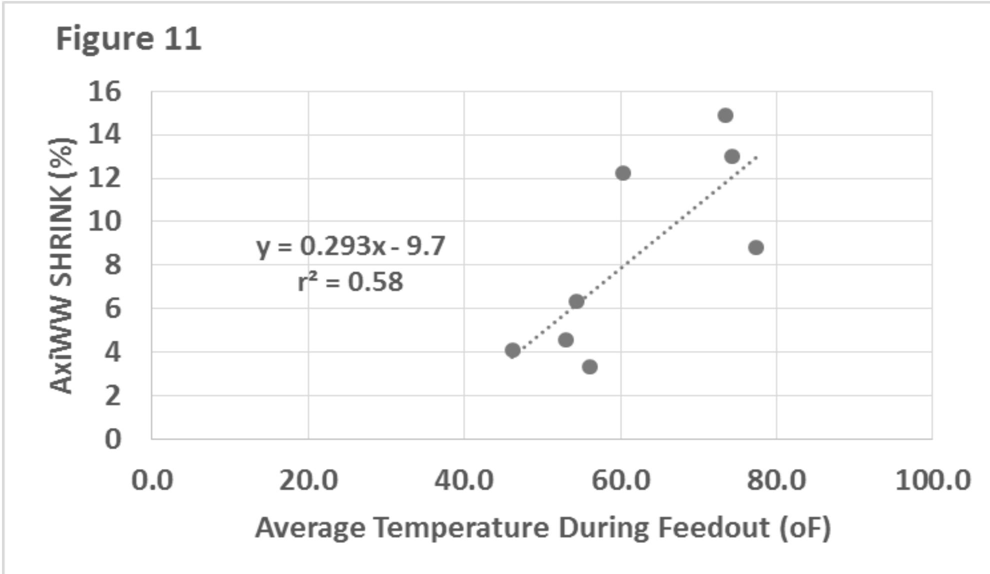
(Figure 9; 1=Dirt, 2=50/50, 3=Concrete). However this interpretation is muddled since both of the dirt base piles were rollover piles and the 50/50 base was a pit with a concrete bottom and dirt sides.



Shrink Losses and Pile Size. Pile size is also a practice which could be changed on-farm. In our piles there was a clear curvilinear relationship of pile size and WW shrink (Figure 10). However this interpretation is also muddled since both of the rollover piles were of intermediate size. Using only the wedge style piles eliminates the relationship.



Shrink Losses and Ambient Temperature at Feedout. Environmental conditions during feedout are certainly not conditions within the control of producers, but it is clear that higher temperatures during feedout did increase shrink losses (Figure 11). Finally something which seems sensible which actually occurred!



Shrink Losses and Chemical Composition of the Fresh Chop Corn Crop. The fresh chop was analyzed for its moisture content (i.e., oDM) as well as the level of neutral and acid detergent fiber, ash, fat and crude protein in the oDM. There were no meaningful relationships (i.e., r^2 <0.15) of these components to WW shrink.

The failure to identify mitigations or practices associated with reduced silage shrink is discouraging as it could be interpreted to suggest that silage shrink is random. This is unlikely to be the case. The more likely explanation is that with only 8 piles, albeit representing an amount of effort that the senior author does not ever wish to expend again on a single project, it is still a very very small data set to examine practices associated with reduced shrink, especially when the number of defined practices that differed among piles, and might be expected to impact shrink losses, is more than the number of piles examined. Obviously the possibility of inter-correlations is high, which could lead to concluding that a mitigation is efficacious when it is not, but is related to a mitigation that is effective.

However another reason for the failure to identify practices that reduce silage shrink may simply be a combination of the variability in the methods which were deployed to examine shrink in large commercial silage piles combined with the relatively small values for shrink, especially vcoDM shrink, compared to expectations at the start of the study. With total shrink in the 3 to 8% range it would likely have required at least 30 piles to create meaningful relationships of silage shrink and practices/mitigations that may have impacted it. There are clearly limits to what can be done in a study such as this one where the piles, albeit carefully selected to be representative and well managed, exhibit a host of differences in factors that may impact silage shrink and, perhaps critically, very low levels of shrink no matter how shrink is expressed.

Conclusions

The extent of silage shrink has been greatly overestimated in large well managed commercial corn silage piles, likely due to incorrect assumptions and inappropriate research models to measure it. However the most important reason may have been due to the failure to measure real shrink (i.e., vcoDM) in favor of WW shrink which is exaggerated due to losses of water, or oDM shrink which classes volatile compounds which are actually in the silage, but lost during oven drying, as being a part of shrink. When the correct measure of silage shrink is used (i.e., vcoDM), total shrink averaged less than 3% in our commercial corn silage piles. Within the context of these low vcoDM losses overall, losses from the face and after defacing were trivial contributors to shrink in contrast to losses while the silage was in the mass prior to face exposure and from unmeasured losses such as weepage, seepage and material which fell off trucks and loaders. While the number of silage piles that we used were too small (relative to the number of definable differences between them) to allow examination of many practices commonly used to minimize shrink (and because many piles had similar characteristics by design), the commonly suggested mitigations of increasing bulk density, increasing face feedout rate and maintaining a 'smooth' face had no discernable impact on total shrink losses, probably because these mitigations are all designed to reduce losses from the exposed face which was a trivial contributor to overall shrink. Only the average ambient temperature during feedout impacted shrink, with warmer temperatures during feedout being associated with higher shrink, but mainly for WW.

While corn silage shrink exists, and can be costly to dairy producers and impactful to air and water quality, the extent of shrink in large well managed corn silage piles is low and the ability to mitigate shrink seems, unfortunately, to be very low due to our inability to find support for several commonly accepted mitigations. However dairy producers should continue to use good silage practices (i.e., common sense) in creating corn silage piles, but recognize that silage shrink is likely only to become excessive under extreme conditions.

Acknowledgements

This project has been a ton or work and would not have been possible without the inputs of time and effort of Trish Price, Grace Cun and Henco Leicester, as well as the four co-operating dairy owners who prefer to remain in the shadows. Thanks guys – you know who you are! Finally, the cooperation and assistance of the silage packing/covering and feeding crews made this project a success. This research was funded in part by grant Agreement 13-0099 SA from the California Department of Food and Agriculture.

* * * *

P.H. Robinson is a Cooperative Extension Specialist responsible for dairy cattle nutrition and nutritional management. He can be reached by phone at (530)754-7565, by fax at (530)752-0172, or by e-mail at phrobinson@ucdavis.edu

Update on Corn Shredlage for Dairy Cows

Lauryn Vanderwerff, Luiz Ferraretto, Gustavo Salvati and Randy Shaver
Department of Dairy Science
University of Wisconsin – Madison
University of Wisconsin – Extension

Introduction

There continues to be a lot of interest in corn silage harvested with a self-propelled forage harvester (**SPFH**) equipped with an aftermarket processor with cross-grooved processing rolls set for 2- to 3-mm roll gap and greater roll speed differential than has typically been used (32% versus 21%). Also, the developer of this processor recommends that the SPFH be set for a longer theoretical length of cut (**TLOC;** 26 to 30 mm) than has typically been used in the past (19 mm TLOC).

This silage has been called corn shredlage by the developer of the new processor (Shredlage®, LLC; http://www.shredlage.com/). Thus far this processor has just been adapted for Claas SPFH, although shredder roll kits have been made available for the other makes of SPFH. During the 2014 harvest approximately 600 shredlage processors and shredder roll kits were in operation according to the developer of the shredlage processor.

We recently completed a second controlled feeding experiment with corn shredlage at the University of Wisconsin - Madison dairy farm in Arlington, Wisconsin. We also recently completed on an on-farm survey of dairy farms about their corn silage harvest, processing and feeding practices, and collected corn silage samples during feed-out for determination of processing score and particle length. The purpose of this article is to provide an update on corn shredlage based on the results from the feeding experiment and the on-farm survey.

Feeding Trial Results

For a detailed summary of our first feeding trial refer to Ferraretto and Shaver (2012). In that study we used a conventional corn silage hybrid harvested as either corn shredlage (30-mm TLOC) or conventional-processed (19-mm TLOC) corn silage. Key findings were as follows:

- The percentage on the top screen of the Penn State shaker box was greater for corn shredlage (32% versus 6% as-fed particles retained on the top screen of the shaker box) and for the TMR which contained corn shredlage (16% versus 4% as-fed particles retained on the top screen of the shaker box); we observed no sorting of either TMR when fed.
- Fat- and energy-corrected milk tended to be 2.3 lb/day per cow greater on average across the treatment period for cows fed the corn shredlage treatment, while feed efficiency and milk composition were unaffected by treatment.

- Corn silage processing score or the percentage of starch passing through a 4.75-mm sieve was greater for corn shredlage (75% versus 60%) and total tract starch and neutral detergent fiber (**NDF**) digestibility were greater for cows fed the corn shredlage treatment.

In the second feeding trial, we evaluated: 1) the response to corn shredlage in a brown midrib (**BMR**) corn silage hybrid, and 2) whether the greater TLOC setting on the SPFH for the harvest of corn shredlage increased the physically-effective fiber (**peNDF**) content of the silage (Vanderwerff et al., 2014).

A Mycogen® BMR corn silage hybrid (F2F627) was harvested in September 2013 with a Claas 940 SPFH equipped with either a Claas conventional processor or a Shredlage® processor on the same day at ½ kernel milkline stage of maturity. The conventional processor was set for a 2-mm roll gap and 40% roll speed differential with the SPFH set for a 19-mm TLOC for harvest of the conventional-processed corn silage (**KP**). Harvest of the corn shredlage (**SHRD**) was done with the Shredlage® processor set at a 2-mm roll gap and 32% roll speed differential with the SPFH set for a 26-mm TLOC. The KP and SHRD were stored in separate silo bags until the bags were opened to begin the feeding trial in January, 2014.

Mid lactation Holstein cows were used in a 16-week continuous-lactation experiment in our university dairy herd with 15 replicated pens of 8 cows each. The respective treatment TMR contained 45% (DM basis) from either SHRD or KP. Both TMR treatments contained 10% alfalfa silage and 45% (DM basis) of the same concentrate mix comprised of dry ground shelled corn, corn gluten feed, solvent and expeller soybean meal, rumen-inert fat, minerals, vitamins, and monensin. Additionally, a third treatment TMR (**KPH**) was included in the experiment to focus on the peNDF question. This ration was formulated with 35% KP, 10% alfalfa silage, 10% chopped hay, and 45% (DM basis) of the same concentrate ingredients adjusted in proportions in the mix to balance dietary crude protein and starch concentrations across the three treatments.

The SHRD and KP were similar in average dry matter (**DM**; 39%) content and pH (3.9). Corn silage processing scores on feed-out samples averaged 72% for SHRD and 68% for KP with less variation observed for SHRD over the duration of the experiment. The sample range (difference between maximum and minimum samples) was 10%-units for SHRD and 21%-units for KP. For SHRD, all processing scores were above 65%. However, for KP 43% of the samples obtained on a weekly basis throughout the feeding trial were at or below a processing score of 65% (refer to Figure 1).

The proportion of coarse stover particles was greater for SHRD than KP for samples collected during feed-out from the silo bags throughout the feeding trial (18% versus 7% as-fed particles retained on the top screen of the shaker box). For the TMR fed throughout the trial, the proportion of as-fed particles on the top screen of the shaker box was greater for SHRD than KP or KPH. Our measurements of weigh-backs during the trial indicated minimal sorting and no differences in sorting among the three treatments.

Averaged over the treatment period, milk yield was 2.5 lb/day per cow greater for SHRD than KP with the SHRD cows averaging 113 lb/day; feed efficiency was similar for the two treatments. Milk yield was 5.9 lb/day per cow lower and feed efficiency was reduced for KPH compared to KP. Milk yield by week on treatment is summarized in Figure 2.

Milk fat content was greater for KPH (3.7%) than KP or SHRD (3.3%). Rumination activity measured using the SCR rumination collars averaged 8.4 hours per day and was not different among the treatments. Using milk fat content and rumination activity data to assess peNDF suggests that the peNDF content of SHRD was not improved despite its longer TLOC and increased percentage of as-fed particles on the top screen of the shaker box compared to KP. Milk fat yield was not statistically different among the treatments, but was numerically greatest for KPH and lowest for KP. Similar to the milk yield differences, milk protein and lactose yields were greatest for SHRD and lowest for KPH. Body condition score (3.1 on average) and body-weight change (1.2 lb/day per cow on average) were similar among the three treatments.

Total-tract DM and organic matter (**OM**) digestibility were greater for cows fed KP and SHRD than for cows fed KPH. Total-tract NDF digestibility (**TTNDFD**) tended to be greatest for KPH and lowest for SHRD. Lower TTNDFD for SHRD may be related to increased dietary starch content for SHRD compared to KPH and increased kernel processing and ruminal starch digestibility for SHRD compared to KP and KPH. The ruminal in situ starch digestibility was greater for SHRD than KP corn silage (88.3 vs. 76.0%, respectively). Total-tract starch digestibility was greater for SHRD than KP. Differences in total-tract starch digestibility between SHRD and KP were, however, biologically small (0.5%-units) and starch digestibility was near 100% for all treatments. Small differences in total-tract starch digestibility along with much larger differences ruminally may be explained by post-ruminal compensatory digestion of starch. Nearly complete digestion of starch in the total-tract may be explained by the nearly 6 month lag between ensiling and the midpoint of the feeding trial, since length of the ensiling period has been shown to increase starch digestibility in corn silage.

In summary, the lactation performance response to corn shredlage using a BMR corn hybrid was of similar magnitude to the response observed in our earlier trial with a conventional corn hybrid. Despite a longer TLOC setting on the SPFH and increased particle size for corn shredlage relative to conventional-processed corn silage, milk fat content and rumination activity were not increased. Evaluate particle size and processing score of corn shredlage to determine the best ration formulation strategies.

Farm Survey Results

Seventy-six corn silage samples were obtained from 69 dairy farms during farm visits April to August 2014. Farms were located in Illinois (n = 1), Minnesota (n = 15) and Wisconsin (n = 53). Detailed results are presented by Salvati et al. (2014). Most farms (61%) harvested corn silage using a Claas SPFH equipped with a Shredlage® processor. Bunkers (95%) and inoculants (87%) were used by most farms. Corn hybrids were solely dual-purpose type for 43% of the farms. Most farmers reported a 22-26 mm TLOC (79%) and a 1.5-2.5 mm roll gap (82%).

Although the percentage retained on the top or coarsest Penn State Separator (**PSS**) sieve was 7%-units greater for shredlage than the other defined sample categories on average, the percentage retained on top 2 PSU sieves and the Wisconsin Separator (**WIS**) mean particle length (**MPL**) were similar. This suggests that there may not have been much improvement in peNDF for the shredlage samples compared to the other samples collected in this survey. The average percentage retained on the top PSS sieve for shredlage was substantially lower than that reported by Ferraretto and Shaver (2012) from their feeding trial (20% versus 32%). It should be noted that the TLOC setting on the SPFH was 30 mm in the study of Ferraretto and Shaver (2012), while the TLOC was usually 22-26 mm for the shredlage samples in this survey. The ranges for PSS top sieve, PSS top 2 sieves, and WIS MPL in the shredlage samples were 32%-units, 21%-units, 6 mm, respectively.

All sample types fell in the adequately-processed category based on processing score. The processing score was only 2%-units greater for shredlage than the other sample categories on average. This was achieved, however, coincident with the greatest percentage fibrous-particle retention on the top sieve of the PSS for shredlage. The range for processing score in shredlage was 33%-units, and both the greatest and lowest processing scores were observed within the shredlage samples.

Feeding experience with new-type corn silage was limited with only 20% of respondents using for over 12 months. Only 22% of respondents increased the total forage content of their diets, while 47% increased the corn silage content of their diets which indicates a greater proportion of corn silage in the total forage DM. With regard to the inclusion of hay or straw in the TMR, 54% of respondents still did so and only 40% of those had reduced the amount fed.

In summary, the physical form and DM results indicate considerable opportunity to improve corn silage quality by reducing variation through better process control during harvest for shredlage and non-shredlage type samples. It appears that major changes in feeding programs were not made coincident with the use of new-type corn silages. Because this survey was a single snap-shot in time and most farmers still had very limited experience harvesting and feeding new-type corn silage, a follow-up survey is warranted.

References

Ferraretto, L. F., and R. D. Shaver. 2012. Effect of Corn Shredlage on lactation performance and total tract starch digestibility by dairy cows. The Prof. Animal Scientist. 28:639-647.

Salvati, G., R. Shaver , M. Lippert, E. Ronk, and Chris Wacek-Driver. 2014. Corn silage processing: Dairy farm survey. Accessed Dec. 10, 2014.
http://www.uwex.edu/ces/dairynutrition/documents/cornsilageprocessingsurveysummaryreport.pdf

Vanderwerff, L.M., L.F. Ferraretto, and R.D. Shaver. 2014. Impact of brown midrib Corn Shredlage® on lactation performance by dairy cows. Selected for late-breaking abstract presentation at ADSA/ASAS Annual Meeting. Kansas City, MO. J. Dairy Sci. 97(E-Suppl. 1).

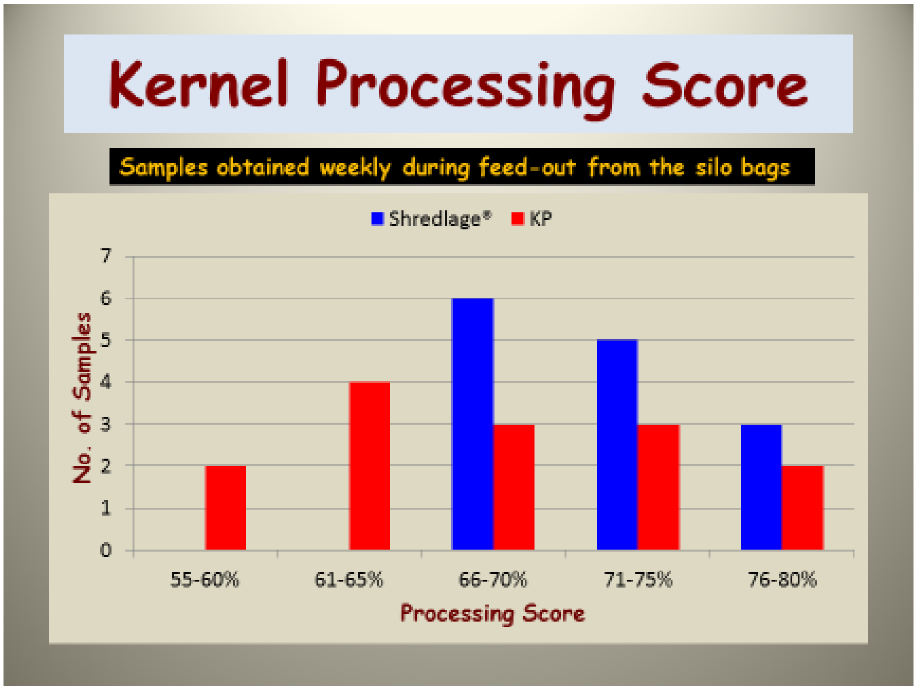


Figure 1. Frequency distribution for corn silage processing score on samples of brown midrib corn shredlage (SHRD) and conventional-processed corn silage (KP).

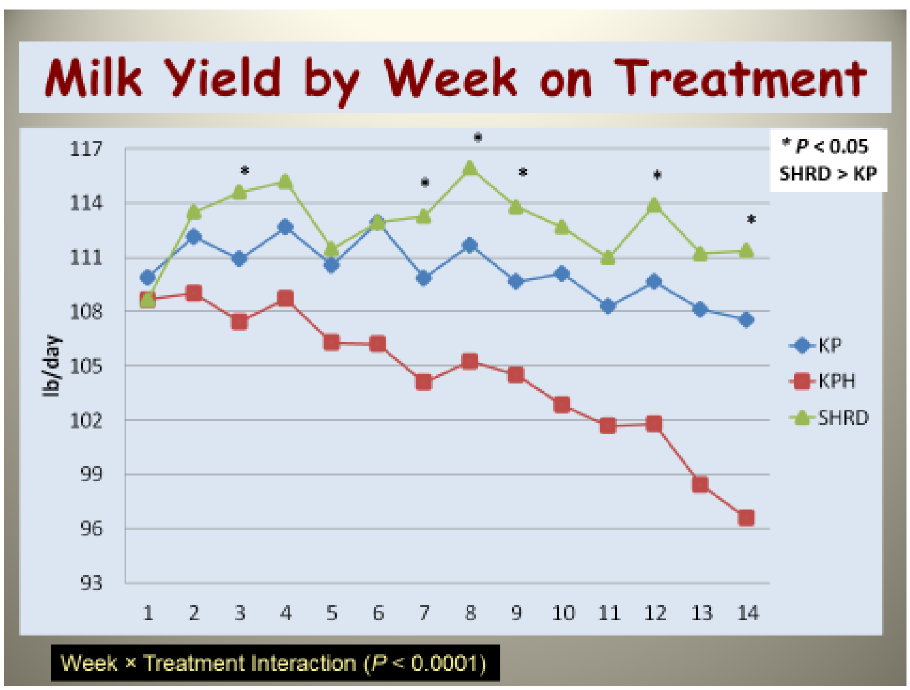


Figure 2. Milk yield by week on treatment for total mixed rations containing brown midrib corn shredlage (SHRD), brown midrib conventional-processed corn silage (KP), and brown midrib conventional-processed corn silage plus hay (KPH).

Notes:

The Dairy Dozen: 12 Key Financial Indicators

Gary Sipiorski
Dairy development manager
Vita Plus, Corporation
Madison, Wisconsin

Most schools still hand out report cards. Every other business measures itself with ratios. The dairy business should not be any different.

More than any article that I have written for Hoard's Dairyman over the years, the article "The Dairy Dozen: 12 key financial indicators" keeps generating producer comments. Producers tell me they have the article hanging in their office over their computer station, on the top page of their financial books and in many other easy-to-see places.

There are a lot of financial ratios and calculations that producers, accountant and lenders use. However, the principle behind the Dairy Dozen is this: I focus on only 12. There are others that are important, but if you get these right, most of the others will fall into place.

1. Income per cow — $5,000 target

The number one cause of business failure is the lack of sales. Milk is 85 percent of the income on most dairy operations. Obviously, this number will be directly related to the milk price. Based on current related expenses, this number must be greater than your expenses. The income per cow calculation is pretty straight forward. Milk sales, cull cow, calf and breeding stock sales, government programs and patronage refunds all equal gross income. Divide the gross income by the average number of cows that were on the dairy for the year.

2. Operation cost as a percentage of gross income — 80 percent

Can you believe in 1980 the operating cost on a dairy farm was 50 percent! That means a dairy producer could do whatever he or she wanted with the other 50 percent. A quick way to get this number is to use the Schedule F from your tax return. Make sure that you add in the cost of family living. Then divide this number by the gross income. If you prepaid expenses for the next year, back those out; if you have unpaid expenses that you carried over to the next year, add those back in. It is better to use your farm-generated income and expense report. The tax return is the second best way to get your expense numbers. If you want to find out your true "cash" cost of production, add up all of your cash expenses as described above, then add in your principal and subtract out the depreciation. That is what really comes out of the checkbook.

3. Milk sold per cow — 24,000 (Holsteins, make a breed adjustment for others)

Every dairy producer breeds with better bulls, tries to feed better feed and tries to improve cow comfort. This keeps raising the pounds of milk sold each year. A higher debt load can be offset by more hundredweights of milk being sold.

4. Ownership equity — 50 percent

Ownership equity is the percentage of the dairy that you own. To determine this ratio, divide the net worth by the total assets. These figures are found on your balance sheet. For many operations, as sole proprietors, this will be on your personal balance sheet. If the business is a corporation, LLC or partnership, this will be found on a separate balance sheet.
In this capital-intense business, 30 percent equity will work but loans must be structured to make sure that there is a comfortable cash flow. Lenders will find it hard to say yes to a borrower with less than 30 percent equity.

5. Current Equity — $2 for each $1 of current liabilities

It shows your ability to pay your bills. It says that you need $2 of current assets for every $1 of current liabilities. Current assets are cash, feed, prepaid expenses and any item that is cash or will be turned into cash in the next 12 months. Current liabilities are bills over 30 days such as bills for feed, veterinary, cropping expenses, real estate taxes that are postponed, and principal payments and any lease payments due in the next 12 months. To calculate, divide the current assets by the current liabilities.

6. Cost of producing 100 pounds of milk — $17.50

There has never been a more important time to know this number. Not to oversimplify the calculation, but if you add up your Schedule F expenses with a reasonable depreciation; add in payables, subtract out prepaid expenses; add in your family living and income taxes; subtract out cull cows, calf sales and government payments; and divide that number by the number of hundredweights of milk that you sold last year, you will come up with a reasonable cost of producing 100 pounds of milk. This number will be directly affected by a producer’s land base. Cost of growing feed presently is less expensive than buying all of your feed needs.

7. Feed cost — 20 to 45 percent of gross income

This was a wild one in 2012. The calculation is completed by dividing the purchased feed on Schedule F by the gross income. Remember to also add back in any feed payables; those were expenses to feed the cows. Growing and buying quality forage has never been more important. There is a huge range in this number, depending on your operation.

If you grow all of your feed, your cost should be at the lower end of the scale but you will have extra cost in cropping, fuel and land. If you are purchasing all of your feed, you will be at the upper range of the scale with no cost in cropping.

8. Livestock expenses — 4 percent

This is a small percentage item, but it is an indicator of possible problems. Metabolic problems before or after calving can push this number up. As do breeding problems which suggest that there will be a drop in milk flow in the future. If used, rBST costs need to be placed in the supply expenses area so the livestock expenses are properly shown. To calculate, add the breeding and veterinarian expenses and then divide that number by the gross income.

9. Debt per cow — $5,000

The inflation values of the major capital investments that touch a dairy operation have driven this number higher. Loan structure is very important in this area to have a comfortable cash flow. Some dairies will choke on $1,000 debt per cow. Others can handle more. Another way to look at this is to have no more than $20 of debt per 100 pounds of milk produced. This does take into consideration the production level to the amount of debt that the cash flow should be able to handle.

10. Debt coverage — no more than 20 percent of gross income for payments

There are a couple of ways to look at how many dollars should be set aside for interest and principal payments. Ideally, not more than 15 percent of the gross income should go toward interest and principal payments. This number can be pushed to 20 percent in times of need. Beyond 20 percent makes making payments very difficult.

Divide the loan payments by the gross income. Another measuring stick is to make sure after all cash expenses, including family living, that there is at least $1.25 left to pay $1 of payments. These ratios must be followed.

11. Asset turnover — 2.5 times

An example here is if you have $1 million invested in your dairy and you generate $400,000 in gross income, you turned those assets in 2.5 years. Most of agriculture takes 3.5 years to turn their assets. That is too long.

This is a key calculation to do when you consider investing in more assets. Make sure you are investing in assets that generate money. Every $1 of a new capital expense should generate 70 cents of gross income each year thereafter.

12. Total investment per cow — $7,500 to $15,000

Divide the total dollars in assets by the number of cows. This number is closely related to asset turnover. Dairies with a limited land base will carry $7,500 of investment per cow. Dairies with large land bases will run up to $15,000 and beyond. Higher land, cow and building values have driven this up over the last 10 years.

One of the owner's jobs today is to get the best return with the least investment per cow. If you have other enterprises on your farm such as the sales of grain, this number will be distorted due to additional investments. I am addressing the farm's milk operation only in my calculations.
Reprinted with permission of Hoard's Dairyman, April 10, 2013.

Targeted Feeding to Save Nutrients

Charles J. Sniffen, Ph.D.
Fencrest, LLC
fencrest@msn.com

William Chalupa, Ph.D.
University of Pennsylvania
wmchalupa@aol.com

Introduction

There is increasing pressure at federal, state and local levels about nutrient waste and pollution relative to N, P, CH_4 and CO_2 discharges from the animal industry. Large animal operations have come under more intense scrutiny than small animal operations, with CAFO regulations being put in place.

This has put increasing pressure on producers and us as nutritionists to provide some of the solutions to the problem. There has been considerable research conducted in the last decade in this area; the focus of this paper will be to examine what can be done in the formulation of rations to save nutrients and as a result to increase efficiency, profitability and sustainability for the producer.

Farm Nutrition Management

As nutritionists, we assess farms as to animal grouping, degree of over stocking, management of the groups and the environment surrounding each group. We then look at the quality of the forages being offered and most importantly the variability of the quality of the forages and other on farm feeds. We then make decisions as to how much safety we need to build into the rations being developed; basically the more variability in the management and the feeds the higher are the safety factors that are built into a ration resulting in a lower efficiency and a greater loss of nutrients. There are several approaches that can be taken to increase efficiency; the first is to have more groups; when we have few replacement groups and few lactating groups, by definition we will need to overfeed some of the animals within that group as well as underfeeding other animals within that group. We will, in developing rations, not feed for the average cow in the group but for the top 20 to 30% of the animals in the group, which will result in inefficiencies. Having multiple groups for many dairies is not possible and so we will need to develop strategies to improve efficiencies within these constraints as well.

There is also an opportunity to increase the efficiency of nutrient use with the use of robotic systems which will allow the ability to target the requirements of the cow more closely; this might mean the development of more than one parlor mix to more properly target each cow's requirements.

Nutrition Advancements

Saving nutrients has been the focus of many studies in recent years; admittedly not always from an environmental viewpoint but to increase efficiency and to reduce costs in feeding the cows. We have fed cows based on the Weende feed analyses system since the late 1800's; this was a significant advance at the time that was so powerful that it has continued to this day!! We still use CP, EE, ash, and calculated NFC routinely in our evaluations of rations. Crude fiber is still being used in parts of the industry. A significant change was made with the change from crude fiber to initially ADF and then NDF and with the latest models aNDFom. We then incorporated the measurement of lignin. With the use of NDF, this resulted in a reduction in the calculated NFC. As we know, N has been a big issue in the environment resulting in many regulations. The fact is we, in the dairy industry, have been overfeeding N for a long time; our standard for many years has been to have a ration for high producing cows with 17 to 18 % CP. We used to be concerned when the MUN went below 14 to 15 or when it went above 18 mg/dl. We now know that we can feed rations for high groups in the 14 to 15 %CP range; This started with the work of Broderick (Colmenero & Broderick, 2006) who did some classic work many years ago showing that milk production could be maintained with a lower CP and further that MUN's and more importantly that there was significantly less wasted N being excreted as urinary N.

Nitrogen intake and excretion from rations varying in CP levels

Ration CP,%	**13.5**	**15**	**16.5**	**17.9**	**19.4**
N intake, g/day	483	531	605	641	711
Milk N, g/day	173	180	185	177	180
Total manure N, g/day	309	316	376	410	467
Fecal N, g/day	196	176	186	197	210
Urinary N, g/day	113	140	180	213	257
Urinary N, % of manure N	36.5	44.3	47.8	52	55
Milk N, % of N intake	36.5	34	30.8	27.5	25.4

Source: Olmos Colmenero and Broderick, J. Dairy Sci. 89:1704, 2006

There have been many other studies since then that corroborated this work. The models used at the time were the early NRC models to formulate these rations. With the initial release of the CNCPS system and NRC 2001, there was a significant step forward in our understanding of N utilization by the cow.

With the release of the latest versions of CNCPS there have been the developments of several platforms incorporating this model. Additionally there are available other platforms based on either CNCPS or NRC. We will use only a two platforms to demonstrate the opportunities to formulate rations to increase efficiency.

Below is an example from NDS of the different things we need to think about monitoring going forward.

Fecal excretion and wet manure				Fecal composition					
	Total lbs	N g	P g		%		%		%
Dry Feces	20.50			Total CHO	57.72	NDF/NDF diet	54.64	Protein	17.42
Wet Feces	121.61	259.20	50.13	Starch	2.67	pdNDF/pdNDF diet	43.79	Lipid	8.67
Urine	48.48	185.62	1.26	Soluble fiber	0.42	Starch/Starch diet	3.68	Ash	16.19
Wet manure	170.09	444.82	51.39	NDF	54.21				
Intake		679.25	90.15	uNDF (240)	19.15				
Productive		234.43	38.76	Lignin	7.98				

Productive N/Total N	34.51 %	Productive P/Total P	43.00 %	CH4 (Mcal)	6.50
Productive N/Urinary N	1.26:1	Manure P/Total P	57.00 %	CH4 (liters/day)	711.09
Manure N/Total N	65.49 %			CH4 (g/day)	509.72
NH3 Potential (g)	120.65			CH4 (g/lbs milk)	5.10
				CO2 (lbs/day)	34.41
				CO2 (lbs/lbs milk)	0.34

The focus is on N and P excretion and CH_4 & CO_2 emissions. We need to become comfortable with monitoring N not only the excretion of N but also the NH_3 potential.

Our challenge is to formulate rations to reduce excess N & P excretion as well as to control CH_4, CO_2 & NH_3 and nitrous oxide (N_2O). The use of the new technologies in the NRC & CNCPS models allows us to make a step forward in achieving a reduction in excess nutrients and emissions. The above figure does not address N_2O but does the others. For N the correlation between excess N intake, N in urine and the MUN are highly correlated. We do not measure the N excreted in the urine or the manure routinely but we all monitor MUN's now. We use to accept MUN's in the 14 to 16 mg/dl area but now we routinely expect to achieve MUN's below 10 mg/dl. Below is an example from AMTS for predicted MUN.

Diet CP	15.33 %DM
RDP	56.58 %CP
RDP	8.67 %DM
Soluble Protein	37.97 %CP
Predicted MUN	10.8 mg/dl

Reports now provide information like above; if using CPM (recently the UPENN Model), Dalex, NDS or AMTS, they all have predictions; with the predictions in Dalex, NDS & AMTS being a little more accurate when using the 6.1 or 6.5 models.

Ration Formulation

Ration formulation starts with a critical evaluation of the groups that are to be fed a ration. This starts with an evaluation of first the mature frame size weight and then the weighted average weight of the cows in the group that are being fed; this is very important in the CNCPS based models, because it impacts not only animal requirements but the prediction of the rate of passage and CHO & protein digestibility. Next we want to define things like the days in milk, the amount of milk and the milk components; milk and milk components is a two-step process; first we need to be in the evaluation mode to determine if the model predicts the current milk and components accurately and if the model is predicting within a few lbs. we can then formulate for the milk and components desired. Additional information is important as well; we need to know about the environment that surrounds the group we are feeding – temperature, humidity, air flow, degree of overcrowding, bunk space and water space, to name a few. With this information we can more accurately assess the performance and to formulate a ration more accurately. We will be using the CNCPS model using AMTS 6.1(AMTS 6.5 will be released in the first quarter 2015) and NDS 6.5 for the demonstration of the concepts in targeted ration formulation.

In order to achieve a high efficiency of N utilization there needs to first be a balance of not exceeding the rumen NH3 and peptide requirements. This is many times difficult to achieve when one is locked into an on farm inventory of feeds that need to be fed out at certain rates. In the long term, working with the nutritionist and agronomist the forages in the rations can be planned to reduce N & P excesses.

Feed	lbs/day (DM)	lbs/day (AF)	%DM
Alfalfa Hay 20 CP 37 NDF 17 LNDF	11.4	12.7	18.848
Corn Silage Processed 35 DM 45 NDF Coarse	18.0	51.4	29.758
Wheat Silage 12 CP 58 NDF 10 LNDF	2.4	7.3	3.968
Corn Grain Ground Fine-fencrest	5.775	6.563	9.547
Corn Grain Flaked 28 lb	7.864	9.145	13.000
Soybean Hulls Ground	2.257	2.480	3.731
Citrus Pulp Dry-fencrest	4.192	4.732	6.930
Almond Hulls 33 NDF	2.240	2.575	3.703
Megalac-fencrest	0.380	0.392	0.628
Urea 281 CP-fencrest	0.225	0.227	0.372
Soybean Meal 475 Solvent	2.100	2.333	3.471
Soy Plus-AMTS	2.700	3.030	4.463
Blood Meal Average	0.000	0.000	0.000
AJIPRO_L-AMTS	0.210	0.219	0.347
Smartamine M-AMTS	0.050	0.051	0.083
Min Vit Premix	0.6954	0.6999	1.150
Total	60.4931	103.8217	100.000

Above is a ration in AMTS 6.1 with a mixture of ingredients that might be used in the Western part of the US. It will be noted that urea and a fat source are put into the ration for consideration when the ration is optimized; again the forages are on farm forages and there may be minimum and/or maximum constraints placed on these forages due to inventory considerations. Note also that blood meal was a consideration but when the ration was optimized it was not used; this of course can change depending on prices.

Below are the results of the optimized ration in AMTS 6.1. For those used to using CPM this is the familiar default screen.

DMI (lbs/day)	60.49	Model	55.74	% Model	108.54
ME Bal (Mcal)	1.6	CP (%)	15.4	NDF (%)	31.2
MP Bal (g)	13.9	RUP (%CP)	43.4	Forage NDF (%NDF)	72.6
NP/MP (%)	67.0	LCFA (%)	3.1	Forage NDF (%DM)	22.7
Bact. MP (%MP)	51.76	EE (%)	4.0	peNDF (%)	23.1
				Lignin (%DM)	3.4
				Lignin (%NDF)	11.3
Rumen N Balance				NFC (%)	44.1
Pept (g)	101	Pept & NH3 (g)	44	Silage Acids (%)	0.7
% Rqd	144	% Rqd	122	Sugar (%)	6.6
				Starch (%)	26.6
Amino Acid Balance				Sol. Fiber (%)	8.8
MET (g)	23.0	LYS (g)	51.6		
MET (%Rqd)	146	LYS (%Rqd)	131	LYS:MET	2.98
MET (%MP)	2.4	LYS (%MP)	7.0		
ME & MP Production					
	Milk (lbs)	Fat (%)	TP (%)		
Trg:	100.0	3.70	3.13		
ME:	103.2	N/A	N/A		
MP:	100.7	N/A	N/A		
Ration DM (%)	58.27	Forage DM (%)	52.57		

The ration CP is at 15.4% which is up a little bit from the original formulation of 14.8% but there was an indication of a potential NH_3 deficit so urea came into the solution. Note that the approach used was to use an optimization procedure rather than by substitution. With this approach one can first establish the prices of the feeds to be considered, next the minimum and maximum amounts to be considered in the ration and then the nutritional constraints such as the minimum MP and ME in the ration. With the advancement of the models we now have the capability to refine rations so that we are not overfeeding N or P as we have in the past. Understand though, nutritionists will overfeed nutrients when they observe day to day variability in the on farm feeds offered to the different animal groups so as to maintain productivity.

One of the challenges is the number of groups we should have. It is advantageous from a nutrient management stand point to have homogenous groups based on a physiological requirements basis as well as being able to fine tune the rations; we can further fine tune this with robotic systems. However, having many groups adds challenges relative to increased labor costs in feeding as well as increased challenges in animals adapting to pen & ration changes. With a one group system we will be overfeeding many of the cows which will potentially decrease efficiencies.

Refinement with the advanced models starts on the carbohydrate side with improved prediction of the ruminal digestibility of the NDF in the ration. We first need a better prediction of the potentially available NDF which we now have with the use of what we now call $uNDF_{240}$. This is an estimate of the indigestible NDF which replaces lignin*2.4. With this and the NDF digestibility at 30 and 120 hours we can improve our estimates of fiber digestion in the rumen. We now have a much improved understanding of the ruminal starch digestibility with the use of the 7hr Invitro measurement, which at this point is a good ranking tool and has allowed us to refine our estimates of

the rate of digestion of the starch being fed. These two sources of fermentable CHO make up the biggest percentage of rumen degradable CHO. With the improved estimates we have an improved prediction of microbial protein yield and also the ability to better predict the ruminal N needs so that we can minimize excess NH_3 being absorbed into the blood and being excreted in the urine. The model continues to use the NRC 2001 mineral submodel with the estimates of the bioavailability's; very important as we consider over formulating minerals and the impact to the environment.
It is suggested that we need to now consider formulating for fermentable CHO fractions rather than total fractions. Below is the fermentable CHO profile from NDS of the above ration. We try to achieve a total CHO fermentability of over 40% DM and a fermentable NDF of over 10% DM. Due to the cost of corn grain in the not too distant past, we started to reduce the amount of purchased fermentable starch which has moved us to higher amounts of fermentable soluble fiber and sugar. Additionally it should be pointed out that when we have less than optimum management situations and/or excessive heat and humidity we can put a maximum on the fermentable starch and increase the fermentable soluble fiber; our goal in this case is to drop the fermentable starch as a % of the total fermentable CHO down closer to 42 to 43% DM.

	Fermentability			Escape	
	% DM	%	% Ferm.CHO	% DM	%
Proteins	8.57	55.7		6.82	44.3
Totals CHO	42.62	56.5		32.73	43.4
NDF	10.72	34.3	25.16	20.56	65.7
Starch	19.51	73.4	45.76	7.07	26.6
Soluble fiber	7.15	80.8	16.77	1.70	19.2
Sugars	4.81	72.8	11.28	1.80	27.2
Other NFC	0.44	21.4	1.03	1.60	78.6

With the optimization of the CHO fermentation, balancing for meeting the ME & MP the CP in the ration will be in the 14 to 15+ %DM; this will increase the risk of certain amino acids being deficit. With high amounts of the proteins coming from corn and soybean meal the first limiting AA are Lys & Met. However, with rations which have significant amounts of barley and canola then His can also be limiting. Further it is also possible for the branch chain AA's to become limiting. A review by Robinson (2010) suggests that considering only Met & Lys may not lead to increases in the efficiencies desired; this thinking is corroborated by Arriola Apelo, et al (2014) suggesting a need to refine the models even though they showed positive results from lowering the CP down to 15%. Below are the AA supplies and balances shown from NDS. It needs to be pointed out that in CNCPS 6.5 as shown in NDS the AA supplies are different than in 6.1 because of the updated CNCPS database. This points out that even though the 6.5 database is improved; assuming that the AA profile of each feedstuff is constant is not true; we will hopefully move to receiving AA analyses as a routine assay sometime in the future. The key points from the table below (NDS) is that when you look at duodenal flow you will see that a significant % of the total AA flow comes from bacterial AA; this points out the importance of good estimates of ruminal CHO fermentation and rumen available N to match the potential CHO fermentation.

		Duodenal AA Flow			MP AA Supply				Metabolizable Amino Acids			Ratios
		Bact.	RUP	Total	Tissue *	Bact.	RUP	Total	Req.	Balance	% Req.	% MP
		g/day	g/day	g/day	g/day	g/day	g/day	g/day	g/day	g/day		
Met	2,30 - 2,65	59.1	41.5	100.6	0.0	43.0	37.3	80.3	70.9	9.4	113.2%	2.55
Lys	6,40 - 7,20	169.2	115.7	284.9	0.0	131.7	92.1	223.8	200.4	23.4	111.7%	7.10
Arg	> 5,00	137.3	93.4	230.8	0.0	111.8	81.3	193.0	129.3	63.7	149.3%	6.13
Thr	> 4,60	111.8	69.1	180.9	0.0	89.8	58.3	148.1	106.6	41.5	139.0%	4.70
Leu	< 8,70	160.1	148.5	308.6	0.0	120.6	125.7	246.3	261.9	-15.6	94.0%	7.82
Ile	4,75 - 5,00	121.2	73.0	194.2	0.0	94.4	62.1	156.6	143.1	13.5	109.4%	4.97
Val	> 5,85	130.4	87.9	218.2	0.0	98.9	74.1	173.0	156.4	16.6	110.6%	5.49
His	> 2,75	54.8	43.1	97.9	0.0	43.2	36.8	80.0	68.2	11.8	117.4%	2.54
Phe	4,90 - 5,10	111.0	85.4	196.4	0.0	82.9	72.6	155.5	143.6	11.9	108.3%	4.93
Trp	< 1,40	37.1	20.3	57.4	0.0	26.2	17.2	43.3	41.2	2.2	105.3%	1.38
Lys:Met		2.79:1		Optimum ratio 2.70:1 (2.68÷2.72)								

The next area is minerals. Our labs give us routinely NIR predictions and they are not quantitative estimates but qualitative; NIR prediction reliability is low. Given that P is a concern it is probably wise to develop good regional mineral analyses for the feeds fed that are regional for the area being served that reflects the soils and the soil management of the regions.

Nutrient	Diet Concentration	Diet Intake	Added	Water Intake	Absorbed			%Rqd
					Supplied	Rqd	Balance	
Ca	0.81 %DM	222.34	49.25	0	112.09	74.36	37.73 g/day	151 %
P	0.36 %DM	98.36	15.1	-	68.48	68.25	0.23 g/day	100 %
Mg	0.22 %DM	60.36	5.02	-	14.32	8.49	5.82 g/day	169 %
K	1.42 %DM	391.38	0.08	0	352.24	258.01	94.22 g/day	137 %
S	0.20 %DM	55.14	6.86	0	55.14	55.1	0.04 g/day	100 %
Na	0.21 %DM	58.15	49.99	0	52.33	52.27	0.06 g/day	100 %
Cl	0.60 %DM	164.36	77.08	0	147.92	64.61	83.31 g/day	229 %
Fe	204.07 ppm	5621.94	734.7	0	562.19	45.71	516.49 mg/day	1230 %
Zn	37.06 ppm	1020.92	359.18	0	204.18	204.4	-0.22 mg/day	100 %
Cu	9.32 ppm	256.68	25.96	0	11.78	11.73	0.05 mg/day	100 %
Mn	24.82 ppm	683.73	24.5	0	6.84	2.66	4.18 mg/day	257 %
Se	0.30 ppm	8.26	6.16	-	8.26	8.26	-0.01 mg/day	100 %
Co	0.19 ppm	5.23	0.82	-	5.23	3.03	2.20 mg/day	173 %
I	0.45 ppm	12.47	10.82	-	11.22	9.82	1.40 mg/day	114 %

In the ration above (AMTS) the minerals were balanced with a little di-calcium phosphate and salt as well as inorganic trace minerals and vitamins. The P was just met as well as the Na & S, but according to the book value analyses other macro minerals were exceeded relative to requirements. This points out the importance of developing a robust mineral analyses in the regions that are served and then going forward having good chemistry for the on the farm supply of forages plus the off farm ingredient suppliers. Note that the ration was balanced to meet the P requirement (Wu et al, 2000, Cerosaletti et al 2004). It has been a concern for several years that we do not over feed the other minerals. Too often the trace minerals are fed to requirement without taking into account the trace mineral contributions from the forages and grains which are organic sources of the trace minerals. We have, for example, seen excess amounts of Cu leading to reduced yields of corn silage. It will also be noticed that there is a column for water analyses. We recommend that it is important to have water analyses done for each source of water on every farm; too often we have excess of minerals that we need to take into account, especially for dry cows where DCAD balances can become crucial.

Nutrient Balances

The goal is to achieve good balances to achieve nutrient savings. The optimized ration shown above resulted in the N & P losses for this group is shown below (NDS).

Fecal excretion and wet manure			
	Total lbs	N g	P g
Dry Feces	20.08		
Wet Feces	119.10	261.73	57.96
Urine	48.30	177.32	1.26
Wet manure	167.40	439.04	59.21
Intake		676.79	98.95
Productive		237.75	39.73

Productive N/Total N	35.13 %	Productive P/Total P	40.15 %
Productive N/Urinary N	1.34:1	Manure P/Total P	59.85 %
Manure N/Total N	64.87 %		
NH3 Potential (g)	115.26		

The key numbers that we are trying to influence are the ratios of Productive N/Total N and then the manure and urine ratios. The P is primarily excreted in the feces and the two ratios we need to monitor. We need to increase the productive P for the total P intake and decrease the manure P per the total P intake.

Below (NDS) are the two major areas that are very much on the global warming radar screen now, methane and carbon dioxide which ironically, we have made great strides in improving over the last 50 years.

CH4 (Mcal)	6.49
CH4 (liters/day)	709.91
CH4 (g/day)	508.88
CH4 (g/lbs milk)	5.09
CO2 (lbs/day)	34.55
CO2 (lbs/lbs milk)	0.35

There has been considerable research in the last few years looking at both CH_4 and CO_2 emissions not only from individual cows but also from farms.

We focused on the high group in this presentation but the more pertinent numbers are the whole farm balances. This means that we need to carefully balance the rations for replacements and dry cows as well. Too often we might do a good job with the lactating herd and then over-feed the replacements, contributing significantly to upsetting the nutrient balances on the farm. As we move forward there will be improvements in the models that predict the outcomes of feeding management and the rations that are being fed. Chase (2010, 2011, 2014), as well as Chase et al (2009) discussed at length the relationships, from controlled and field research as well as field experiences and the use of the CNCPS model and the predictions of excretions of N & P as well as gaseous emissions. Higgs et al (2012) in two papers discussed both controlled studies as well as a case study in with the use of the CNCPS system relative to N excretion. Below is an Excretion Report from AMTS which depicts the annual whole farm N & P excretions.

Example of an annual whole farm excretion of N & P.

Location	# Animals	# Days	Feces (Total lbs)	Urine (Total lbs)	Manure (Total lbs)	Fecal N (Total lbs)	Urine N (Total lbs)	Manure N (Total lbs)	Fecal P (Total lbs)	Urine P (Total lbs)	Manure P (Total lbs)
Dry Cow barn	40	365	748,383	581,754	1,330,137	3,485	4,392	7,876	725	39	764
Heifer Barn	300	365	2,379,714	2,589,452	4,969,166	14,400	20,286	34,686	2,726	171	2,897
Lactating Barn	430	365	14,338,040	7,554,685	21,892,720	77,896	74,004	151,899	14,583	453	15,036
Total			17,466,130	10,725,890	28,192,020	95,780	98,682	194,462	18,035	663	18,698

Cela et al (2014) did an in depth analysis of whole farm N, P and K balances using detailed data from many NY farms, concluding when 70% of the feeds fed the cows are produced on the farm and the rations are balanced to meet requirements then the farms will be in nutrient balance. Given the concerns about NH_3, N_20, CH_4 & CO_2 emissions we need to include these in the reports in the future as well.

Summary

With rapid and affordable access to forage and feed analyses, improved nutrition models and the platforms that they are in, we have the opportunity to improve our capabilities in targeting feeding in a manner to increase the amount of nutrients fed into productive nutrients with a reduction in nutrient losses.

It is important for a farm to not only just look at the potential losses from inefficiencies but also when looking at N & P consider what % of these losses are recycled back through the soil and retained by forages grown either on the farm or through neighbors' farms who are using the nutrients to grow crops; in this scenario where less than 70% of the feeds are grown on the farm, a regional balance. Also it is important for a farm to consider how to reduce the variability of the on farm feeds as well as the purchased feeds; this will allow the nutritionist to formulate closer to the needs of each group of animals on the farm. Additionally there can be opportunities to regroup animals and to improve the environment surrounding the cows as well as the management that will reduce nutrient losses.

We have made significant progress over the last several decades in reducing nutrient wastage and our carbon footprint but we still have some challenges ahead.

References

Arriola Apelo, S. I., A. L. Bell, K. Estes, J. Ropelewski, M. J. de Veth, and M. D. Hanigan. 2014. Effects of reduced dietary protein and supplemental rumen-protected essential amino acids on the nitrogen efficiency of dairy cows. J. Dairy Sci. 97:5688

Cela, Sebastian, Quirine M. Ketterings, Karl Czymmek, Melanie Soberon, and Caroline Rasmussen. 2014. Characterization of nitrogen, phosphorus, and potassium mass balances of dairy farms in New York State. J. Dairy Sci. 97:7614

Cerosaletti, P. E., D. G. Fox, and L. E. Chase. 2004. Phosphorus reduction through precision feeding of dairy cattle. J. Dairy Sci. 87:2314

Chase, L. E. 2010. How much gas do cows produce? Proc. Cornell Nutr. Conf. pg. 186

Chase, L. E. 2011. Ammonia emissions from dairy operations – what do we know? Proc. Cornell Nutr. Conf. pg. 173

Chase L. E. 2014. Using Models on Dairy Farms – How Well Do They Work? Mid-South Nutr. Conf.

Chase, L.E., R.J. Higgs and M. E. Van Amburgh. 2009. Feeding low crude protein rations to dairy cows – opportunities and challenges. Proc. Cornell Nutr. Conf. pg. 220

Higgs R. J., L. E. Chase, and M. E. Van Amburgh. 2012. Development and evaluation of equations in the Cornell Net Carbohydrate and Protein System to predict nitrogen excretion in lactating dairy cows. J. Dairy Sci. 95:2004

Higgs R. J., L. E. Chase, and M. E. Van Amburgh. 2012. *C*ASE STUDY: Application and evaluation of the Cornell Net Carbohydrate and Protein System as a tool to improve nitrogen utilization in commercial dairy herds. The Professional Animal Scientist 28:370

Olmos Colmenero, J. J. and G. A. Broderick. 2006. Effect of Dietary Crude Protein Concentration on Milk Production and Nitrogen Utilization in Lactating Dairy Cows. J. Dairy Sci. 89:1704

Robinson, P.H. 2010. Impacts of manipulating ration metabolizable lysine and methionine levels on the performance of lactating dairy cows: A systematic review of the literature. Livestock Science 127:115

Wu Z., L. D. Satter, and R. Sojo. 2000. Milk Production, Reproductive Performance, and Fecal Excretion of Phosphorus by Dairy Cows Fed Three Amounts of Phosphorus. J Dairy Sci. 83:1028

Current issues in animal welfare - what must be done and how do we improve?

Marina A.G. von Keyserlingk and Daniel M. Weary

Animal Welfare Program, University of British Columbia, 2357 Mall, Vancouver, BC, Canada, V6T 1Z4 Email: nina@mail.ubc.ca

Summary

Concern about the welfare of dairy cattle is nothing new; producers and veterinarians have always been concerned about the condition of animals in their care and have tried to ensure that they are healthy and well nourished. Although good welfare has traditionally been viewed by farmers and veterinarians to be seen as good health and production there is a growing acceptance that concerns such as pain and distress and the ability to engage in highly motivated behaviors is also of importance. In this proceedings chapter we discuss the concept of animal welfare from three different perspectives: biological functioning, affective state and natural behavior. Drawing largely on the research undertaken by our students we provide examples of how science can help provide solutions to welfare concerns that address each of these concepts. Animal welfare science addresses all three types of concern by identifying problems in production systems and developing solutions to these problems. The best solutions are win-win, improving the lives of cattle and the people that work with them.

Introduction

Concern about the welfare of dairy cattle is nothing new; producers and veterinarians have always been concerned about the condition of animals in their care and have tried to ensure that they are healthy and well nourished (von Keyserlingk et al., 2009). In the tradition of good animal husbandry, good welfare can be seen largely as maintaining production and the absence illness or injury. However, more recent interest in farm animal welfare stems more from concerns about pain or distress that the animals might experience, and concerns that animals are kept under “unnatural” conditions, with limited space and often a limited ability to engage in social interactions and other natural behaviors. Our first objective is to describe a conceptual framework for these different types of animal welfare concern (reviewed in more detail by Fraser, 2008), using examples from dairy production systems. Over the past decade we have seen a tremendous increase in scientific research on the welfare of cattle. Although research alone cannot tell us which types of concerns are most important, it can and has provided solutions to a number of issues. Our second objective is to provide examples of how science can help provide solutions to welfare concerns (these and other examples are reviewed in Rushen et al., 2008).

Animal welfare: a conceptual overview

Animal welfare includes three types if concern: 1) is the animal functioning well (biological functioning), 2) is the animal feeling well (affective state), and 3) is the animal able to live a reasonably natural life (natural living; Fraser et al., 1997). Farm animal care givers are naturally concerned about the first category; addressing issues such as disease, injury, poor growth rates and reproductive problems, issues that are good for the animal and ultimately also vital in terms of the economic viability of the farm enterprise. However, people are also concerned with the affective state of the animal, and focus upon whether the animals are suffering from unpleasant feelings such as pain, fear or hunger. For some people (including many producers and consumers of organic products), a key concern is whether the animal is able to live a relatively natural life (Fraser and Weary, 2004). For example, is the calf kept with the cow and do cows have access to pasture?

These different types of concern about animal welfare can and do overlap. A lactating dairy cow unable to seek shade on a hot day (natural living), will likely feel uncomfortably hot (affective state), and may show signs of hyperthermia and ultimately reduced milk production (biological functioning). In such cases, research directed at any or all the levels can help address the welfare problem. In other cases, overlap may be less obvious or the different concerns may even be in conflict. For example, group housing of dairy calves allows them to engage in natural social interactions, but when poorly managed can lead to increased incidence of certain diseases or aggressive interactions. Different people can thus reach opposite conclusions about the relative advantages of different housing systems by favoring different welfare indicators (see Fraser, 2003 for case study). Clearly the best solutions will be those that address all three concerns, for example, by creating group-housing systems for calves that avoid competition, allow for social contact and maintains healthy calves. In this way, the three types of concerns can be considered as a checklist with researchers working to identify and solve the various welfare issues. Below we review a few examples of recent work showing how science can be used to address dairy cattle welfare issues from the perspective of biological functioning, natural living and affective states.

Biological functioning

Problems in biological functioning, such as disease and injury, are clearly a welfare concern. For example, lameness is now widely regarded as a major welfare problem for dairy cows and in recent years has received considerable attention in the scientific literature. Compounding the problem is that producers find it difficult to identify animals at the early stages of lameness, likely because dairy cows remain stoic unless injuries are relatively severe (Whay et al., 2003).

Current research is developing improved gait scoring system that can be used to identify cows that are becoming lame. Better scoring systems will require improved knowledge of cows' gait, and this can be derived from computer-assisted kinematic techniques that obtain precise measures of gait and how this changes with different types of hoof injuries

(Flower et al. 2005). Our group uses a gait scoring system based on several specific gait features (e.g. asymmetric steps, tracking up etc.), and these scores have proven sensitive in identifying cows with sole ulcers (Flower and Weary, 2006), pain reduction following use of local anesthetic (Rushen et al., 2007) or non-steroidal anti-inflammatory drug (Flower et al. 2008), and the advantages of softer walking surfaces for lame cows (Flower et al., 2007). Improved training in lameness detection, can serve to recognize which cows will benefit from treatment, and perhaps more importantly identify management and environmental factors to reduce the risk of cows becoming lame.

Poorly designed and managed facilities cause injuries and increase the risk of health problems including lameness and transition cow disease, arguably two of the most serious welfare challenges facing the dairy industry (see von Keyserlingk et al. 2009). Producers spend millions of dollars building indoor housing for dairy cattle, with the aim of providing a comfortable environment for their animals - one that ensures adequate rest, protection from climatic extremes, and free access to an appropriate, well-balanced diet. Despite these laudable aims, housing systems do not always function well from the perspective of the cow – poorly designed and maintained facilities can cause injuries, increase the risk of disease, and increase competition among herd mates for access to feed and lying space.

Our aim is to provide science based solutions that can facilitate better designs and improvements in management that will prevent some of these problems. Our work has generally evaluated housing systems from the cow's perspective by asking how the housing affects cow health (e.g. by reducing the risk of hock injuries; Barrientos et al., 2013), what housing the cow prefers (Fregonesi et al., 2007; Fregonesi et al., 2009), and how the housing affects behavior (e.g. by reducing competition and increasing feeding time; Huzzey et al. 2006).

Variation in lameness rates can be explained in part by how the facilities are designed and managed, but these factors vary greatly among regions due to differences in tradition, barn builders, and availability of materials such as bedding. This means that the factors associated with lameness also vary among regions. For example, in recent analyses we have found major differences in factors associated with lameness in freestall facilities between the northeastern (NE) – US versus California (Chapinal et al., 2013). In the NE – US, where many farms used mats or mattress with just a little sawdust bedding, the risk of lameness reduced by half for farms using deep bedding and for farms that provided some access to pasture during the dry period. In CA, all farms used deep-bedded stalls (typically with dry manure bedding) and almost all farms provided outdoor access (typically to a well bedded dirt lot). Under these conditions, rates of lameness were much lower than in the NE – US. Rates of lameness were lowest on farms where stalls were kept clean (i.e. not contaminated with feces) and on farms that used rubber in the alley to the milking parlour.

Unlike lameness, hock lesions are obvious to anyone who cares to look. Indeed, it is pretty hard to avoid noticing hock lesions when you are standing at hock level in the milking parlour. But even though we can see these lesions they remain common on many farms. Again, we found that prevalence varied among regions, from 42% in British Columbia, to 56% in California, to 81% in NE – US (von Keyserlingk et al., 2012). And again, the good news is that within each region some farms had very low rates suggesting that others could learn from these most successful producers.

One of the greatest challenges is to translate science into practice. Our recent work on benchmarking lameness shows promise as a possible vehicle to promote the adoption of best practices that result in improved dairy cattle welfare (von Keyserlingk et al., 2012; Chapinal et al., in press). In summary, across regions, farms that use well-maintained, deep-bedded stalls have lower risk of lameness and lower rates of hock injuries. Benchmarking programs that provide famers the relevant data from their farms and other farms in their region can motivate farmers to change practices resulting in improved welfare. Farmers can use this data, together with the recommendations described here and elsewhere, to develop formulate tailor-made solutions to problems with lameness and leg injuries.

Affective state

Measures of biological functioning, like disease and growth, can normally be characterized scientifically with little disagreement. The same cannot always be said for measures of how animals feel. Developing validated measures of animal affect remains one of the most interesting and challenging problems in animal welfare science. Painful procedures remain part of the everyday business of dairy farming, but new scientific studies are showing ways that this pain can be reduced or avoided. Considerable research has shown that all methods of dehorning and disbudding cause pain to calves (reviewed by Stafford and Mellor, 2005) but recent research has also shown that hot iron dehorning an result in negative judgment bias argued to reflect low mood in calves (Neave et al., 2013; Daros et al., 2014).

It is now also becoming clear that use of local anesthetic alone does not fully mitigate this pain. For example, local anesthetic does not provide adequate post-operative pain relief. Lidocaine is effective for 2 to 3 h after administration and treated calves actually experience higher plasma cortisol levels than untreated animals after the local anesthetic loses its effectiveness (Stafford and Mellor, 2005). However, the use of non-steroidal anti-inflammatory drugs, in addition to a local anesthetic, can keep plasma cortisol and behavioral responses close to baseline levels in the hours that follow disbudding and dehorning. A second consideration is that animals respond to both the pain of the procedure and to the physical restraint. Calves dehorned using a local anesthetic still require restraint, and calves must also be restrained while the local anesthetic is administered. The use of a sedative (such as xylazine) can essentially eliminate calf responses to the administration of the local anesthetic and the need for physical restraint during the administration of the local anesthetic and during dehorning (Grøndahl-Nielsen et al., 1999). Thus a combination of sedative, local anesthetic and a non-steroidal anti-inflammatory drug reduces the response to pain during dehorning and in the hours that follow. Unfortunately, such a combination of treatments may not be practical for farmers and may itself have drawbacks for the animal. For example, an effective local block requires repeated injections and additional restraint.

One common alternative to hot-iron dehorning is using caustic paste to cause a chemical burn. This method of dehorning is still painful for the calves (Morisse et al., 1995), but the pain appears easier to control. Calves treated only with the sedative xylazine showed no immediate response to application of the paste, and little response in the hours that followed (Vickers et al., 2005). Moreover, caustic paste dehorning combined with a sedative actually resulted in less pain to calves than dehorning with a hot iron combined with both a sedative and a local anesthetic. This example shows how methods of pain treatment can be developed that are effective and practical for use on farm.

In this section we have focused on pain, in part because the science is clear but also because there is considerable social consensus regarding the ethics of intentionally causing (or failing to prevent) pain to animals. However, we urge readers not to focus only on pain; other affective states may be equally or more important to many cattle, including negative states like fear associated with poor handling practices and facilities and perhaps also positive affect associated by cows suckling their calf or grazing on pasture. The ability to perform these types of natural behavior are also considered important in their own right, as we turn to in the next section.

Natural living

For some, the natural living criteria may seem clear – simply allowing animals to live as naturally as possible. We see this approach as naïve; some natural conditions such as exposure to climatic extremes, disease, parasite infections and predator attacks cannot be seen as good for the animals. Thus the welfare benefits of providing more natural living must be assessed through the lens of the first two criteria. We use the example of more natural feeding systems for calves to illustrate how research can be used to determine if access to more natural environments also provides benefits to the animals in terms of biological functioning and affective state.

Traditionally calves are fed milk twice daily at 10% body weight, but calves often fail to gain weight during the first weeks of life (Hammon et al. 2002). When provided the opportunity, calves consume considerably more than 10% of their body weight (de Passillé and Rushen, 2006). Calves grow much more rapidly when allowed to suckle from the dam (Flower and Weary, 2003), but this biological functioning benefit does to not require keeping the cow and calf together. Simply feeding more milk allows for much higher weight gains, better feed conversion, and reduced age at first breeding (Jasper and Weary 2002; Diaz et al. 2001; Shamay et al., 2005). A better understanding of the calf's natural behavior and preferences, and how allowing this behavior this can benefit calf growth, is helping to revolutionized calf feeding practices.

The milk feeding practices also affect calf hunger. Calves vocalize when hungry and this vocal response, even in the first days after separation from the cow, can be much reduced or eliminated by providing more milk or colostrum (Thomas et al., 2001). Calves that are fed restricted amounts of milk from an automated calf feeder typically visit the feeder more than 20 times a day even when they only receive milk on 2 of these visits. Increasing the milk ration much reduces the frequency of these ‘non-nutritive’ visits (Jensen 2006; De Paula Vieira et al. 2008). This reduction benefits the other calves using the feeder by reducing feeder occupancy and competition for feeder access. Thus allowing more natural feeding behavior reduces hunger and in this case also improves the efficiency of the feeding system facilitating group housing of calves.

The benefits in terms of improved growth and reduced hunger can be achieved by proving the calves more milk. Nipple feeding is clearly more natural but does this provide other benefits for the calf or the producer? Calves allowed to suck on a teat during or after a meal show higher concentrations of cholecystokinin and insulin (de Passillé et al., 1993) and a greater degree of relaxation after the meal (Veissier et al., 2002). Group-housed milk-fed calves will sometimes suck each other (i.e. cross sucking), but this cross-sucking can be much reduced or eliminated if calves consume their milk ration via free access to a teat (de Passillé, 2001), likely because the sucking behavior per se, rather than the ingestion of milk, is responsible for reducing sucking motivation (de Passillé, 2001). Thus nipple feeding also facilitates group housing, saving labor for producers (Kung et al., 2001) and perhaps providing other benefits to the calves.

For the past decades, common wisdom among North American dairy experts was that calves should be housed individually, in separate pens or hutches. This practice was considered to maximize performance and minimize the risk of disease. Individual housing also helps avoid behavioural problems such as competition and cross-sucking.

The new calf-feeding methods described above work well for individually housed calves, but also facilitate group housing. Group housing provides more space for calves and allows for social interactions. For the past decades, common wisdom among North American dairy experts was that calves should be housed individually, in separate pens or hutches. This practice was considered to maximize performance and minimize the risk of disease. Individual housing also helps avoid behavioural problems such as competition and cross-sucking.

The new calf-feeding methods described above work well for individually housed calves, but also facilitate group housing. Group housing provides more space for calves and allows for social interactions. Research and practical experience show that group rearing of calves can result in considerable benefits through reduced labour requirements for cleaning pens and feeding. Calves are social animals that need exercise and keeping dairy calves in groups may provide a number of advantages to both producers and their calves. Successful adoption of group housing will mean avoiding problems such as increased disease and competition. Recent research provides some insights into how these risks can be minimized.

We evaluated the behaviour and growth rates of calves housed in pairs versus individually (Chua et al., 2002); calves gained weight steadily regardless of treatments. Interestingly, during the week of weaning (approximately 5 weeks of age), pair-housed calves continued to gain weight normally but the individually housed calves experienced a slight growth check. There were no differences between groups in the amounts of milk, starter or hay consumed, or in the incidence of scouring or other diseases. Aggressive behaviour and cross-sucking were almost never observed (less than 0.2% of time).

In a more recent study, De Paula Vieira et al. (2010) found that calves housed in pairs vocalized less during weaning than did individually housed calves. The results of this study also illustrated some longer-term costs to housing calves individually. When all calves were eventually introduced to a group pen after weaning calves that had previously been single housed took on average 50 h to begin feeding, in comparison to just 9 h for the pair-reared calves. Calves are also able to learn a simple colour discrimination task, and then re-learn the task when the colour treatments were reversed. However, despite the speed of learning for the simple discrimination task being similar for individually housed and pair-housed calves, the pair-housed calves are able to adapt more easily when the training stimuli are reversed. Together, the results of these studies suggest that individual housing of dairy calves can result in measurable learning deficits. Social housing for calves may result in animals that are more flexible in their responses to changes in management and housing (de Paula Vieira et al., 2012; Gillard, et al., 2013).

Successful group rearing requires appropriate management, including feeding method and group size. Large epidemiological surveys of U.S. and Swedish dairy farms found increased mortality and disease on farms keeping calves in large groups (more than 7 or 8) (Losinger and Heinricks, 1997). Thus, small groups are likely a better alternative than large ones.

Calf immunity and the design and management of the housing systems, such as its cleanliness and ventilation, likely affect disease susceptibility more than group housing per se. Our work shows that housing young dairy calves in small groups is viable in terms of calf health, performance and behaviour. New research is now required on management strategies that will help prevent disease. For now, we encourage producers to consider keeping a closed herd (i.e. no new animals entering the herd), keeping groups small and physically separated from one another (e.g. in super hutches), and managing group pens in an all-in-all-out basis.

Calves in groups sometimes compete with pen mates. In one experiment using a simple teat-feeding system, we found that group-housed calves can displace one another from the milk teat many times each day if there are not enough teats (von Keyserlingk et al., 2004). However, giving each calf access to its own teat greatly reduced these displacements. This improved access to teats resulted in longer feeding times and increased milk intakes.

Other research has focused on how computerized feeding stations can be managed to reduce competition between calves. Increasing the daily milk allowance for calves from 5 to 8 litters per day reduced by half the number of times calves visited the feeder, reducing occupancy time and displacements from the feeder, and improving the efficient use of this equipment (Jensen and Holm, 2003; de Paula Vieira et al. 2008; Sweeney et al., 2010). Our research shows that young calves can be introduced into a group with little disruption when they are trained to feed from the computerized feeding station prior to the introduction (O'Driscoll et al., 2006). Although the calves visited the feeder less frequently on the day of mixing, they were able to compensate by increasing both the duration and amount consumed per meal, and established their pre-mixing feeding pattern after just one day.

Conclusions

Many in the dairy industry may have assumed that animal welfare concerns can be met by working to ensure good health and productivity for the cows and calves in their care. We have argued above that good biological functioning is a necessary component of welfare, but this focus alone is not sufficient; affective states like pain or hunger, and concerns about naturalness are also important. Animal welfare science addresses all three types of concern by identifying problems in production systems and developing solutions to these problems. The best solutions are win-win, improving the lives of cattle and the people that work with them.

Acknowledgements

We thank our colleagues, especially David Fraser, Jeff Rushen and Anne Marie de Passillé and the many students in the Animal Welfare Program that helped develop these ideas. The Program is funded by Canada's Natural Sciences and Engineering Research Council Industrial Research Chair Program with industry contributions from the Dairy Farmers of Canada, Westgen, Intervet Canada Corp. (Merck), Zoetis, BC Cattle Industry Development Fund, the BC Milk Producers Association, Alberta Milk, Valacta, CanWest DHI. This is an updated version of conference proceedings initially written for the 2nd Boehringer forum on Farm Animal Well Being held in Madrid, Spain in June 2009.

References

Barrientos, A. K., N. Chapinal, D. M. Weary, E. Galo, and M. A. G. von Keyserlingk. 2013. Herd-level risk factors for hock injuries in freestall-housed dairy cows in the northeastern United States and California. J. Dairy Sci. 96:3758–3765.

Chapinal, N, A. K. Barrientos, M. A. G. von Keyserlingk, E. Galo, and D. M. Weary. 2013. Herd-level risk factors for lameness in freestall farms in the northeastern United States and California. J. Dairy Sci. 96:318–328.

Chua, B., E. Coenen, J. van Delen, and D. M. Weary. 2002. Effects of pair versus individual housing on the behavior and performance of dairy calves. J. Dairy Sci. 85:3360–3364.

Chapinal., N. D.M. Weary, L. Collings and M.A.G. von Keyserlingk. In press. Lameness and hock injuries improve on farms participating in an assessment program. The Veterinary J.

Daros R.R, J.H.C. Costa, M.A.G. von Keyserlingk M.J. Hotzel, and D.M. Weary. 2014. Separation from the Dam Causes Negative Judgement Bias in Dairy Calves. PLoS ONE 9(5): e98429.

De Paula Vieira, A., V. Guesdon, A. M. de Passillé, M.A.G. von Keyserlingk and D. M. Weary. 2008. Behavioural indicators of hunger in dairy calves. Appl. Anim. Behav. Sci. 109: 180–189.

De Paula Vieira A, de Passillé A M, Weary D M. 2012. Effects of the early social environment on behavioral responses of dairy calves to novel events. J Dairy Sci 95: 5149-5155.

De Paula Vieira A, M.A.G. von Keyserlingk and D.M. Weary 2010 Effects of pair versus single housing on performance and behavior of dairy calves before and after weaning from milk. J Dairy Sci 93: 3079-3085.

de Passillé, A. M. 2001. Sucking motivation and related problems in calves. Appl. Anim. Behav. Sci. 72: 175-187.

de Passillé, A.M.B., Christopherson, R. J., and Rushen, J. 1993. Nonnutritive sucking and the postprandial secretion of insulin, CCK and gastrin in the calf. Physiol. Behav. 54: 1069-1073.

de Passillé, A. M., and J. Rushen. 2006. Calves' behaviour during nursing is affected by feeding motivation and milk availability. Appl. Anim. Behav. Sci. 101: 264-275.

Daros R.R, Costa J.H.C., von Keyserlingk M.A.G., Hotzel M.J., Weary D.M. 2014. Separation from the Dam Causes Negative Judgement Bias in Dairy Calves. PLoS ONE 9(5): e98429.

Diaz, M. C. M. E. Van Amburgh, J. M. Smith, J. M. Kelsey, and E. L. Hutten. 2001. Composition of growth of holstein calves fed milk replacer from birth to 105-kilogram body weight. J. Dairy Sci. 84:830-842.

Flower, F.C., M. Sedlbauer, E. Carter, M. A. G. von Keyserlingk, D. J. Sanderson, and D. M. Weary. 2008. Analgesics Improve the Gait of Lame Dairy Cattle. J Dairy Sci 2008 91: 3010-3014.

Flower, F. C., A. M. de Passillé, D. M. Weary, D. J., Sanderson, and J. Rushen. 2007. Softer, higher-friction flooring improves gait of cows with and without sole ulcers. J. Dairy Sci. 90: 1235-1242.

Flower, F. C. and D. M. Weary. 2006. Effect of hoof pathologies on subjective assessments of dairy cow gait. J. Dairy Sci. 89:139-146.

Flower, F.C., D. J. Sanderson, D.M. Weary. 2005. Hoof pathologies influence kinematic measures of dairy cow gait. J. Dairy Sci. 88:3166-3173.

Flower, F. C. and D. M. Weary. 2003. The effects of early seperation on the dairy cow and calf. Animal Welfare 12:339-348.

Fraser, D. 2008. Understanding Animal Welfare: The Science in its Cultural Context. Wiley-Blackwell, Oxford, UK .

Fraser D., D. M. Weary, E. A. Pajor, and B. N. Milligan. 1997. A scientific conception of animal welfare that reflects ethical concerns Anim. Welfare. 6:187-205.

Fraser, D. 2003. Assessing animal welfare at the farm and group level: the interplay of science and values. Anim. Welfare 12:433-443.

Fraser, D., and D. M. Weary. 2004. Quality of life for farm animals: linking science and ethics. Pages 39-60 in The Well-Being of Farm Animals: Challenges and Solutions. G. J. Benson and B.E. Rollins, ed. Iowa State Press, Ames, IA.

Fregonesi, J. A., D. M. Veira, M. A. G. von Keyserlingk, and D. M. Weary. 2007. Effects of Bedding Quality on Lying Behavior of Dairy Cows. J Dairy Sci 2007 90: 5468-5472.

Fregonesi, J.A., M.A.G von Keyserlingk, D.M. Veira, and D.M. Weary. 2009. Cow preference and usage of free stalls versus an open lying area. J. Dairy Sci. 92: 5497-5502.

Grøndahl-Nielsen, C., H. B. Simonsen, J. Damkjer Lund, and M. Hesselholt. 1999. Behavioural, endocrine and cardiac responses in young calves undergoing dehorning without and with use of sedation and analgesia. Vet. J. 158:14-20.

Hammon, H.M., G. Schiessler, A. Nussbaum, and J. W. Blum. 2002. Feed intake patterns, growth performance, and metabolic and endocrine traits in calves fed unlimited amounts of colostrum and milk by automate, starting in the neonatal period. J. Dairy Sci. 85:3352-3362.

Huzzey, J. M., T. J. DeVries, P. Valois, and M. A. G. von Keyserlingk. 2006. Stocking density and feed barrier design affect the feeding and social behavior of dairy cattle. J. Dairy Sci. 89: 126-133.

Jasper, J., and D. M. Weary. 2002. Effects of ad libitum milk intake on dairy calves. J. Dairy Sci. 85:3054-3058.

Jensen, M.B. 2006. Computer-controlled milk feeding of group-housed calves: The effect of milk allowance and weaning type. J. Dairy Sci. 89:201–206.

Jensen, M. B., and L. Holm. 2003. The effect of milk flow rate and milk allowance on feeding related behavior in dairy calves fed by computer controlled milk feeders. Appl. Anim. Behav. Sci. 82:87–100.

Kung, L., S. Demarco, L.N. Siebenson, E. Joyner, G.F.W. Haenlein, and M.R. Morris. 1997. An evaluation of two management systems for rearing calves fed milk replacer. J. Dairy Sci. 80: 2529-2533.

Losinger, W.C. and A.J. Heinrichs. 1997. Management practices associated with high mortaility among preweaned dairy heifers. J. Dairy Res. 64:1-11.

Morisse, J. P., J. P. Cotte, and D. Huonnic. 1995. Effect of dehorning on behaviour and plasma cortisol responses in young calves. Appl. Anim. Behav. Sci. 43:239-247.

Neave H.W., R.R. Daros, J.H.C. Costa, M.A.G. von Keyserlingk and D.M. Weary. 2013. Pain and Pessimism: Dairy Calves Exhibit Negative Judgement Bias following Hot-Iron Disbudding. PLoS ONE 8(12): e80556.

O'Driscoll, K., M. A. G. von Keyserlingk, and D. M. Weary. 2006. Effects of mixing on drinking and competitive behavior of dairy calves. J. Dairy Sci. 89:229-233.

Rushen J., E. Pombourcq, and A. M. de Passillé. 2007. Validation of two measures of lameness in dairy cows. Appl. Anim. Behav. Sci. 106, 173-177.

Rushen, J., A.M. de Passillé, M.A.G. von Keyserlingk, D.M. Weary. 2008. The Welfare of Cattle. Springer, Dordrecht, The Netherlands.

Shamay, A., D. Werner, U., Moallem, H. Barash, and I. Bruckental. 2005. Effect of nursing management and skeletal size at weaning on puberty, skeletal growth rate and milk production during first lactation of dairy heifers. J. Dairy Sci. 88:1460-1469.

Stafford, K. J., and D. J. Mellor. 2005. Dehorning and disbudding distress and its alleviation in calves. Vet. J. 169:337-349.

Sweeney, B.C., J. Rushen, D. M. Weary, and A. M. de Passillé. 2010. Duration of weaning, starter intake, and weight gain of dairy calves fed large amounts of milk. J. Dairy Sci. 93:148–152.

Thomas, T.J., D.M. Weary and M.C. Appleby. 2001. Newborn and 5-week-old calves vocalize in response to milk deprivation. Appl. Anim. Behav. Sci. 74:165-173.

Veissier, I., A. M. de Passillé, G. Despres, J. Rushen, I. Charpentier, A. R. Ramirez de la Fe, and P. Pradel. 2002. Does nutritive and non-nutritive sucking reduce other oral behaviors and stimulate rest in calves? J. Anim. Sci. 80:2574-2587.

Vickers, K. J., L. Niel, L. M. Kiehlbauch, and D. M. Weary. 2005. Calf response to caustic paste and hot-iron dehorning using sedation with and without local anesthetic. J. Dairy Sci. 88:1454-1459.

von Keyserlingk, L. Bruisus, and D.M. Weary. 2004. Competition for teats and feeding behavior by group-housed dairy calves. J. Dairy Sci. 87:4190-4194.

von Keyserlingk, M.A.G., J. Rushen, A.M.B. de Passillé, and D.M. Weary. 2009. Invited review: The welfare of dairy cattle – Key concepts and the role of science. J. Dairy Sci. 92:4101-4111

von Keyserlingk, M.A.G., A. Barrientos, K. Ito, E. Galo, E., and D.M. Weary. 2012. Benchmarking cow comfort on North American freestall dairies: Lameness, leg injuries, lying time, facility design, and management for high-producing Holstein dairy cows. J. Dairy Sci., 95:1-10.

Weary, D. M., L. Niel, F. C. Flower and D. Fraser. 2006. Identifying and preventing pain in animals. Appl. Anim. Behav. Sci. 100:64-76.

Wells, S. J., D. A. Dargatz, and S. L. Ott. 1996. Factors associated with mortality to 21 days of life in dairy heifers in the United States. Prev. Vet. Med. 29:9–19.

Whay, H. R., D. C. J. Main, L. E. Green, and A. J. F. Webster. 2003. Assessment of the welfare of dairy cattle using animal-based measurements: direct observations and investigation of farm records. Vet. Rec. 153:197-202.

Effective Use of Genomics in Sire Selection and Replacement Heifer Management

Kent A. Weigel, Ashley A. Mikshowsky, and Victor E. Cabrera
Department of Dairy Science
University of Wisconsin – Madison
phone: (608) 263-4321
fax: (608) 263-9412
email: kweigel@wisc.edu

Introduction

For more than half a century, progeny testing has been the foundation of genetic selection programs in dairy cattle, and it has led to rapid genetic gains in traits such as milk production, for which breeding values of bulls and cows have increased by roughly 200 pounds per year. However, progeny testing is expensive and time-consuming due to a long generation interval in cattle, and it is not an effective method for improving traits that are difficult or expensive to measure routinely on commercial dairy farms, such as feed efficiency. Whole genome selection, more commonly known as genomic selection, refers to using information about single nucleotide polymorphisms (SNP) markers in the cattle genome to predict the genetic merit of young animals that have no offspring or performance data at the time selection decisions are made. The information obtained by genomic testing a young heifer or bull is compared with genomic data from a reference population of older animals of the same breed. The Council on Dairy Cattle Breeding (CDCB) provides routine genomic predicted transmitting abilities (PTA) for US dairy cattle, and more than 800,000 dairy bulls, cows, heifers, and calves have been tested to date.

Genome-Tested Young Sires

Virtually every bull offered to US dairy farmers has been chosen based on the results of genomic testing. The National Association of Animal Breeders (NAAB) denotes young genome-tested bulls with no milk-recorded offspring as "G" status (genomic), whereas older bulls that have 10 or more milking daughters in the US are denoted as "A" status (active).

Table 1. Average PTA values and corresponding reliability (REL) values for milk yield, daughter pregnancy rate (DPR), and Lifetime Net Merit (NM$) for active and genomic bulls marketed to US dairy farmers, based on December 2014 CDCB genetic evaluations.

Breed	Status	No.	Milk (lb)		DPR (%)		Net Merit ($)	
			PTA	REL	PTA	REL	PTA	REL
Brown Swiss	Active	33	251	89	0.1	69	149	84
	Genomic	43	576	62	0.3	50	315	59
Holstein	Active	618	515	94	0.3	82	240	90
	Genomic	1,499	860	76	1.1	68	479	73
Jersey	Active	104	411	93	-0.2	75	238	87
	Genomic	317	650	69	-0.3	52	366	65

As shown in Table 1, the number of young "G" status bulls currently in the marketplace far exceeds that of "A" status bulls that have completed progeny testing. The difference in average genetic merit between these groups is striking – Net Merit of young bulls is $166, $239, and $128 greater than for progeny tested bulls in Brown Swiss, Holsteins, and Jerseys, respectively. The price we pay for higher predicted genetic merit is lower reliability, a difference of 25% for Brown Swiss, 17% for Holsteins, and 22% for Jerseys (these losses in reliability are proportional to the size of the corresponding genomic reference populations for these breeds). The best strategy for managing the risk associated with lower reliability of young genome-tested bulls is to increase the number of different bulls that are used, as shown below in Table 2. The REL values of individual genomic bulls range from 70 to 76%, whereas the REL of average genetic merit for a team of three bulls ranges from 90 to 92%. Increasing team size to six provides 95 to 96% REL for the team average, and increasing team size to twelve leads to 98% REL.

Table 2: Example PTA and REL for Net Merit of active and genomic Holstein bulls versus REL of a team of the same bulls, where Team REL = [1 – (1 – average REL of individual bulls in the team)/(number of bulls in the team)], with REL expressed as a proportion (93% REL = 0.93).

<table>
<tr><th rowspan="2">Bull Type</th><th rowspan="2">Individual NM PTA ($)</th><th rowspan="2">Individual NM REL (%)</th><th colspan="2">Team of 3</th><th colspan="2">Team of 6</th><th colspan="2">Team of 12</th></tr>
<tr><th>PTA</th><th>REL</th><th>PTA</th><th>REL</th><th>PTA</th><th>REL</th></tr>
<tr><td rowspan="12">Active</td><td>256</td><td>93</td><td rowspan="3">266</td><td rowspan="3">97</td><td rowspan="6">344</td><td rowspan="6">99</td><td rowspan="12">235</td><td rowspan="12">99</td></tr>
<tr><td>461</td><td>86</td></tr>
<tr><td>81</td><td>98</td></tr>
<tr><td>295</td><td>89</td><td rowspan="3">422</td><td rowspan="3">98</td></tr>
<tr><td>328</td><td>96</td></tr>
<tr><td>643</td><td>93</td></tr>
<tr><td>85</td><td>88</td><td rowspan="3">83</td><td rowspan="3">96</td><td rowspan="6">127</td><td rowspan="6">98</td></tr>
<tr><td>270</td><td>85</td></tr>
<tr><td>-106</td><td>87</td></tr>
<tr><td>-138</td><td>92</td><td rowspan="3">170</td><td rowspan="3">97</td></tr>
<tr><td>340</td><td>93</td></tr>
<tr><td>309</td><td>91</td></tr>
<tr><td rowspan="12">Genomic</td><td>314</td><td>72</td><td rowspan="3">222</td><td rowspan="3">91</td><td rowspan="6">374</td><td rowspan="6">96</td><td rowspan="12">454</td><td rowspan="12">98</td></tr>
<tr><td>416</td><td>76</td></tr>
<tr><td>-63</td><td>74</td></tr>
<tr><td>499</td><td>73</td><td rowspan="3">525</td><td rowspan="3">91</td></tr>
<tr><td>496</td><td>71</td></tr>
<tr><td>581</td><td>73</td></tr>
<tr><td>585</td><td>70</td><td rowspan="3">621</td><td rowspan="3">90</td><td rowspan="6">535</td><td rowspan="6">95</td></tr>
<tr><td>712</td><td>71</td></tr>
<tr><td>566</td><td>70</td></tr>
<tr><td>182</td><td>74</td><td rowspan="3">449</td><td rowspan="3">92</td></tr>
<tr><td>611</td><td>75</td></tr>
<tr><td>553</td><td>75</td></tr>
</table>

Genomic Results from the UW-Madison Herd

Demonstrating the relationship between genomic predictions and future performance is the key to gaining farmers' confidence in this technology. Over the past three years, every heifer calf in the Allenstein Dairy Herd at UW-Madison has been tested with a Zoetis low-density chip (CLARIFIDE®). Our research and teaching herd consists of 764 cows, with a rolling herd average of 28,362 pounds of milk, 1,076 pounds of fat, and 894 pounds of protein on 2X milking. The protocol calls for testing upon arrival at our heifer rearing site, the Marshfield Agricultural Research Station, and more than 1,000 calves have been tested to date. Of these, roughly 400 have entered the milking herd, and we can compare their early genomic predictions with their subsequent lactation performance. The analysis was based on sorting heifers into quartiles based on their sires' current PTA values or their own genomic PTA values predicted at 12 months of age. Note that sire misidentification errors discovered through genomic testing (about 5% in our herd, compared with 15% nationally) were corrected prior to carrying out the analyses described below. A total of 411

Holstein cows were beyond 60 days in milk, and their predicted performance was compared with actual 305-day mature equivalent (ME) milk yield in first lactation, as shown below in Figure 1.

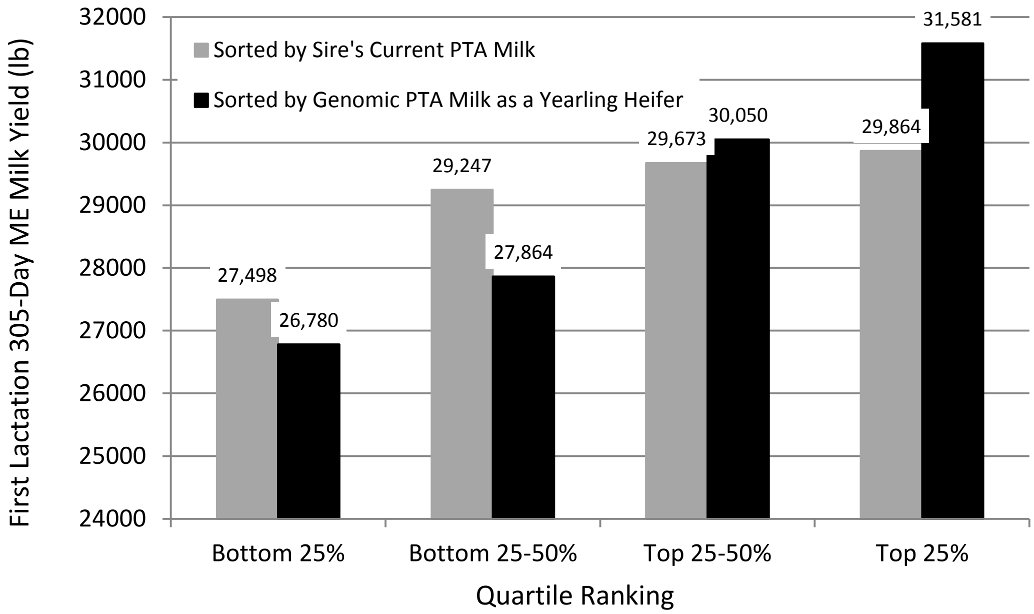


Figure 1. Average first lactation ME 305-day milk yield for 411 Holstein cows in the Allenstein Dairy Herd at UW-Madison, according to quartile for genomic PTA milk at 12 months of age and quartile for sire's current PTA for milk yield.

As shown in Figure 1, the difference between the top and bottom quartiles in actual 305-day milk yield when cows were sorted by current sire PTA was 2,366 pounds per lactation, whereas this difference was 4,801 pounds when cows were sorted by genomic PTA at 12 months of age. This indicates that genomic data of young calves and heifers can be used to predict future lactation performance effectively, and that genomic predictions provide much greater accuracy than simply using information from their sires.

What would have been the cost of selection errors made by culling the bottom 25% of our heifers based on sire PTA values rather than their own genomic PTA information? The difference in actual milk yield between the top 75% of cows based on sire PTA (29,595 pounds) and the top 75% of cows based on early genomic PTA (29,832 pounds) is 237 pounds per lactation. If we multiply this by 2.75 lactations per cow, we get a difference in lifetime production of 652 pounds. After subtracting the cost of extra feed to produce this milk (43% of the value of extra milk) and multiplying by a 3-year average mailbox price of $20.39 per hundredweight, we get a gain in lifetime net revenue of $76 per animal. The total gain for all 309 heifers retained as herd replacements would be $23,484. The cost of genomic testing is roughly $45 per animal, so the total cost of testing 411 heifers is $18,495, which leads to a net profit of $4,989 after accounting for testing costs. In practice the gain would be greater, because a portion of the genetic improvement is passed along to daughters, granddaughters, and so on. And, of course, the primary reason a farmer would consider culling young animals with poor genetic merit is to reduce feed costs during the rearing period. Assuming a rearing cost of $2.30 per day during the post-weaning period, we could have saved approximately $147,798 in feed costs by culling the 102 heifers with lowest genomic

PTA values at 3 months of age. The ability of a farmer to cull a significant proportion of genetically inferior heifer calves depends on several management factors, such as survival rate in pre-weaning calves, pregnancy rate in yearling heifers and lactating cows, and involuntary culling rate in the milking herd.

We also analyzed the data of 240 Holstein cows that were beyond 250 days in milk at the time of the analysis, and their female fertility, as measured by daughter pregnancy rate (DPR) was compared with their actual days open in first lactation, as shown in Figure 2.

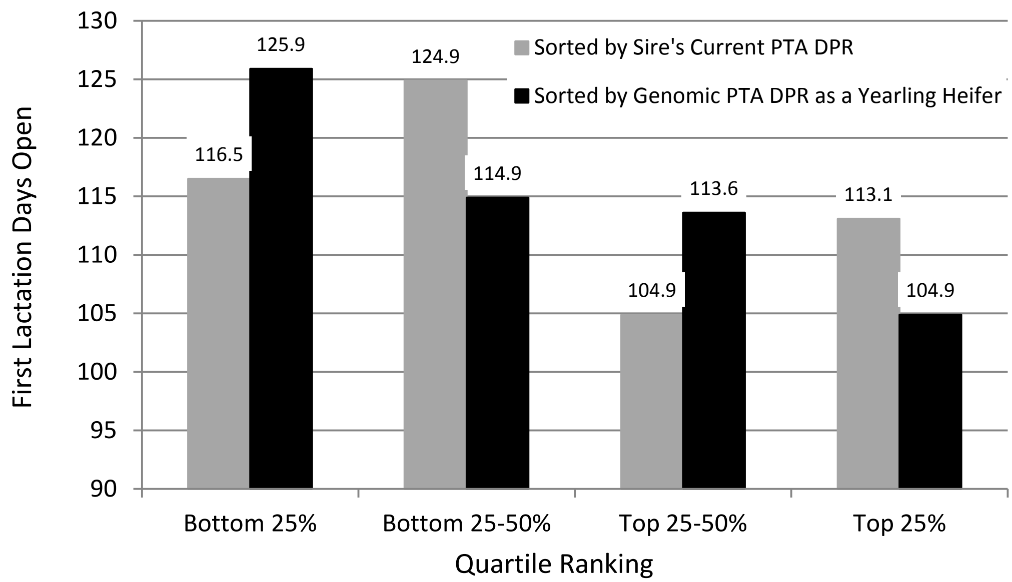


Figure 2. Average days open in first lactation for 240 Holstein cows in the Allenstein Dairy Herd at UW-Madison, according to quartile for genomic PTA for daughter pregnancy rate at 12 months of age and quartile for sire's current PTA for daughter pregnancy rate.

As shown in Figure 2, the difference in actual days open in first lactation was quite large when heifers were sorted by genomic PTA, with the top and bottom quartiles differing by 21.0 days. When we sorted animals by sire PTA, this difference was only 3.4 days, so genomic predictions were significantly more accurate as predictors of future reproductive performance. At a typical value of $2.00 to $3.00 per additional day open, it is clear that savings in labor, technician, and semen costs can help offset the cost of genomic testing.

What about udder health? We compared the genomic predictions for somatic cell score (SCS) with actual average monthly log somatic cell count (SCC) in first lactation for 216 Holstein cows. As shown in Figure 3, there was a clear increase in first lactation log SCC when cows were sorted based on genomic PTA for SCS as a yearling heifer, and the difference between highest and lowest quartiles for genomic PTA (2.38 vs. 1.56) was much greater than for sire PTA (2.20 vs. 1.56). Thus, genomics can also be used to identify heifers that are more likely to suffer from clinical or subclinical mastitis than their contemporaries once they enter the milking herd.

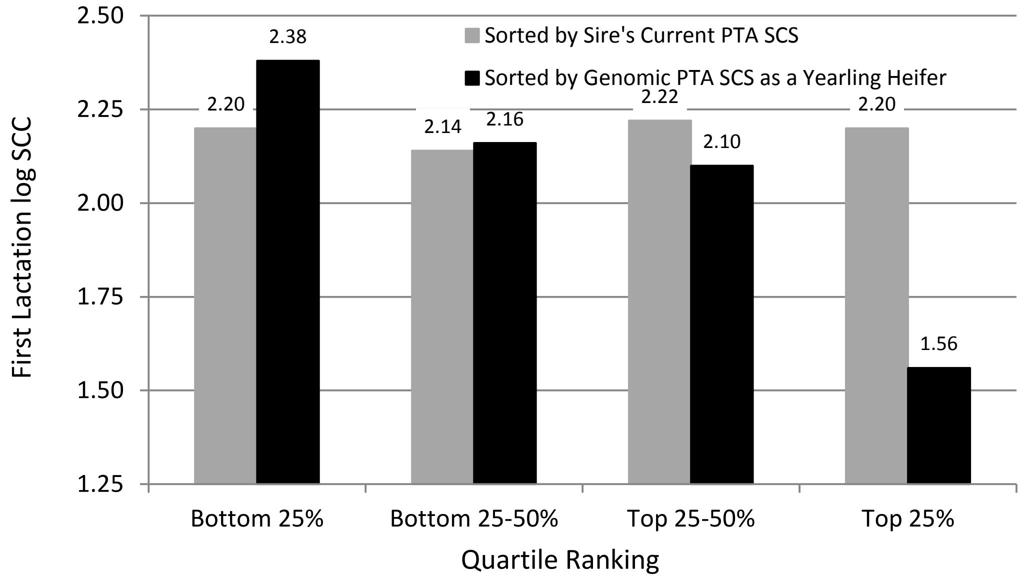


Figure 3. Average log somatic cell count in first lactation for 216 Holstein cows in the Allenstein Dairy Herd at UW-Madison, according to quartile for genomic PTA for somatic cell score at 12 months of age and quartile for sire's current PTA for somatic cell score.

Genomic Results from a Leading Commercial Herd

To confirm the results from the UW-Madison herd, a second analysis was carried out using data from one of the top commercial dairies in Wisconsin, where genomic testing is part of the management routine for all heifer calves. This herd has 920 Holstein cows, with a rolling herd average of approximately 31,000 pounds on 3X milking. All animals with genomic predictions in August 2013 were used in the analysis, and the genomic predictions were compared with their subsequent first lactation performance. Cows with first calving prior to August 2013 were excluded, so none of these animals had performance data of their own at the time of genomic predictions. All cows had the chance to complete at least 60 days in milk for the milk, fat, protein, and SCS analyses (407 cows) or 250 days in milk for the days open analysis (192 cows).

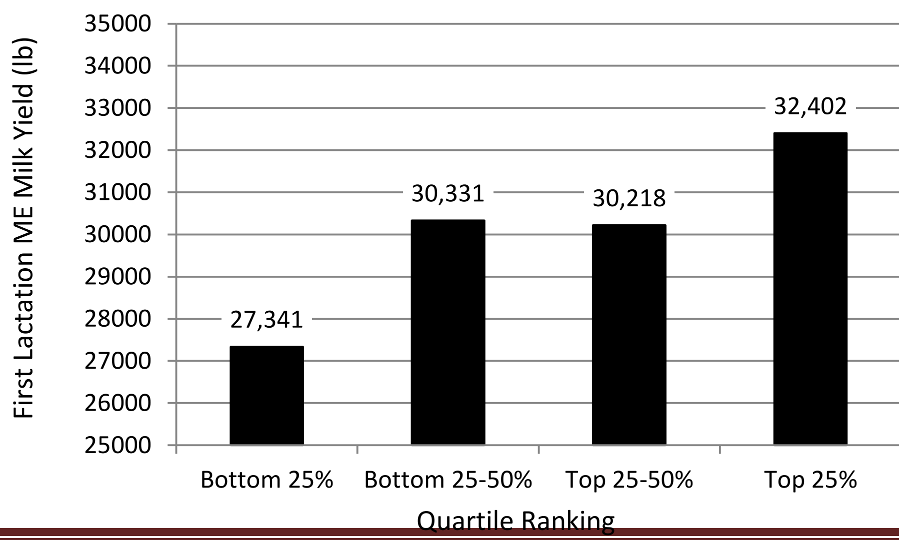


Figure 4. Average standardized 305-day ME milk yield in first lactation for 407 Holstein cows in a leading commercial herd, according to quartile for genomic PTA for milk yield as a yearling heifer.

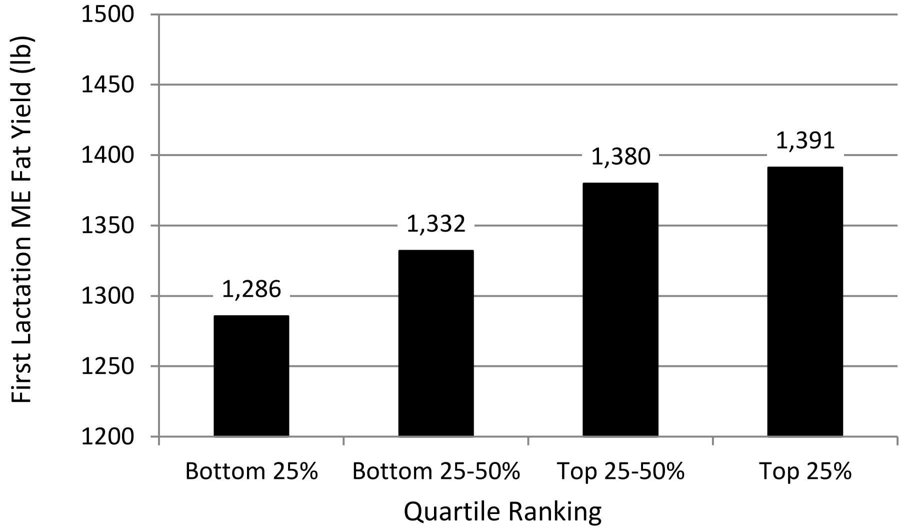


Figure 5. Average standardized 305-day ME fat yield in first lactation for 407 Holstein cows in a leading commercial herd, according to quartile for genomic PTA for fat yield as a yearling heifer.

As shown in Figures 4 and 5 above, as well as Figure 6 below, genomic predictions as a yearling heifer were exceptionally effective as predictors of future lactation performance. Differences in average first lactation yield between the highest and lowest quartiles were 5,061 pounds of milk, 105 pounds of fat, and 93 pounds of protein. More importantly, with respect to early identification and culling of genetically inferior heifer calves to reduce feed costs, differences between the third quartile (bottom 25-50%) and fourth quartile (bottom 25%) were 2,990 pounds of milk, 46 pounds of fat, and 50 pounds of protein.

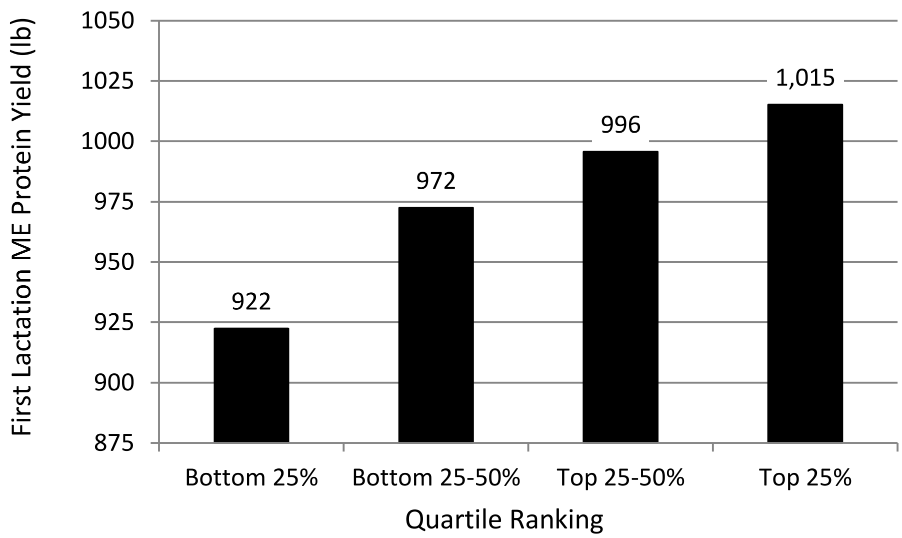


Figure 6. Average standardized 305-day ME protein yield in first lactation for 407 Holstein cows in a leading commercial herd, according to quartile for genomic PTA for protein yield as a yearling heifer.

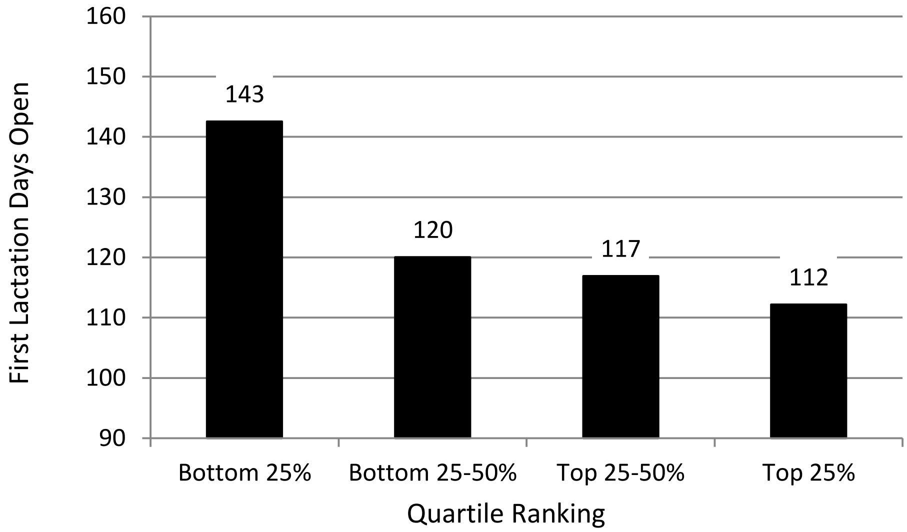


Figure 7. Average days open in first lactation for 192 Holstein cows in a leading commercial herd, according to quartile for genomic PTA for daughter pregnancy rate as a yearling heifer.

As shown in Figure 7, early genomic predictions were quite effective for identifying heifers that will have inferior reproductive performance in the future. Cows that were in the bottom quartile of genomic PTA for daughter pregnancy rate averaged 143 days open, as compared with 120, 117, and 112 for the three other quartiles. Likewise, as shown in Figure 8, early predictions for somatic cell score identified animals that were more likely to suffer from clinical or subclinical mastitis in the future, with average first lactation SCS of 2.48 for the cows with poorest genomic predictions and 2.03, 1.97, and 1.92 for the other three quartile groups.

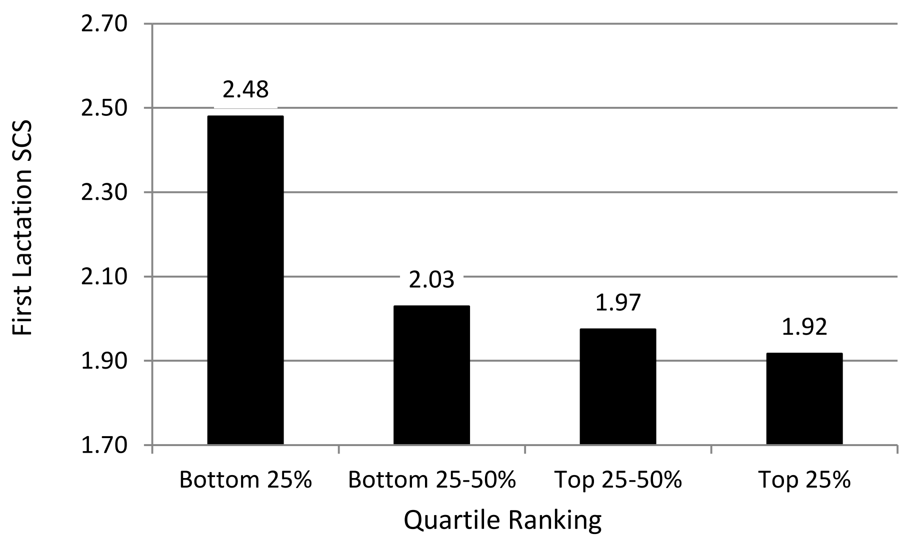


Figure 8. Average somatic cell score in first lactation for 192 Holstein cows in a leading commercial herd, according to quartile for genomic PTA for somatic cell score as a yearling heifer.

Which Animals are Good Candidates for Genomic Testing?

Should a farmer invest in genomic testing of every heifer calf on the farm? This decision depends on the intended use of the genomic results. If the objective is to identify elite heifers for the purpose of marketing embryos, for example, then testing the calves with poorest pedigrees might not be sensible. Likewise, if the only objective is to cull genetically inferior animals, then testing heifers with the top pedigrees might not be useful. Several decision tools are now available to assist farmers with such decisions, as described below:

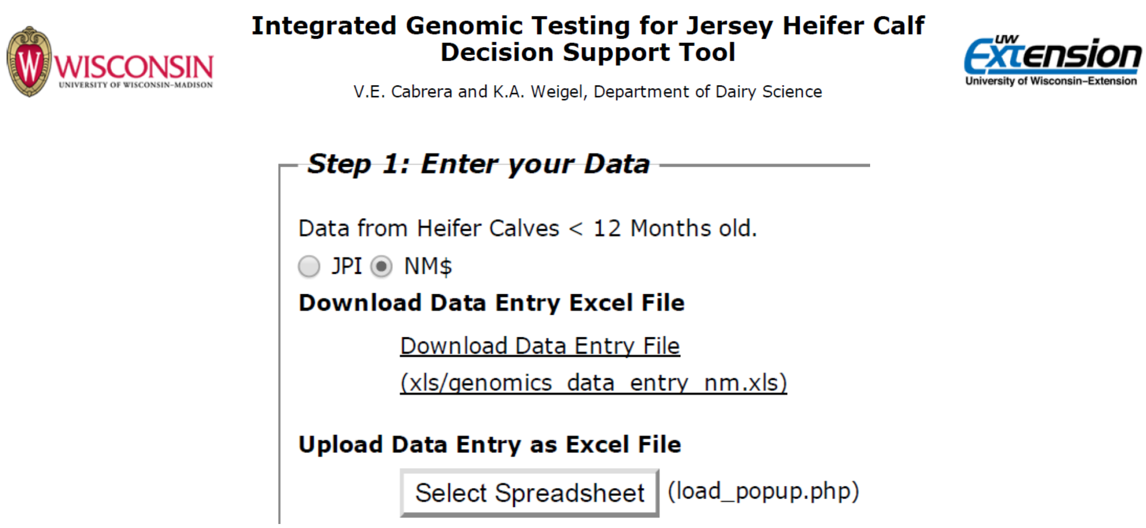


Figure 9. Screen shot of a decision support tool for helping farmers determine which heifer calves are good candidates for genomic testing (http://dairymanagement.wisc.edu/tools/genomics).

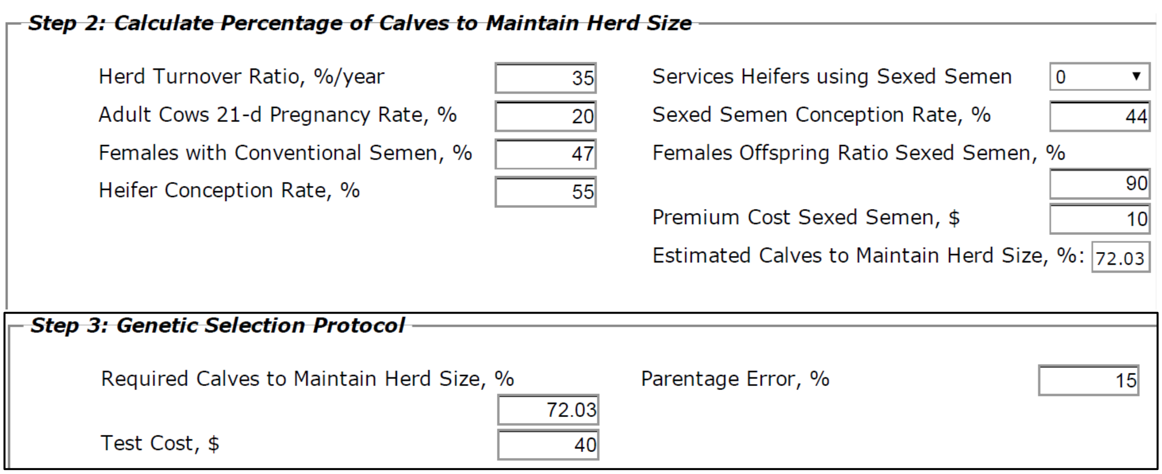


Figure 10. Screen shot of the user interface for the aforementioned genomic decision support tool, using an example data set and default parameters (http://dairymanagement.wisc.edu/tools/genomics).

As shown in the example in Figure 10, a typical herd with 35% turnover rate and 20% pregnancy rate will need to keep a minimum of 72% of heifer calves as herd replacements, leaving the opportunity to reduce rearing costs by culling 28% of calves identified as genetically inferior. The results in Figure 11 suggest that testing every heifer calf (range 0-100) may not be optimal.

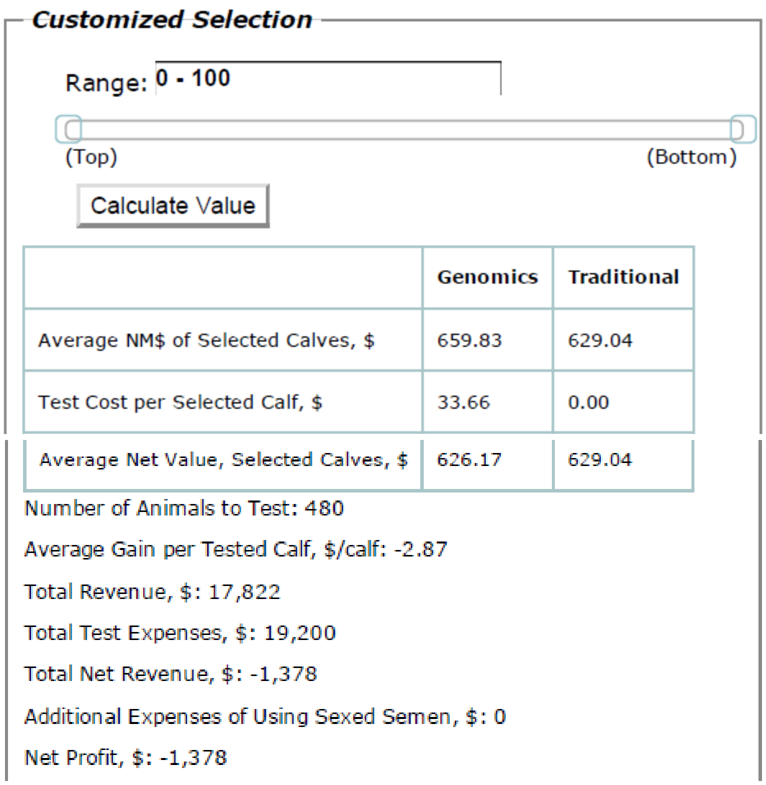


Figure 11. Screen shot of results from the aforementioned genomic decision support tool, using example data and default parameters (http://dairymanagement.wisc.edu/tools/genomics).

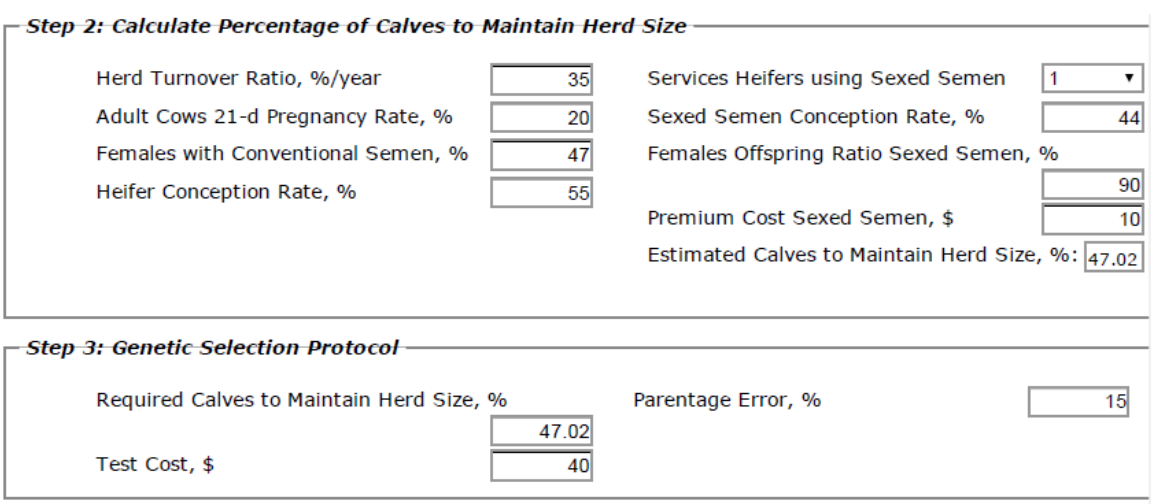
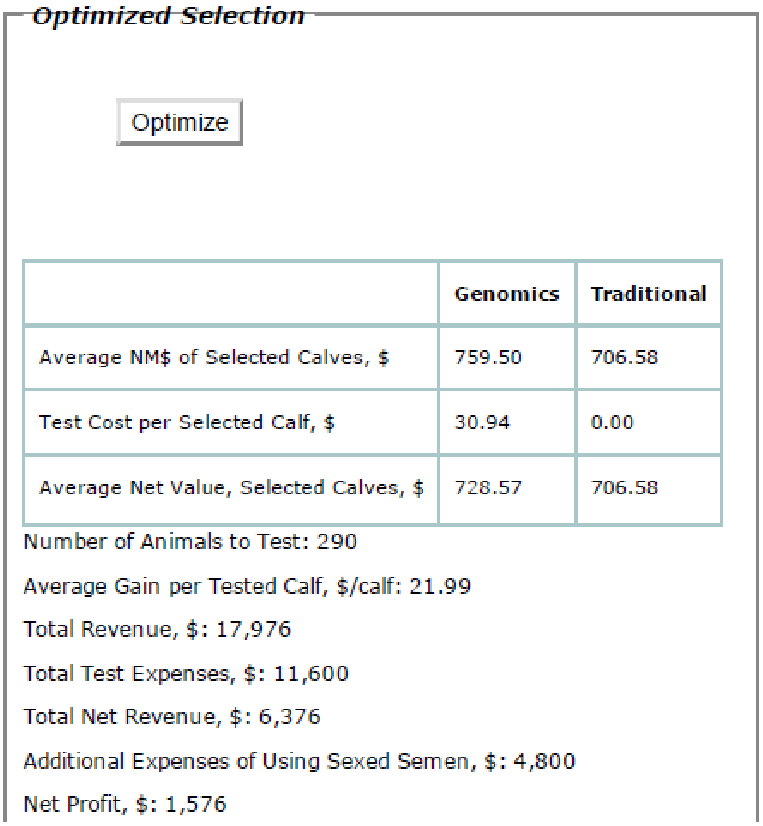


Figure 12. Screen shot of the user interface for the aforementioned genomic decision support tool, using example data and default parameters (http://dairymanagement.wisc.edu/tools/genomics).

Sexed semen can be used to create more selection opportunities, as shown in Figure 12, and allowing the program to optimize the proportion of calves that are tested (in this case, 290 out of 480 total calves) can lead to a more profitable genomic testing strategy (Figure 13).



Optimized Selection

Optimize

	Genomics	Traditional
Average NM$ of Selected Calves, $	759.50	706.58
Test Cost per Selected Calf, $	30.94	0.00
Average Net Value, Selected Calves, $	728.57	706.58

Number of Animals to Test: 290

Average Gain per Tested Calf, $/calf: 21.99

Total Revenue, $: 17,976

Total Test Expenses, $: 11,600

Total Net Revenue, $: 6,376

Additional Expenses of Using Sexed Semen, $: 4,800

Net Profit, $: 1,576

Figure 13. Screen shot of results from the aforementioned genomic decision support tool, using example data with sexed semen and optimization (http://dairymanagement.wisc.edu/tools/genomics).

Other Tools and Opportunities

The key to successful implementation of genomic testing in the long term is development of additional tools that will allow farmers to take an appropriate action for every heifer, depending on the outcome of the genomic test. Such actions might include culling, insemination with sexed semen, use as an embryo donor or recipient, or insemination with beef semen. The Holstein Association USA, in cooperation with Zoetis, has developed a genomic selection “dashboard” for managing the information from your cows, heifers, and calves. In addition to the typical young stock reports, herd reports, and individual cow pages, which show genomic PTA and REL values for production, health, and type traits, there are a number of tools for monitoring and benchmarking the genetic level of your herd, as shown below.

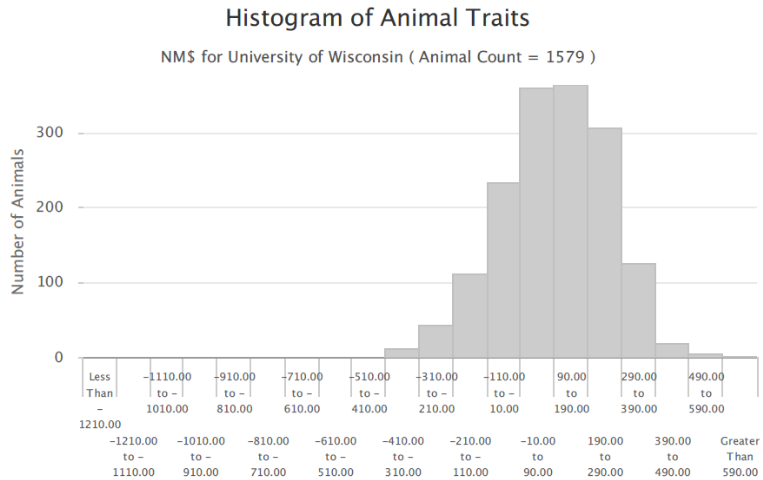


Figure 14. Screen shot of a histogram of Net Merit predictions for genotyped animals in the UW-Madison Allenstein dairy herd, using the Enlight genomic management tool (www.enlightdairy.com).

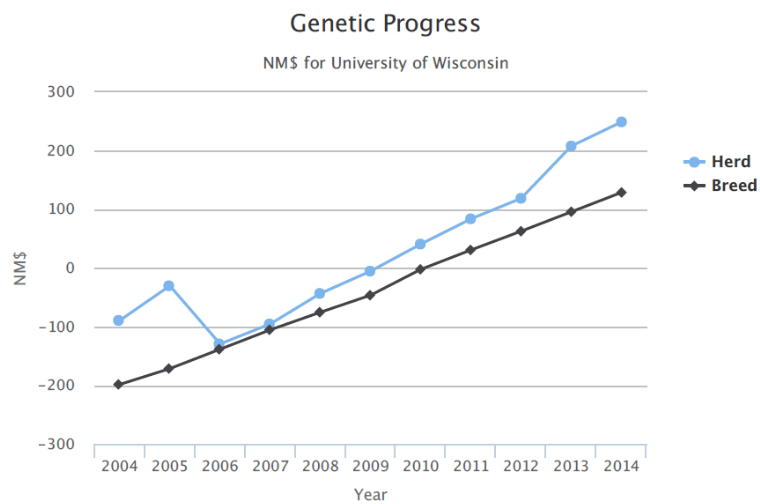


Figure 15. Screen shot of the trend in genetic progress for Net Merit of genotyped animals in the UW-Madison Allenstein dairy herd, using the Enlight genomic management tool (www.enlightdairy.com).

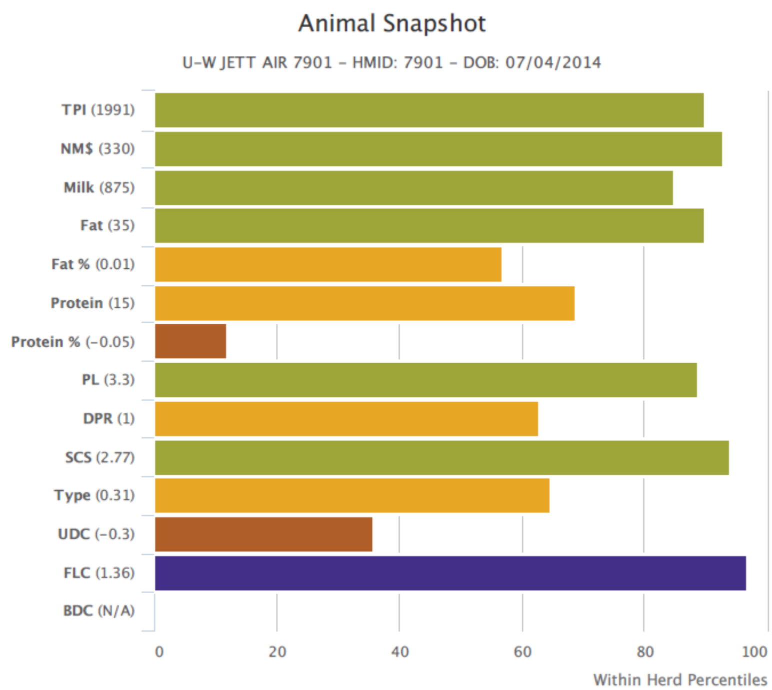


Figure 16. Screen shot of the genomic profile of an example heifer calf in the UW-Madison Allenstein dairy herd, using the Enlight genomic management tool (www.enlightdairy.com).

Additional information is also available, such as data regarding known genetic defects and conditions (e.g., BLAD, Mulefoot, red coat color) and yet-to-be-mapped genetic disorders (e.g., HH1, HH2), and this can be extremely useful for avoiding carrier by carrier matings.

Take Home Messages

- Genomic testing has become fully integrated into dairy cattle selection programs in North America, and nearly every potentially elite bull, cow, heifer, and calf is genotyped.
- Young genome-tested bulls represent the majority of semen in the marketplace, and farmers should manage the risk of their lower reliability values by selecting teams of bulls, rather than focusing too heavily on individual bulls.
- The ability of early genomic predictions to identify heifer calves that will be inferior or superior for production, health, and fertility traits later in life has been firmly established using data from both experimental and commercial herds.
- Decision support tools have been developed that will allow farmers to more effectively identify candidates for genomic testing, evaluate the expected costs and benefits of genomic testing, and monitor their inventories at the herd level and individual animal level.
- Herds that develop standardized protocols for genetic management of replacement animals, including genomic testing, culling, breeding, mating, and related decisions, will reap the greatest benefits of this technology.

Notes:

Variation in Nutrient Composition of Ingredients and TMR and Does it Matter to a Cow?

W. P. Weiss and N. R. St-Pierre
Department of Animal Sciences
Ohio Agricultural Research and Development Center
The Ohio State University, Wooster 44691
Email: weiss.6@osu.edu and st-pierre.8@osu.edu

Introduction

Regardless of the sophistication of the nutritional model or software used to formulate a diet, good feed composition data is essential, and the foundation of feed composition data is a feed sample. Nutrient composition of feeds is not constant; feeds must be sampled repeatedly. The nutrient composition of diets can change because of changes in the nutrient composition of the ingredients or because of formulation changes by the nutritionist. At times ingredient composition will change unknowingly (for example, the silage being fed today came from a weedy part of the field), but at other times compositional changes may be expected (for example, a new load of hay was delivered). Ideally, a change in diet formulation results in a planned change in diet composition or the change was designed to maintain the nutrient profile while changing the ingredient make-up of the diet. However, if a diet is reformulated based on bad feed composition data, the nutrient composition of the diet will change and the diet will not have the expected nutrient profile. This paper will discuss the importance of good sampling in diet formulation, provide some advice on good sampling techniques and discuss effects of diet variation on cows.

Is Sampling Error an Issue?

An ideal sample perfectly reflects the population from which it was taken. If you ground and analyzed an entire 1000 lb. bale of hay and it was 19% CP you would know the exact protein concentration of the hay (assuming the analysis was perfect), but you would have nothing left to feed. On the other hand, if you took a perfect 0.25 lb sample of hay from a 1000 lb bale and assayed it you would know the hay contained 19% CP and still would have about 1000 lbs of hay left to feed. However, if the sample was not perfect you could obtain a CP concentration of 17 or perhaps 23%. If either of those values were used to formulate the diet, the resulting diet would not contain the desired concentration of CP.

The heterogeneity of the nutrient composition of the physical components of a feed is a major factor (probably the most important factor) related to the ability to obtain a representative sample. If a feedstuff is comprised of nutritionally uniform particles, obtaining a biased sample would in fact be extremely difficult. For example, suppose that you are sampling a container of salt (sodium chloride) that is a blend of large salt crystals and fines (salt dust), if your sample contained only large crystals or only salt dust, upon assay both samples would have about 39% sodium and 61% chloride because the individual particles of salt are nutritionally homogeneous. Many common feedstuffs, however are comprised of physical components that are extremely heterogeneous with respect to nutritional composition. Corn silage has particles of corn cob, corn grain, corn leaves and corn stalks. The different plant components are in particles of different size and shape and have different nutrient composition (Table 1).

Table 1. Concentration and 30 hr in vitro digestibility (IVNDFD) of NDF in corn silage and its component parts (Thomas et al., 2001)

	Proportion of plant DM,%		
	% of Plant DM	NDF, % of DM	IVNDFD, % of NDF
Cob	6.5	84.0	55.8
Grain	49.8	11.0	89.7
Husk	5.6	80.3	62.2
Leaves	12.3	63.6	64.5
Stalks	25.1	76.7	39.2
Tassel	0.7	78.1	32.8

If your sample contained a similar proportion of particles from the various plant parts as did the silage, your sample should reflect the nutrient composition of the silage as a whole. However, if your sample contained more or less stalk than the actual population (for example, small pieces of silage fell out of your hand before you put the sample in the bag enriching the stalk portion of the sample), concentrations of starch and NDF and in vitro NDF digestibility values could change substantially (Table 2).

The concentrations of NDF in corn silage on two commercial dairy farms over a 14 day period are shown in Figure 1. Each data point represents a value from a single analysis of a single daily sample. From Figure 1, one could reach the conclusion that the corn silage on Farm 1 is relatively consistent with respect to NDF because its range was only 4 percentage units or about ± 2 percentage units from the mean. Corn silage from Farm 2 appears much more variable (range of 10 percentage units). An alternative and just as plausible explanation to the data in Figure 1 is that the day to day variation is not caused by the silage actually changing but rather by unrepresentative samples. Perhaps the person taking the samples from Farm 1 was just a better sampler than the person taking samples from Farm 2. The usual way we sample forages does not allow separating sampling variation from real day to day variation. If you were formulating diets for Farm 2 (Figure 1) and you sampled on day 4 you would formulate a diet assuming the corn silage had 42% NDF. If you sampled again on day 14, you would reformulate the diet assuming the silage had 33% NDF.

The silage may have actually changed; however, just as plausibly, the silage never changed and actually contains about 38% NDF.

Table 2. Hypothetical effects of biased samples on concentration and 30 hr in vitro digestibility of NDF (IVNDFD) of corn silage

	Representative sample[1]	Biased Sample[2]	
		Extra stalk	Less stalk
% of Whole plant DM	100	100	100
Cob	6.5	5.8	7.2
Grain	49.8	44.3	55.3
Husk	5.6	5.0	6.2
Leaves	12.3	10.9	13.7
Stalk	25.1	33.4	16.8
Tassel	0.7	0.6	0.8
Whole plant NDF[3], % of DM	43.0	46.8	39.3
Whole plant IVNDFD[3], % of NDF	54.6	56.3	53.0
Whole plant starch[4], % of DM	34.9	31.0	38.7

[1] Plant proportions and concentrations of NDF and IVNDFD of the components are from Thomas et al. (2001).
[2]The Extra Stalk biased sample has 33% more stalk than the representative sample (all other components were decreased proportionately) and the Less Stalk biased sample as 33% less stalk than the representative sample.

To determine whether sampling error was a major issue in the field, we undertook a project in which corn silages and haycrop silages were sampled over 14 consecutive days on farms located near Wooster OH (5 for corn silage and 4 for haycrop) and Ferrisburgh VT (3 for corn silage and 4 for haycrop). Every day, 2 independent samples of each silage were taken on each farm. Those samples were sent to the OARDC Dairy Nutrition Lab and analyzed in duplicate using standard wet chemistry methods for DM, NDF, starch (corn silage only) and CP (haycrop only). This resulted in 4 values for each analyte per farm per day (2 farm duplicates x 2 lab duplicates x 14 days x 8 farms = 448 analyses per silage type). This design allowed us to partition the overall variation into that caused by farm, sampling, and analytical. Any variation remaining was assumed to be true day to day variation.

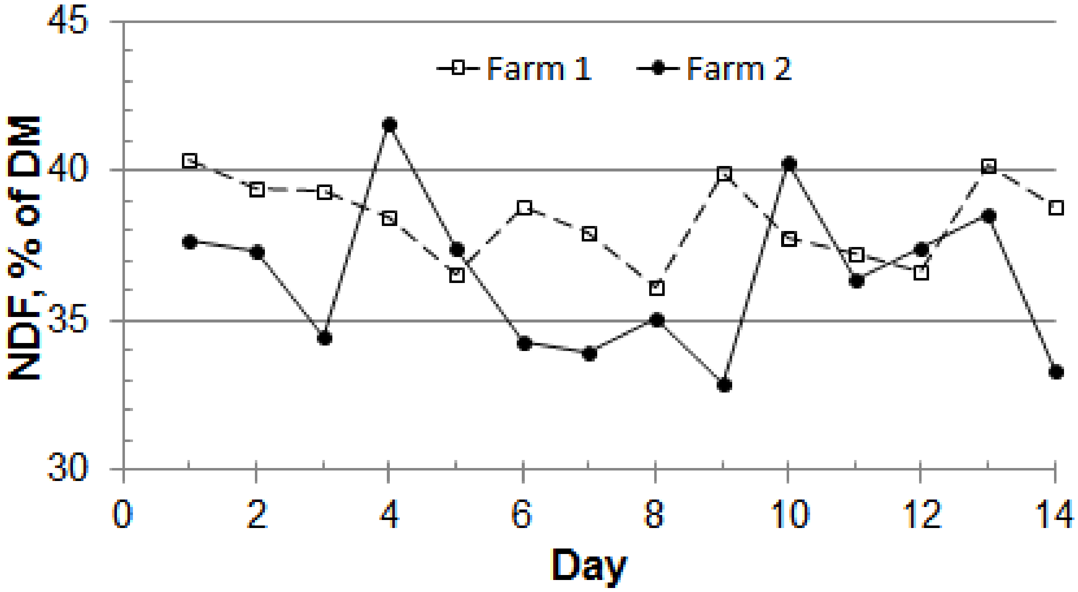


Figure 1. Concentrations of NDF in corn silage from two different dairy farms over a 14 day period. Each data point represents the value from a single assay of a single sample. The coefficient of variation (CV) for Farm 1 is 3.7% and 7.1% for Farm 2.

As expected, farm to farm variation for all measured nutrients in both corn silage and haycrop silage was the greatest contributor to overall variation (Figure 2). Farm contributed between about 70 and 90% of the total variation. Although farm is by far the greatest contributor to variation, it really is not that important. Large farm to farm variation means that you should not take data from corn silage or haycrop silage collected on one farm and use it to formulate diets on another farm. Most nutritionists are well aware of that. Because farm to farm variation was not of major importance, we expressed analytical, sampling and day to day variation as a percent of total within farm variation (Figure 3). With the exception of corn silage DM, analytical variation usually comprised 10% or less of the total within farm variation. Because the same procedure is used to measure DM in all feeds, the high analytical variation for corn silage DM was likely caused by subsampling error. The DM concentrations of the components of corn silage are extremely different. The average DM concentration of the ear (cob, husk, and grain) portion of corn silage is about twice as high as the DM concentration of the stover portion of silage (Hunt et al., 1989). Overall, this data suggest that analytical (or lab)

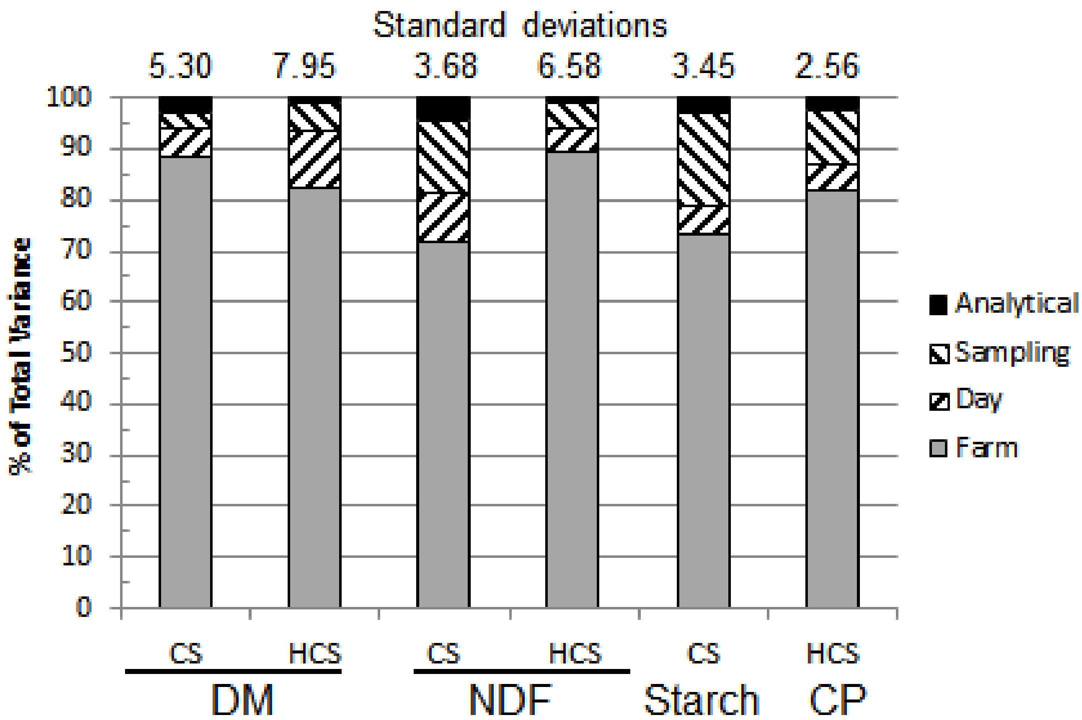


Figure 2. Partitioning total variation from sampling corn silage (CS) and haycrop silage (HCS) from multiple farms over a 14 day period.

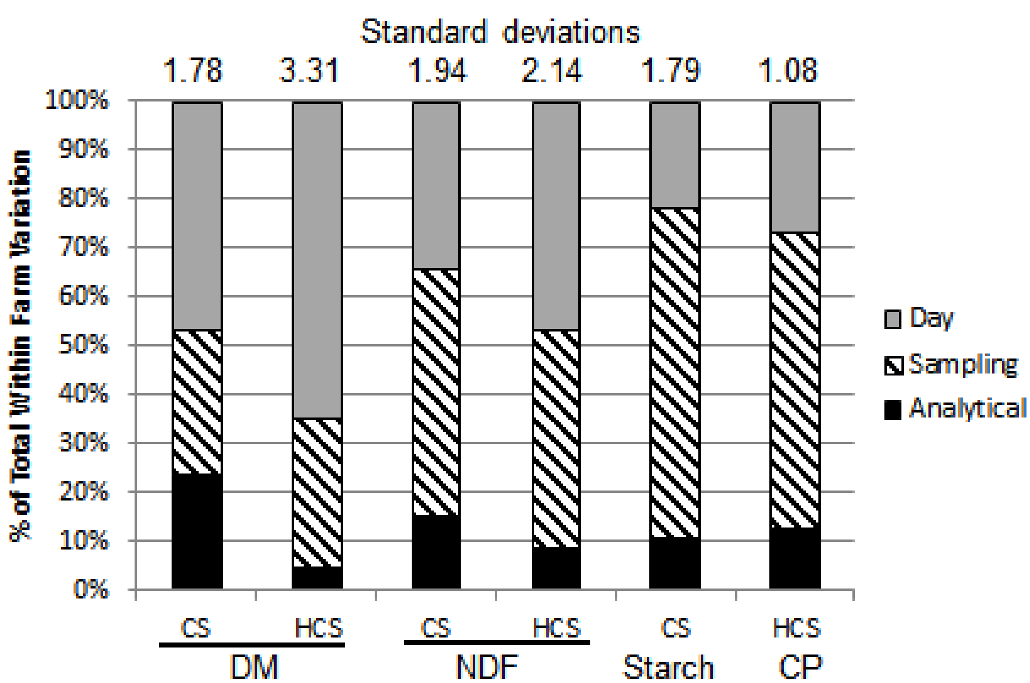


Figure 3. Partitioning within farm variation for corn silage (CS) and hay crop silage (HCS) with 14 daily samples and each assay duplicated by a single lab.

variation is not a major contributor to within farm variation. However, only one lab (a research scale lab) was evaluated. Lab variation may be more or less with other labs. Sampling variation ranged from about 30 to 70% of the total within farm variation, and it was the major source of within farm variation for NDF and starch in corn silage and CP in haycrop silage. True day to day variation ranged from about 20 to 65% of total within farm variation. It was the majority source of within farm variation only for haycrop DM concentration, but the proportion of within farm variation from day to day variation was also high for corn silage DM. True day to day variation in haycrop silage and corn silage DM is expected. The DM concentration of haycrop silage at the time of harvest can change over very short periods of time because of drying conditions. Multiple fields (with different drying rates) could be represented and moisture content can change because of precipitation during storage for both haycrop and corn silage depending on storage method. The proportion of within farm variation caused by day to day changes was also high for haycrop NDF concentration. This could be caused by multiple fields or cuttings being represented over the sampling period. Within field variation of NDF concentrations could also be high because of changing proportions of grass and legume within the field that the silage was grown.

The very large contribution sampling makes to within farm variation has important ramifications for ration formulation. First, high sampling variation means that a single sample of a silage is probably not a good representation of the actual silage; multiple samples are needed to obtain an accurate nutrient description of the silage. Second, high sample variation means that very often what appears to be a change in silage composition (e.g., comparing data from a sample of corn silage taken in May to one in April) actually did not occur. A nutritionist may reformulate a diet because of an apparent change in forage composition when the silage actually did not change. This reformulation based on bad data could result in a poorly balanced diet and a loss in milk yield or perhaps increases health problems such as ruminal acidosis.

What Can Be Done About Sampling Error?

Sampling error can be eliminated by using a sampling protocol that always results in perfectly representative samples. Although this probably is an unobtainable goal, sampling techniques often can be improved which should reduce sampling error. Mix what you going to sample as much as possible before sampling. If you take a grab sample from the face of a bag of corn silage, the sample represents that specific site in the silo. However if you take several loader buckets of the silage, put it in a mixer wagon and sample that, your sample represents a substantially larger amount of silage. We sample physical components of a feed (e.g., a piece of corn cob) we do not sample specific nutrients (e.g., a piece of CP). Therefore sampling procedures that allow for segregation of different particles will increase sampling variation if the different particles have different nutrient composition. Corn silage is arguably the most difficult feedstuff to sample properly. It is comprised of particles that differ greatly in shape, size, density and nutrient composition. Sampling techniques that can result in an enrichment of specific types of particles include: pulling a handful of silage from a face of a bag or bunker silo. Not only should the face of a bunker silo never be sampled because of the real risk of getting killed by a silage avalanche it also can result in a biased sample. Longer pieces (usually leaves and stalks) can be stuck in the silage mass and the handful of silage you pull away will be enriched with smaller particles (likely higher starch particles) and contain fewer large pieces (likely high in NDF). Removing a sample with your palm facing down allow smaller particles to drop away which could reduce the starch concentration of the sample and enrich its NDF concentration. Because of size and density, with movement, larger particles tend to rise to the top of a pile and small particles migrate to the bottom. Not sampling all the vertical strata of a pile could result in a biased sample.

Feeds other than corn silage also present sampling challenges. The liquid and solid phases of wet byproducts such as wet brewers and wet distillers grains can separate during storage. The liquid phase is obviously enriched in water compared with the solid phase but the two phases also differ in NDF and total, soluble, and undegradable CP concentrations. For these feeds, using sampling techniques that ensures the sample contains similar proportions of liquid and solid as the feed is essential. Smaller, less dense particles of ground hay, especially legume hay are enriched in CP and nonfiber carbohydrate. Rolled high moisture corn and cob meal have particles of cob (high fiber, less dense) and particles of grain which can segregate if the meal is removed from the silo and piled prior to sampling and feeding.

Evaluating Sampling Techniques

A good sampling technique should reduce sampling error (i.e., the nutrient composition of repeated samples is similar) and should be accurate (sample results are similar to the true composition of the feed). Accuracy is very difficult to determine because you never know the true composition of the feed you are sampling. Sampling error, however, can be evaluated by repeated sampling. Consider developing a written standard operating procedure (SOP) for sampling. Then over a relatively short period (1 or 2 weeks) take 4 samples of the forage following your SOP, send the samples to a good lab (use a single lab) and have the samples analyzed for DM and NDF. On larger farms that are removing substantial amounts of silage, the repeated sampling could occur during the same day (e.g., sample when feeding different pens of cows). Calculate the standard deviation (SD) and mean and then calculate the coefficient of variation (CV) by dividing the standard deviation by the mean and multiplying by 100. This process should be done on more than one of your client's farms. Based on data we collected from multiple farms, a CV of 4% or less indicates consistent sampling. If the CV you obtained is greater than 4%, make modifications to your SOP (write down the modifications) and repeat. Once you have developed good sampling techniques, occasionally test yourself by repeating this process.

The Value of Multiple Samples

Once you have developed good sampling techniques, taking multiple independent samples of the same forage still has value. For this discussion, multiple samples mean samples of the same silage taken over a short period of time (days or a few weeks). Independent means that the repeated samples are not subsamples. Using the average of repeated samples for diet formulation, rather than a single sample reduces the likelihood that a really bad diet will be formulated because of bad feed composition data. Figure 4 shows the NDF concentration of corn silage from a single farm over a 14 day period. The dashed line represents data from a single sample per day from a single assay. The range, mean, SD, and CV for that line are: 9 percentage units, 36.5%, 2.61, and 7.1%. The solid line in Figure 4 represents the mean of duplicate samples taken each day (single assay per sample). The range, mean, SD, and CV for that line are: 5 percentage units, 36.7%, 1.38, and 3.8%. Duplicate sampling had almost no effect on the overall mean but reduced measures of variation by about 50%. A single sample could have been as much as 5.2 percentage units from the overall mean; whereas the mean of duplicate samples was at most 3 percentage units from the mean. Using means of repeated samples greatly reduces the risk of a bad sample.

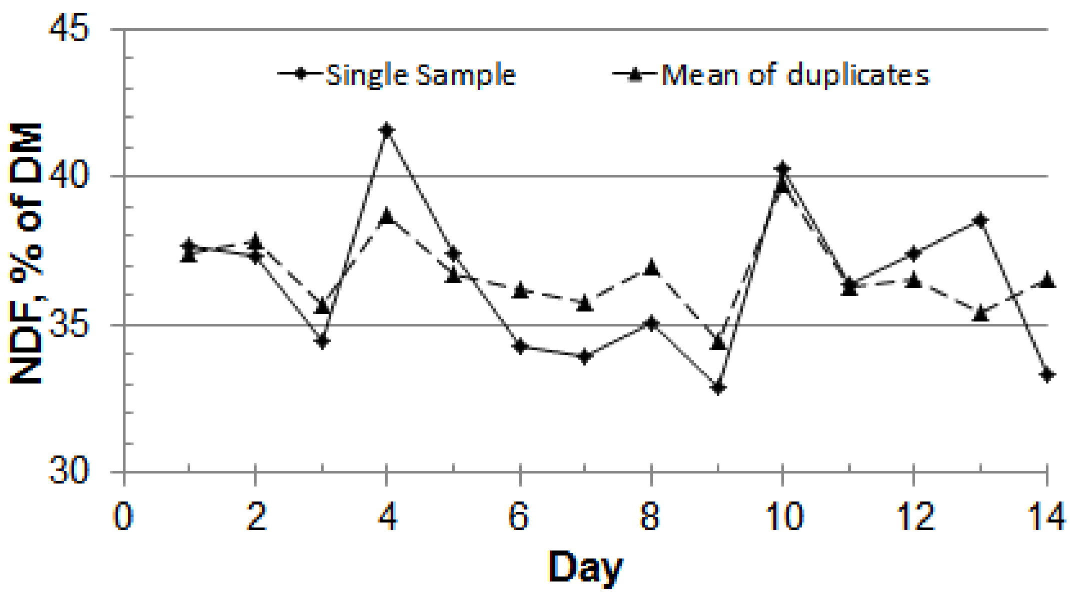


Figure 4. Effect of duplicate daily sampling on reducing variation in corn silage NDF. The solid line is data from a single assay of a single daily sample. The dashed line is the mean of the sample used in the solid line plus its duplicate sample. The coefficient of variation for the Single sample line is 7.1% and 3.8% for the duplicate sample line.

Does Variation Matter to a Cow?

Although sampling error is a major cause of short term variation in composition of feed ingredients and TMR, feeds do have real variation. If you have read articles or attended conferences about dairy cattle nutrition, you have likely heard or read something to the effect, "cows do better when fed a diet that is consistent day to day". Although this seems to make sense, essentially no research has evaluated the effect of diet inconsistency on dairy cows. In the past few years we have conducted 4 studies at Ohio State to address the question, does short term variation or transient changes in diet composition affect dairy cows. We have evaluated effects of varying silage dry matter concentration (McBeth et al., 2013) and dietary concentrations of long chain fatty acids (Weiss et al., 2013), crude protein (Brown and Weiss, 2014), and forage NDF (Yoder et al., 2013). Extreme variation in concentrations of dietary fatty acids (from corn oil and distillers grains) reduced dry matter intake and milk yield but considering the degree of variation (diets changed from 4.8 to 7.0% long chain fatty acids), the effects were small. In another experiment cows were fed a diet with 16.4% crude protein (CP) or 13.4% CP every day or a diet that contained 10.3% CP for 2 days followed by a diet with 16.4% CP for 2 days over a 28 day period. The average CP concentration of the oscillating treatment was 13.4%. Concentrations of milk urea nitrogen accurately reflected the oscillation in dietary protein however it had a 1 day lag. Milk yield also followed a cyclic pattern in cows fed the oscillating treatment, but average milk yield for the entire period was not significantly different between treatments (78, 76, and 74 lbs/day for cows fed the 16.4%, 13.4% or oscillating treatments). Although not statistically different, if the experiment went longer, milk yield by cows on the oscillating treatment would likely be lower. Even though milk yield was likely reduced because of variation in dietary protein concentration, the imposed variation was extreme (10.3% to 16.4% CP).

Effects of transient variation in silage dry matter

Transient changes in silage DM concentrations can occur because of weather events (e.g., unprotected silage in a bunker gets rained upon); therefore, this experiment (McBeth et al., 2013) was conducted to determine whether short terms changes in silage DM affected cows and whether as-fed rations should be adjusted to account for the short term change in silage DM. One treatment was a consistent diet over the 21 day experiment that contained 55% forage (2/3 alfalfa silage and 1/3 corn silage) on a DM basis and 45% concentrate. The second treatment was the same as the first treatment except during two 3-day bouts when wetted silage was fed. Wetted silage was made by adding enough water to the mix of alfalfa and corn silage to reduce its DM concentration by 10 percentage units. During those two 3-day bouts the wetted silage replaced the normal silage on an equal as-fed basis. Because the silage was wetter, the forage to concentrate ratio during the bouts for this treatment was reduced to 49:51 on a DM basis. During the bouts the NDF concentration was lower for this treatment and the starch concentration was higher. The third treatment was the same as the second treatment except that during the bouts the amount of as-fed forage offered was increased to maintain the same forage to concentrate ratio, and concentrations of NDF and starch (on a DM basis) as the control diet. Over the 21 day experiment, DM intake of the two wet silage treatments did not differ from the control but milk yield was higher than control for the unbalanced, wetted silage treatment (87.6 vs. 86.5 lbs/day). The increased milk yield is likely in response to the increased concentrate in the diet during the bouts. Milk yield was the same for cows fed the control or fed the diet with wetted silage that was reformulated to account for the added water. **In this experiment, cows were offered excess feed so that when the wetter diets were fed, the cows did not run out of feed.** This approach was likely the reason we did not observe any negative effects. When fed the wetted silage, as-fed intake of the cows increased immediately; this could not have happened if excess feed was not offered to the cows. As-fed intake continued to increase during the second day of the bouts and it was not until the second day of feeding wetted silage that DM intake returned to normal for those cows.

An interesting finding of this experiment, which also has practical application, is the intake pattern of cows when they switched from the wetted silage back to their normal diet. The day following each bout, DM intake was higher than control. Cows appeared to consume about the same amount of as-fed feed on the day when they returned to the normal DM silage but because the diet was drier, DM intake increased compared to control. This implies that extra feed should be offered to cows when they are switched from wet silage back to the normal silage. From our study, rebalancing diets for a short term (a few days) change in silage DM is not necessary. However, increasing the amount of feed offered is probably important to maintain production, and excess feed should be offered for a day or two after the silage DM returns to normal.

Extreme Day to Day Variation in Forage Quality

Because of variation within fields, the composition of a mixed legume-grass silage can be extremely variable. This experiment (Yoder et al., 2013) was conducted to evaluate the effects of extreme daily variation in forage quality. The experiment had 3 treatments but because of space limitations, only 2 treatments will be discussed. One treatment was the control and forage quality was as consistent as possible day to day (SD for dietary concentration of forage NDF = 0.5). The second treatment (Variable) had a constant forage to concentrate ratio (same as the control), but the ratio of alfalfa to grass varied daily in a random pattern resulting in large variation in the concentration of forage NDF in the diet (fNDF SD = 2.0). On average, over the 21 day period, treatments were equal in percent forage, alfalfa to grass ratio, forage NDF (25%), CP, and starch.

Over the 21 day experiment, cows on the Variable treatment consumed similar amounts of DM and produced similar amounts of milk compared to the Control. Daily within cow variation in milk yield and DM intake were significantly greater for cows on the Variable treatment compared with Control. Based on other measurements we made, there are two likely reasons cows were not negatively affected by extreme daily variation in forage quality in this study. First excess feed was provided to cows every day. On days when cows were fed a high forage NDF diet, dry matter intake was reduced (high feed refusal) but then on days when lower forage NDF diets were fed, the excess feed delivery allowed cows to consume additional feed. Effects of diet variation were also probably mitigated by transient mobilization of body energy. On days when cows were fed high concentrations of grass (i.e., lower quality forage), DM intake was reduced but cows mobilized energy to maintain milk yield. On days when cows were fed a better diet (more alfalfa and less grass), cows ate more and produced more milk. This suggests that over a longer time period (this experiment only lasted 3 weeks) a highly variable diet could reduce body condition which can have long term negative impacts on reproduction and production. Unquestionably, long term losses in body condition is a negative, the very modest potential effects on body condition must be put in context of the extreme variation imposed in this experiment.

Conclusions

Good samples are the cornerstone of good diet formulation; however sampling error for some feeds is large. If sampling technique is poor and the uncertainty surrounding feed composition data is expressed as plus or minus several percentage units, using nutritional models that formulate diets to the tenth decimal place will not result in well formulated, consistent diets. Good SOP for sampling should be developed and followed. Multiple samples of feeds should be taken to monitor sampling variation and averages of composition data should be used rather than data from a single sample to reduce the impact of improper sampling. Although sampling is a major source of variation in diet composition, real variation does exist but substantial day to day variation in nutrient composition did not have large negative effects on cows. This may mean that a 24 hour day is not the correct periodicity for assessing variation. Some of our data suggest that a period of 2 or 3 days may be more appropriate. In other words, if nutrient composition differed between two successive 3-day periods, cows might be more likely to respond to that variation. We have some evidence that diet variation may have cumulative negative effects and that over a longer term (months), negative effects of variation may increase. A key management factor that appeared to reduce the effects of variation was ensuring cows had access to adequate feed on all days. If the diet changes and cows need to consume more feed (e.g., the diet becomes wetter) or the diet changes and the cow can consume more feed (e.g., diet changes from a higher concentration of NDF to a lower concentration), feed must be available to allow the cow to compensate. If this compensation cannot occur, the effects of variation would likely be exacerbated. Although providing excess feed may mitigate some negative effects of variation, it will also increase feed costs.

Acknowledgements

Part of this project was supported by a grant from the National Research Initiative from the USDA National Institute of Food and Agriculture. We also want to thank the farmers and nutritionists who participated in this project.

References

Brown, A. N. and W. P. Weiss. 2014. Effects of oscillating the crude protein content in dairy cow rations. J. Dairy Sci. 97 (E-suppl. 1):169 (abstr.).

Hunt, C. W., W. Kezar, and R. Vinande. 1989. Yield, chemical composition and ruminal fermentability of corn whole plant, ear, and stover as affected by maturity. J Prod Agr. 2:357-.

McBeth, L. J., N. R. St-Pierre, D. E. Shoemaker, and W. P. Weiss. 2013. Effects of transient changes in silage dry matter concentration on lactating dairy cows. J. Dairy Sci. 96:3924-3935.

Thomas, E. D., P. Mandebvu, C. S. Ballard, C. J. Sniffen, M. P. Carter, and J. Beck. 2001. Comparison of corn silage hybrids for yield, nutrient composition, in vitro digestibility, and milk yield by dairy cows. J. Dairy Sci. 84:2217-2226.

Weiss, W. P., D. E. Shoemaker, L. R. McBeth, and N. R. St-Pierre. 2013. Effects on lactating dairy cows of oscillating dietary concentrations of unsaturated and total long-chain fatty acids. Journal of Dairy Science 96:506-514.

Yoder, P. S., N. R. St-Pierre, K. M. Daniels, K. M. O'Diam, and W. P. Weiss. 2013. Effects of short term variation in forage quality and forage to concentrate ratio on lactating dairy cows. J. Dairy Sci. 96:6596-6609.

Notes: