Byproducts for Dairy Cows: Unlocking Their Value and Dealing with Their Limitations

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INTRODUCTION

Byproduct feeds have long been fed to ruminant animals. For example, an ancient Greek writer noted that in an attempt to supplement poor pastures, sheep on the Greek island of Ceos were fed fig leaves, olive leaves, and plant husks (Wilson, 2006). Today feed byproducts still originate from many human activities such as the production of food, fiber, beverages, and more recently bioenergy industries. Many byproducts are produced and available in large quantities and sold as commodities across the country and world; but it is also important to remember that byproducts produced are usually a secondary objective of some process (Crawshaw, 2004). Although they may contain a high concentration of nutrients and improve palatability of dairy rations; their existence, chemical composition, and nutrient availability may be affected by changes in the primary industry and production process. Nonetheless, the dairy industry has historically welcomed the availability of new byproducts and has also learned to adapt to changes in those commonly offered. Obviously, the type of byproducts vary by geographical location, but the objective of this work is to outline some major byproducts used by the dairy industry in the mid-south region of the U.S. and to outline their origin, chemical composition, and nutrient availability.

CORN MILLING BYPRODUCTS

Dry Milling

The dry milling industry produces the following feed products; distillers grains (**DG**), distillers grains and solubles (**DGS**), and distillers solubles (**DS**). Depending on the plant, and whether it is producing wet or dry feed, the proportion of DG and DS that are mixed together may vary. However, our current estimates are that wet distillers grains (**WDG**) + DS are approximately 65 % DG and 35 % DS (DM basis). Distillers grains (and DS) will hereby be referred to as either wet distillers grains (**WDDGS**) or dry distillers grains (**DDGS**) and our assumption is that both contain some solubles. The dry milling process is relatively simple. Specifically corn (or possibly some other starch sources) is ground, fermented, and the starch converted to ethanol and CO_2. Approximately 1/3 of the DM remains as the feed product following starch fermentation. As a result, all the nutrients are concentrated 3-fold because most grains contain approximately 2/3 starch. For example, if corn is 4 % oil, the WDDGS or DDGS will contain approximately 12 % oil; however more recently some of this oil is removed through centrifugation and the crude fat (**CF**) of these feeds may be as low as 6 %.

Feeding Distillers Grains to Dairy Cattle: How Much Can We Feed?

The American dairy industry consumes about 42 to 46 % (National Corn Growers Association, no date; Renewable Fuel Association, 2008) of the total DG produced in the U.S. Several studies have shown the effects of utilizing DG in dairy rations. It has generally been demonstrated to be an effective feed when incorporated into dairy feeding systems as it supports similar or higher milk yield than compared to control diets (Schingoethe et al., 2009). In feedlot diets inclusion of 20 % DDGS (DM) has resulted in greater economic returns (Buckner et al., 2008). It is likely that in dairy rations inclusion of DDGS results in a similar situation as it can replace proportions of highly priced feedstuffs, such as corn and soybean meal and even forages.

Even though DDGS have a valuable nutritional composition, dairy nutritionists tend to limit the inclusion of DDGS to 10 % of the dietary DM (Janicek et al., 2008; Schingoethe et al., 2009). Historically one reason for this is that the fat content was high, generally ranging between 10 and 12 % (Kleinschmit et al., 2006; Schingoethe et al., 2009). This may result in milk fat depression (**MFD**) due to the high content of polyunsaturated fatty acids (**PUFA**) present in DDGS, which has been observed experimentally. For example, Leonardi et al. (2005) reported a linear decrease in milk fat percentage as the inclusion of DDGS increased in the diet. This

reduction was only significantly different between 10 and 15 % DDGS when milk fat dropped from 3.33 to 3.24 %. Similarly, Hippen et al. (2010) reported that DDGS fed at 20 % of the diet resulted in a reduction in the concentration of fat in milk. These changes were slight and not very dramatic as diets with no DDGS averaged 3.21 % and 3.13 lb of milk fat; whereas diets with DDGS averaged 3.03 % and 2.82 lb. The reason for this reduction in milk fat is likely due to the high ruminal load of PUFA that may affect the extent of biohydrogenation and lead to accumulation of *trans* fatty acids that may ultimately cause MFD. The recent reductions in fat content of DDGS make the threat of MFD less likely (Ramirez-Ramirez et al., 2016)

When formulating a ration containing DDGS, nutritionists and producers must be careful to take into account not only the amount of neutral detergent fiber (**NDF**) in the diet but also the source of NDF. Ethanol byproducts have high content of fiber (from the bran fraction of the corn kernel); however it may not be effective fiber, meaning that it does not elicit high rates of ruminal motility, rumination activity, and saliva production. The end result of these factors is that ruminal pH may drop, leading to ruminal acidosis; which has the potential to exacerbate the negative effects of a high load of PUFA in the rumen. It is critical to fully understand the nutritional composition of DDGS, particularly as the fat content; nonetheless, it can also replace corn, which lowers the starch content of the diet and decreases the risk of developing low rumen pH (Ramirez Ramirez et al., 2015).

Nutrient Variation and Distillers Grains and Solubles

Investigations have demonstrated that there may be a high degree of variation in the nutrient content of co-products, such as DG, both within and across production plants (Knott et al., 2004; Spiehs et al., 2002). For example, Knott et al. (2004) demonstrated that the crude protein (**CP**) level in DG may range from 25 – 35 %, with variation also observed in fat (10-12 %), NDF (8-10 %) and phosphorus (0.8 – 1 %). These investigators note that one of the greatest sources of nutrient variation for DDG depends on the amount of solubles that were added to the grains. Along with the concentration of CP, the availability of these nutrients may also vary. Hence researchers are beginning to direct their attention towards creating practical methods for controlling this variation. Research from The Ohio State University (St-Pierre and Weiss, 2015) suggests that routine feed sampling is essential. Because it may be difficult and time consuming to sample and formulate rations based on lab results of individual loads, numerous load samples should be collected and analyzed over time. This will allow for estimation of the mean values and also the variation of these estimates. Consequently, it becomes possible to protect against underfeeding a nutrient, such as protein, by feeding an anticipated mean value of the feed.

Wet Milling

Compared to the dry milling process, the wet milling process is the more complex of the 2 because the corn kernel is partitioned into several components to facilitate high value marketing. For example, the oil is extracted and sold and the corn gluten meal, that contains a large amount of bypass protein, is commonly marketed to the dairy, poultry, or pet industries. Wet milling is a process that requires use of high quality (No. 2 or better) corn that results in numerous products that are produced for primarily human use. During this process, corn is *steeped* and the kernel components are separated into corn bran, starch, corn gluten meal (protein), germ, and soluble components. Wet corn gluten feed (**WCGF**) usually consists of corn bran and steep, with germ meal added if the plant possesses the capabilities. Wet CGF can vary depending on the plant capabilities. Steep liquor contains more energy than corn bran or germ meal as well as protein (Scott et al., 1997). Therefore, plants that apply more steep to corn bran or germ meal will produce wet CGF that is higher in CP and energy. Wet CGF contains 16 to 25 % CP, with a rumen undegradable protein (**RUP**) value of approximately 24 - 30 % CP (NRC, 2001). During wet milling, corn gluten meal is removed and marketed in higher value markets. Corn gluten meal *should not* be confused with CGF, as corn gluten meal contains approximately 60 - 65 % CP and a RUP value of approximately 64 - 75 % CP (NRC, 2001). Distinct differences exist for WCGF, even within companies, due to plant-to-plant variation.

A number of studies demonstrate the general concept that traditional forages may be partially replaced and byproducts may be included to maintain milk production. For example, VanBaale et al. (2001) observed that when fed diets containing 20 % WCGF, cows consumed more DM and produced more milk than those consuming diets higher in alfalfa hay, corn silage, and corn grain. Boddugari et al. (2001) demonstrated that a wet corn milling product, similar to WCGF, may be effective in diets for lactating dairy cows. When used to replace concentrate, the product could be included at 45 % of the ration DM and at over 60 % when used to replace

corn and forage. In a feeding trial these investigators also observed that, on average, cows consumed less feed but produced over 10 lb more milk when the WCGF replaced 50 % of the concentrate and 30 % of the forage of the control diet. These results suggest that the optimal inclusion level depends upon the feedstuffs being substituted for, as well as other ingredients contained in the ration.

Clearly the dairy cow is adaptable and can use non-traditional feedstuffs as sources of nutrients to make milk; however there clearly are limitations to her abilities. In a study designed to test the inclusion of corn gluten feed, Rezac et al. (2012) formulated diets in which both corn silage and alfalfa were completely removed from the ration and substituted with CGF and tallgrass prairie hay. On average, the complete removal of corn silage and alfalfa resulted in a reduction in the concentration of NE_L from 0.74 Mcal/lb to 0.72 Mcal/lb and resulted in a reduction of almost 5 lb of energy corrected milk (**ECM**). Certainly these results are not ideal; but the rations used in the study were dramatically different. For example, the concentration of starch was reduced from 21 to 13 % and forage NDF was reduced from 15 to 11 %. These treatments were designed to test strategies that could be used when the availabilities of traditional forages are poor and feeding conditions are not ideal. A more recent study evaluated the inclusion of WCGF at 20 or 30 % of the diet DM (Shepherd et al., 2014), both concentrations of inclusion maintained milk production and composition, but the authors suggested that the increase to 30 % requires careful consideration of effective fiber. Care should be taken to ensure that animals are consuming enough forage NDF to maintain healthy rumen conditions.

Effective Fiber Corn Milling Co-Products

Effective fiber is the portion of the diet that is believed to stimulate rumination, chewing activity, and saliva secretion; all of which is designed to help to maintain healthy rumen function and pH levels. Nutritionists are often concerned about rumen pH because, when pH levels fall below 6.0 fiber digestion may be impeded and milk fat levels may become depressed (Russell and Wilson, 1996). It is believed that rumen pH is a function of lactic acid and VFA production and is buffered by saliva (Maekawa et al., 2002). Because of this finding, it is a common practice to feed diets of longer particle size; therefore a greater amount of effective fiber, so that salvia production is stimulated. In support of this hypothesis, Krause et al. (2002) noted that the intake of particles > 19.0-mm was negatively correlated with the amount of time rumen pH was below 5.8. However, it is also known that diets should not be excessively long or coarse as they are more difficult to mix and may induce cattle to sort out ration ingredients (Kononoff et al., 2003). When co-products are used to substitute forage in the TMR, chewing activity is believed to be reduced due to the finer particle size. Nutritionists should not necessarily use this logic to infer that feeding co-products will result in lower rumen pH. In fact it is likely that diets may be balanced so that the inclusion of co-products will not influence rumen pH. When evaluating a dairy diet to determine a possible risk of subclinical acidosis, it is important to also consider levels of fiber and non-structural carbohydrates, along with their associated fermentability (Yang et al., 2001). Currently it is difficult to find robust feeding recommendations for effective fiber. Recently studies in which byproduct NDF replaced forage, concentrate, or both; have been conducted (Bradford and Mullins, 2012) and in some cases provide good examples for formulation but research on a field-ready, robust system to estimated effective fiber is still needed. Without this system it is wise to follow particle size recommendations previously established, which suggest that 3-8 % of the TMR should be retained on the top (19 mm) screen of the Penn State Particle Separator and 30 - 40 % should be retained on the second (8 mm) sieve (Heinrichs and Kononoff, 2002).

CANOLA MEAL

Canola is a trademarked name for rapeseed which contains < 2 % erucic acid in the oil and < 30 µmoles of alkenyl glucosinolates/g of oil-free DM. As a result canola meal contains less erucic acid and glucosinolates than conventional rapeseed meal (Bell, 1993). This is important because glucosinolates are bitter and negatively affect palatability and may even impair the uptake of iodine and interfere with the synthesis of thyroid hormones (Woyengo et al., 2016). In a summary of publication studies Huhtanen et al. (2011) reported that when fed to dairy cattle canola meal was at least as good as soybean meal and that some improved responses are due to increases in feed intake. It should however not be forgotten that feeding high concentration of canola meal may affect iodine status of the animals. Although feeding additional iodine to cattle has been shown to improve iodine status (Weiss et al., 2015), this practice is not common and additional research and recommendations must be made to fully understand the potential effects on humans consuming this milk.

OTHER NONFORAGE FIBER SOURCES

In a study designed and conducted at the William H. Miner Research Institute (Chazy, NY) to test the impact of feeding rations lower in both starch and forage, 4 treatments were formulated to contain decreasing proportions of forage (52, 47, 43 and 39 % of diet DM) by increasing the proportion of non-forage fiber sources (**NFFS**), namely wheat middlings (Farmer et al., 2014). Additionally, in an attempt to maintain energy and effective fiber in the rations, these investigators increased the proportion of rumen protected fat and wheat straw as the proportion of forage was reduced. In this study, DM intake increased with reducing forage but no differences were observed in milk production or composition. Interestingly, these ration strategies successfully maintained milk production over 94 lb/d and 3.6 % fat and 3.0 % protein. It should be noted while reducing forage in the ration, that this strategy involved careful attempts to maintain effective fiber. The reduction of forage did reduce the proportion of particles greater than 8.0 mm; however, no reductions were observed in rumination times, which suggests that effective fiber was still adequate.

In a similar study, Hall and Chase (2014) tested the impact of feeding varying proportions of chopped wheat straw and sugar beet pellets, which replaced a portion of both corn and alfalfa silage. Specifically forage was reduced from 61 % of the diet DM in the control to 40 % in the treatments containing variable mixes of straw and beet pulp pellets. The study included 48 cows in late lactation (average days in milk = 280 ± 79) and although the inclusion of the straw and beet pellets resulted in an increase in feed intake, the investigators successfully maintained fat and protein corrected milk yield. The partial replacement of forages with NFFS in close-up diets has also been evaluated at the William H. Miner Research Institute (Dann et al., 2007). In that study, oat hay was reduced from 30 to 15 % and beet pulp was increased to 15 % and fed to 64 cows from d -21 relative to expected calving date. Despite pronounced differences in ration particle size no differences were observed in periparturient intake or metabolism of production.

In vitro Laboratory Measures to Understand the Fermentability of Fiber

Today a number of assays are commercially available that attempt to measure the nutritional value of rumen feeds. For example investigators at Cornell University have developed an assay which attempts to estimate the RUP and intestinal digestibility of RUP (**dRUP**) in feed samples (Ross et al., 2013). Additionally, investigators at University of Wisconsin have developed an *in vitro* NDF fermentation assay to estimate total-tract digestibility (**TTNDFD**; Lopes et al., 2015a,b). Assays such as this hold great promise as the cost of routine testing feeds *in vivo* is prohibitive. These methods may be useful in screening feeds for differences between sources or manufacturing facilities. For example we have recently used the TTNDFD assay to test for differences in fiber digestion between DDGS originating from different corn-ethanol facilities (Dufour et al., 2017). In this study TTNDFD was observed to be 65.5 ± 1.59 % and differences between production sites were observed with differences > 10 %. It is difficult to identify driving factors responsible for observed differences in TTNDFD, but results support the notion that in addition to differences in chemical composition (Spiehs et al., 2002) differences in nutrient availability also exist between production facilities. The TTNDFD method represents an important and powerful tool to estimate *in vivo* fiber digestibility; but it should also be noted that the method does not account for selective retention of feed particles in the rumen (Huhtanen et al., 2007; Lopes et al., 2015b) which is affected both by particle fragility and particle size (Grant, 2010) and as a result it may be difficult to compare estimates of TTNDFD across feedstuffs.

CONCLUSIONS

The dairy cow is adaptable and can use byproduct feedstuffs as sources of nutrients to make a high quality food, namely milk. Although there are limitations in her ability to do so, extensive research has been conducted on the topic. This research on inclusion levels, chemical composition, and nutrient availability helps us understand how these byproducts can be included in a formulation. The dairy industry will continue to make extensive use of feed byproducts and the availability, type, and composition will likely change over time. To overcome these changes the practice of regular and consistent characterization of feed is important.

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Immune Dysfunction in Periparturient Dairy Cows: Insight into Pharmacologic and Dietary Immune Treatments

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INTRODUCTION

With a $40.5 billion gross domestic value for milk produced in the U.S. during 2013, the dairy industry was the third largest sector of the 2013 U.S. animal agriculture economic engine. The value of milk produced in 2013 represented 24 % of the total value of animal agriculture production; this figure had grown from $21-23 billion/y over a decade ago. The 2007 NAHMS Dairy Study reported that during 2006, 23.6 % of cows were culled from operations, 26.3 % and 23 % were removed for reproductive and udder health problems (USDA, 2007). In addition, 16.5 % of cow mortalities were due to mastitis. Clearly, the economic value of controlling mastitis pathogens is immense. Most economic analyses of the cost of mastitis cite a 10 % production loss as only one part of the overall cost of the disease. A majority (65 to 70 %) of losses are associated with decreased milk yield resulting in lower production efficiency; the remaining costs are attributed to treatment. In addition to these direct losses, mastitis causes significant problems in milk quality control; dairy manufacturing practices; quality and yield of cheese; nutritional quality of milk; antibiotic residue problems in milk, meat and the environment; and genetic losses due to premature culling. These additional costs are very significant and are not always included in economic analyses of mastitis costs.

Because of the need for a safe, economical, and stable supply of food, those of us serving the livestock health industry must be prepared to provide the best quality advice and care in managing our nation's dairy herd. For dairy producers, the critical factor in providing a low somatic cell count milk supply is keeping cows free from mastitis. Mastitis is anything causing inflammation of the mammary gland, and infectious mastitis is caused by a plethora of microbial agents (Watts, 1988). Nearly half of the nation's herd of dairy cows will experience at least 1 episode of mastitis during each lactation. Research has already resulted in genetic selection for cows with lower somatic cell counts by the incorporation of this trait into the A.I. sire summary ranking indices. This approach mainly serves to reduce the normal increase in mastitis incidence that occurs as milk production goes up. Coliforms and environmental streptococci are the most common etiologic agents isolated from clinically severe mastitis cases on well-managed dairy farms (Anderson et al., 1982; Hogan et al., 1989). Clinical trials and experimental studies have demonstrated repeatedly *no benefits* of antibiotic therapy in cattle with clinical or subclinical coliform mastitis (Erskine et al., 1991; Jones and Ward, 1990; Kirk and Barlett, 1984). Hence, the advent of the *Escherichia coli* J-5 and other endotoxin core mutant vaccines in veterinary medicine many years ago provided us a tool to reduce the incidence and severity of clinical coliform mastitis (Gonzalez et el., 1989; Hogan et al., 1992a,b, 1995). However, there remains an unmet veterinary medical need of new ways to prevent or treat mastitis caused by environmental pathogens. For several years, research at the USDA's National Animal Disease Center in Ames, IA undertook a 2-fold approach for improving the dairy cow's resistance to mastitis - immunomodulation and genetic selection for superior immune systems. In this paper, we will focus on:

- The evidence for immune suppression in periparturient dairy cows,
- How this sets the cow up for infectious diseases such as mastitis, metritis and retained placental membranes, and
- Some of the early research on immune modulation of the transition dairy cow and how that impacted resistance to mastitis.

[1] No endorsements are herein implied. USDA is an equal opportunity provider and employer.

ROLE OF THE IMMUNE SYSTEM IN MASTITIS

Immunity against infectious diseases of cattle is mediated by diverse, yet interdependent, cellular and humoral mechanisms. Many environmental and genetic factors influence the ability of livestock to mount effective defense strategies against the various pathogens and normal flora that they are exposed to throughout their lifetime. Innate resistance to infectious diseases reflects the inherent physiological attributes of an animal that make it more or less susceptible to disease development by a particular pathogen. There are several cell lineages that comprise the immune system (e.g., B-cells, T-cells, neutrophils, eosinophils, basophils, macrophages, and mast cells). Each of these cell types has distinct responsibilities in providing host defense. Innate immunity represents the various immune components that are not intrinsically affected by prior contact with an infectious agent (Roitt, 1994). Lymphocytes provide the adaptive immune reactions that are antigen specific in nature and possess memory for future encounters with the same pathogen. In this paper we will present a novel approach of immune modulation of the innate immune system as a potential means to reduce antibiotic usage in veterinary medicine.

Our first understanding of cellular immunity is more than a century old and it actually involves research into the causes of bovine mastitis and the immune response. In his 1908 Nobel Lecture the Russian zoologist, Elie Metchnikoff, described disease as consisting "of a battle between a morbid agent, the external microorganism, and the mobile cells of the organism itself. A cure would represent the victory of the cells, and immunity would be the sign of an activity on their part sufficiently great to prevent an invasion of microorganisms (Metchnikoff, 1908)." Metchnikoff cited the work of a Swiss veterinary expert, Zschokke, who found that "plentiful phagocytosis of streptococci in the battle against infectious mastitis in cows, was a good sign. When phagocytosis was insignificant or not present, the cows were written off as no longer capable of producing good milk." This was later extended to include the idea that not only must the phagocytes engulf the microorganisms, but that these devouring cells must utterly destroy the microorganisms. In some cases, the streptococci of mastitis were found to "destroy the phagocytes after being engulfed by them thus liberating themselves to carry on their deadly work."

Today we have a far more detailed knowledge of the cow's immune response to pathogens in the mammary gland (and elsewhere). Neutrophils are one of the most important cell types of native defense mechanisms because they respond quickly (within minutes) and do not require previous exposure to a pathogen to effectively eradicate the microbe. A major function of neutrophils is the phagocytosis and destruction of microorganisms that invade the body. Phagocytosis is probably the most widely distributed defense reaction, occurring in virtually all phyla of the animal world.

NEUTROPHILS ARE CRITICAL AGAINST MASTITIS

Native defenses of cattle are continually challenged by exposure to pathogens (bacteria, fungi, and viruses) and many factors affect the outcome of this interaction. Establishment of an infection in any organ or tissue is dependent upon a delicate balance between defense mechanisms of the body and the abilities of pathogens to resist unfavorable survival conditions. The neutrophil is one of the most important cells of the innate defense mechanisms because it can act quickly (within minutes) in large numbers, and in most cases, does not require previous exposure to a pathogen to effectively eradicate the microbe. Studies have shown that it takes approximately 1-2 h for neutrophils to accumulate in response to *E. coli* infection in tissues (Persson et al., 1988, 1992, 1993; Persson and Sandgren, 1992). What this means is that microorganisms will have a 2-h head start on the host immune response and any further delay in the inflammatory response will result in significantly more pathogens for the host to deal with. Unfortunately, delays in inflammatory responses in stressed animals are well documented (Shuster et al., 1996; Hill et al., 1979; Hill, 1981), and some of the mechanisms responsible for delayed inflammation have been identified (Lee and Kehrli, 1998; Burton and Kehrli, 1995; Burton et al., 1995). The importance of the neutrophil in protecting virtually all body tissues (especially against bacteria) has been repeatedly demonstrated experimentally and in nature (Schalm et al., 1964a,b; Jain et al., 1968, 1978; Ackermann et al., 1993, 1996; Gilbert et al., 1993a). Early and rapid accumulation of sufficient numbers of neutrophils is paramount in the ability of the host to effect a cure of invading pathogens (Anderson, 1983). Neutrophils can also release cytokines that in turn result in additional recruitment signals for more neutrophils (Canning and Neill, 1989; Cicco et al.,

1990; Goh et al., 1989; Ohkawara et al., 1989). Circulating *neutrophils represent the major recruitable host defense against acute tissue infection*, such as mastitis (Hill, 1979, 1981; Jain, 1968; Schalm et al., 1976).

IMMUNOSUPPRESSION IN THE PATHOGENESIS OF MASTITIS

A literal definition of immunosuppression is diminished immune responsiveness. This simplistic definition impacts a highly diverse system that affords protection against disease. Periparturient immunosuppression research was initiated by the observation that most clinical mastitis occurs in dairy cows in early lactation and the view that most bovine mastitis is caused by opportunistic pathogens and; therefore, these cows must be immunosuppressed. What evidence supported the hypothesis of periparturient immunosuppression? Practical experience teaches us that opportunistic infections are associated with severe compromises of host defense mechanisms. Over the past couple decades, an overwhelming amount of evidence of immunological dysfunction of lymphocytes and neutrophils in periparturient cattle (Figure 1) and sows has been generated in research institutes around the world (Shuster et al., 1996; Lee and Kehrli, 1998; Burvenich et al., 1994, 2007; Cai et al., 1994; Detilleux et al., 1994, 1995a,b; Dosogne et al., 1998, 1999; Guidry et al., 1976; Harp et al., 1991; Heyneman and Burvenich, 1989; Hoeben et al., 1997, 2000a,b; Ishikawa and Shimizu, 1983; Ishikawa, 1987; Ishikawa et al., 1994; Kehrli and Goff, 1989; Kehrli et al., 1989a,b; Kelm et al., 1997; Kimura et al., 1999a,b, 2002a,b; Lippolis et al., 2006; Löfstedt et al., 1983; Mehrzad et al., 2001, 2002; Monfardini et al., 2002; Nagahata et al., 1988, 1992; Nonnecke et al., 2003; Pelan-Mattocks et al., 2000; Shafer-Weaver and Sordillo, 1997; Sordillo et al., 1991, 1992, 1995; Stabel et al., 1991; Van Werven et al., 1997; Vandeputte-Van Messom et al., 1993). Periparturient immune dysregulation impacts the occurrence of infectious diseases of virtually any organ system of livestock (e.g., gastrointestinal, respiratory, and reproductive tracts all have increased disease incidence in postpartum animals).

First of all, there is an extremely high incidence of clinical disease in postpartum cows with nearly 25 % of all clinical mastitis occurring during the first 2 wk after calving. Clinical mastitis caused by virtually all pathogens (but especially coliform bacteria and streptococci other than *Streptococcus agalactiae*) has a very high incidence in early lactation. Cows must first become infected and then develop clinical mastitis. The rates of new intramammary infections (**IMI**) caused by environmental pathogens are highest during the first and last 2 wk of a 60-d, nonlactating period of dairy cows (Hogan et al., 1989; Smith et al., 1985a,b; Oliver and Mitchell, 1983). The rate of new IMI during these periods of peak susceptibility is 2 to 12 X higher than any other time in the production cycle of the cow. Most coliform and environmental streptococcal infections, established in the nonlactating period and that are present at parturition, result in clinical mastitis soon afterward (Smith et al., 1985a; McDonald and Anderson, 1981). The proportion of all cases of clinical coliform mastitis that develop during the first 2, 4, and 8 wk of lactation has been reported to be 25, 45 and 60 %, respectively (Malinowski et al., 1983; Jackson and Bramley, 1983).

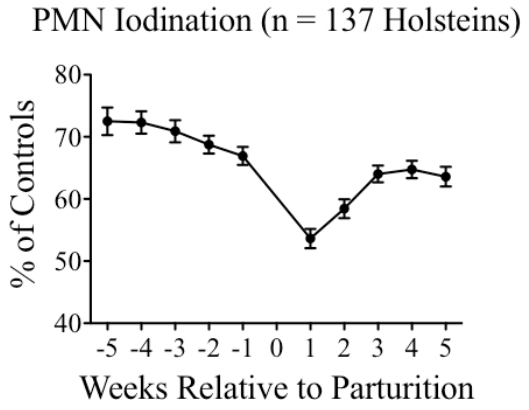

Figure 1. Neutrophil (PMN) iodination measures the myeloperoxidase-catalyzed halogenation of proteins, a phenomenon that takes place in phagolysosomes of neutrophils that have phagocytosed bacteria. *In vivo*, this halogenation disrupts the function of critical bacterial membrane proteins and results in the oxidative killing of the bacteria by the neutrophil. This bactericidal activity depends on a series of events to occur in the process of phagocytosis: successful opsonization and uptake of the bacteria by the β2-integrins into a phagosome, the generation of superoxide anion and its dismutation into hydrogen peroxide (H_2O_2), the fusion of the phagosome with a primary granule to produce a phagolysosome in which myeloperoxidase utilizes the H_2O_2 and cellular halides to halogenate the bacterial surface proteins. (Data from Detilluex, et al., 1995b.)

The second piece of evidence supporting the notion of immunosuppression in the pathogenesis of mastitis was that we are traditionally taught that opportunistic infections are associated with severe

compromises of host defense mechanisms. Most mastitis pathogens are considered opportunistic pathogens. These 2 points led to experiments evaluating how functional a cow's immune system is around calving time. Today the data tells us the immune system becomes progressively more compromised at the end of gestation, cows become more readily infected in the mammary gland, then as the immune system *bottoms out* the first week or two after calving, these subclinical infections begin to win the battle with the cow's immune system and clinical mastitis results.

WHAT CAUSES PERIPARTURIENT IMMUNOSUPPRESSION?

Many neuroendocrine changes develop in cows during the periparturient period. Periparturient hormone fluxes may adversely affect immune cell function. Surprisingly, there is no effect of estrogen on bovine neutrophil function either during the follicular phase of the estrous cycle in cows or after administration of high doses of estradiol to steers (Roth et al., 1982, 1983). However, supraphysiologic concentrations of estradiol have been reported to suppress neutrophil function (Bodel et al., 1972; Klebanoff, 1979). These high concentrations of estrogens may be germane to immunosuppression and the high new IMI rates prior to calving. Before calving, total plasma estrogen concentrations increase in the cow (at least 10 X greater than during estrus) (Comline et al., 1974). Moreover, during normal pregnancy, the progesterone binding capacity of human lymphocytes is increased (perhaps as a result of increasing estrogen levels) and the concentration of progesterone in serum during pregnancy combine as sufficient to reduce lymphocyte functions (Szekeres-Bartho et al., 1983, 1985). This raises the possibility that hormone sensitivities of immune cells during late gestation may be altered and result in functional changes in immune cells due to rising estrogen levels. Very high concentrations of both estrogens and progesterone are reached during the final days of gestation in cows (Comline et al., 1974). This may be germane to the onset of impaired lymphocyte function in the prepartum cow whose lymphocyte hormone binding capacity may be higher than that in barren cows.

Many of the hormonal and metabolic changes that prepare the mammary gland for lactation take place during the 3 wk preceding parturition. Lymphocyte and neutrophil function could be affected by prepartal increases in estrogen, prolactin, growth hormone, and/or insulin (Comline et al., 1974; Houdebine et al., 1985; Convey, 1974; Akers, 1985). During this critical period, the dairy cow's metabolism shifts from the demands of pregnancy to include those of lactation, with increased demands for energy and protein. Negative energy and protein balances that exist during early lactation may also contribute to impaired neutrophil function and, thus, account for a portion of the periparturient immunosuppression observed. The nutritional demands of lactation contribute to the duration of immune suppression (Kimura et al., 1999b; Nonnecke et al., 2003; Stabel et al., 2003) and postpartum neutrophil glycogen stores have been associated with postpartum uterine diseases (Galvão et al., 2010).

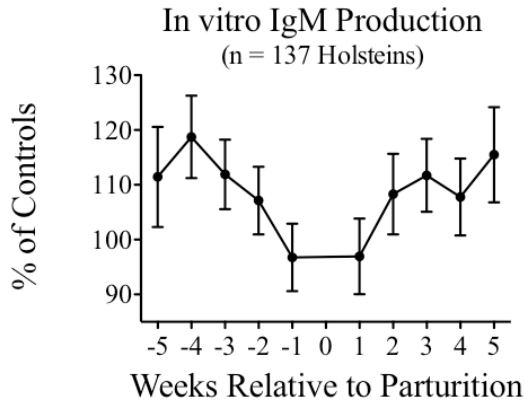

Figure 2. *In vitro* production of IgM by lymphocytes is reduced in the immediate week around calving time. (Data from Detilleux et al., 1995b.)

The specific physiological factors contributing to periparturient immunosuppression and increased incidence of clinical disease have not been fully elucidated. We do know, however, that there is a very broad-based suppression of immune function in cows the 1st wk or 2 after calving. Wide variation in leukocyte functional activities has been documented between dairy cows and between different production stages (e.g., around calving time) (Ishikawa, 1987, 1994; Nagahata et al., 1988, 1992; Guidry et al., 1976; Newbould, 1976; Manak, 1982; Gunnink, 1984a,b,c; Saad et al., 1989; Gilbert et al., 1993b). Most importantly, associations between neutrophil dysfunction and periparturient disorders in cows have been reported (Kelm et al., 1997; Kimura et al., 2002a; Cai et al., 1994). Periparturient immunosuppression is not limited to cattle. Investigations of immunosuppression and coliform mastitis in sows revealed depressed neutrophil function to be associated with the susceptibility to postpartum mastitis caused by *Escherichia coli*

(Löfstedt et al., 1983). Defects in lymphocyte function also contribute to immune suppression during the periparturient period (Figures 2 and 3). In addition to reduced antibody production, other impacted roles of lymphocytes in periparturient cows include reduced production of cytokines that activate and direct both innate and adaptive immunity (Detilleux et al., 1995; Ishikawa, 1987; Ishikawa et al., 1994; Manak, 1982; Wells et al., 1977; Kashiwazaki, 1984; Kashiwazaki et al., 1985).

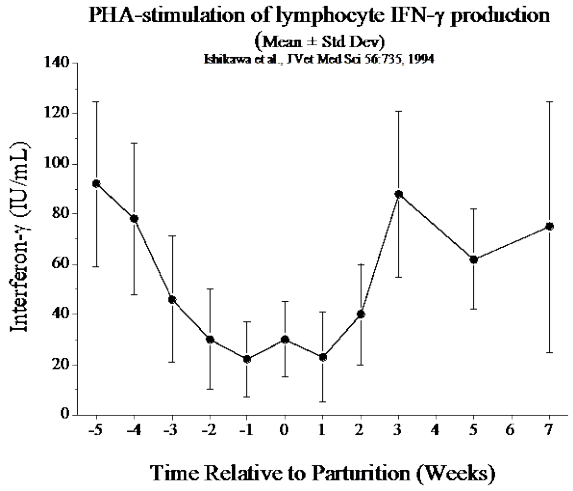

Figure 3. *In vitro* production of interferon- γ (INF- γ) by lymphocytes is reduced in the week around calving time. (Data from Ishikawa et al., 1994.)

Today it is well recognized that the bovine immune system is less capable of battling pathogens during the periparturient period. The periparturient cow has suppressed immune competence, manifest as reduced capacity for nearly all types of immune cells that have been studied. Interestingly, there may be a teleological reason for immunosuppression in the Th1 branch of the immune system that may be essential in preventing unwanted immune reactions against self and fetal antigens exposed to the mother's immune system as a result of normal tissue damage in the reproductive tract during parturition (Kehrli and Harp, 2001). However, an inadvertent and perhaps unintended consequence of this suppression of the Th1 branch of the immune system is that many of the cytokines normally produced by these cells are critical to fully activate neutrophils that are absolutely critical to the defense of the mammary gland. Without a fully functional cellular immune system, both adaptive and innate branches of the cellular immune system operate at diminished capacity for immune surveillance and pathogen clearance. This is the very circumstance that periparturient cows find themselves in and why it is so critical to manage transition cows to minimize their exposure to pathogens in the environment and to avoid metabolic disorders that might further stress their immune system.

The take-home message here is a multitude of factors of the immune system of a dairy cow become impaired as early as 2 - 3 wk before she actually gives birth (long before the elevation of endogenous cortisol which occurs from 36 h before to 36 h after calving). The cow's immune system then bottoms out and is seriously impaired for 1 - 2 wk after calving. This effect is known as periparturient immunosuppression. Regardless of its causation, periparturient immunosuppression makes the dairy cow highly susceptible to the establishment of new infections (particularly in the mammary gland) and the subsequent progression of these new subclinical infections into clinical disease (mastitis, metritis, and postpartum outbreaks of intestinal diseases such as salmonellosis, just to name a few).

WHAT ARE THE PROSPECTS FOR IMMUNOMODULATION TO PREVENT DISEASE?

Pharmacologic treatments that serve as immune modulators in cattle and other species have been under investigation for many years. Biotherapeutic immune modulators can be given to prevent or lessen disease symptoms caused by various pathogens (viral and bacterial). A general goal of such a biotherapeutic compound is to provide the desired effect on host immunity for a sufficient period of time to sustain immunity through a period of immune dysfunction the host is experiencing. In the past couple years 2 products have received approval by regulatory agencies that fall under this category but that work through very different innate immunity mechanisms.

According to the manufacturer, Zelnate™ (Bayer Healthcare LLC, Animal Health, Shawnee Mission, KS) was approved in 2015 as a USDA-Center for Veterinary Biologics approved immune modulator based on technology developed by Juvaris BioTherapeutics (Pleasanton, CA). As such, it represented a new class of drug for bovine respiratory disease (**BRD**) as an immune modulator; it is not an antibiotic nor a vaccine. Zelnate DNA Immunostimulant is a bacterial-produced plasmid DNA with a liposome carrier that stimulates the

innate immune system in cattle. Per the label claim, Zelnate is indicated for use as an aid in the treatment of BRD due to *Mannheimia haemolytica* in cattle 4 mo of age or older, when administered at the time of, or within 24 h after, a perceived stressful event. Although no peer-reviewed publications are available at this time, a summary of the technical studies conducted for regulatory approval is available: http://www.zelnate.com/static/documents/Zelnate-ChallengeStudy_Detailer.pdf.

In 2016, Imrestor™ (pegbovigrastim) (Elanco Animal Health, Indianapolis, IN) was approved by the Food and Drug Administration as the first and only immune restorative for periparturient dairy cows and heifers. Per the label claim usage, Imrestor reduces the incidence of clinical mastitis by 28 % in the first 30 d of lactation in dairy cows and heifers. Recent peer-reviewed studies describe the mechanism of action of pegbovigrastim and report an even greater reduction in clinical mastitis incidence in 4 studies conducted in the United States (Kimura et al., 2014; Hassfurther et al., 2015; Canning et al., 2017; McDougall et al., 2017).

Pegbovigrastim is a cytokine that is naturally part of a cow's immune system that works to turn on the innate immune response provided by neutrophils. Cytokines are a class of compounds that have been investigated for many years for potential biotherapeutic value. Administration of recombinant cytokines to modulate immunity in immunocompromised hosts is thought to prevent bacterial infections (Broxmeyer and Vadhan-Raj, 1989). In an effort to study methods to ameliorate the effects of periparturient immunosuppression, several scientists have evaluated various cytokines that are part of the cow's normal immune system (Sordillo et al., 1991b,1992; Zecconi et al., 1999, 2009; Sordillo and Babiuk, 1991; Campos et al., 1992; Sordillo and Peel, 1992). Granulocyte-colony stimulatory factor (**G-CSF**) is a cytokine that triggers the bone marrow to produce leukocytes – neutrophils in particular, which in turn, fight infectious disease. Human G-CSF has been successfully used for many years as an adjunct therapy for cancer patients undergoing chemotherapy. In a series of studies, G-CSF has been evaluated for its effects on bovine immunity and as a prophylactic against mastitis (Stabel et al., 1991; Kehrli et al., 1991a; Cullor et al., 1990a,b, 1992; Nickerson et al., 1989). Our research findings indicate no adverse effects and that it can reduce the incidence and severity of clinical coliform mastitis by 50 % during the 1st wk of lactation following experimental challenge (Kehrli, 1998). G-CSF has also been shown to be beneficial against *Staphylococcus aureus* and *Klebsiella pneumoniae* mastitis (Nickerson et al., 1989; Kehrli et al., 1991b). It is crucial to understand that immunomodulators work best in immunocompromised hosts; hence the periparturient period is an excellent time for such compounds to be given to cows as they will work to restore the immune system. Acceptable alternatives to the use of antibiotics in food animal practice need to be explored and the use of immunomodulators is a promising area for therapeutic, prophylactic, and metaphylactic approaches to prevent and combat infectious disease during periods of peak disease incidence. Research in the area of biotherapeutic immune modulation continues today (Kimura et al., 2014).

Dietary immune treatments are also an area of intense investigation. While not a major focus of this paper, considerable research has been done and managing optimal nutrition levels, with ingredients such as vitamin E and selenium, is well recognized to avoid immune impairment associated with nutrient deficiencies (Weiss et al., 1990, 1992, 1997; Hogan et al., 1990, 1992c, 1993, 1994; Smith et al., 1997). However, there is little evidence to support hyper-supplementation of nutrients such as these, as a means to enhance immune function.

Immunomodulatory feed ingredients have also received considerable research interest investigating possible beneficial effects on immunity and health in dairy cows. One such product, Omnigen-AF (Phibro Animal Health Corp., Teaneck, NJ), is perhaps the best studied product reported to enhance innate immunity parameters and increase milk production in dairy cows (Brandao et al., 2016; Leiva et al., 2017; Fabris et al., 2017; Wang et al., 2009; Ryman et al., 2013; Nace et al., 2014).

WHAT DOES THIS ALL MEAN FOR YOU?

Bovine mastitis is one of the most economically important diseases to the beef and dairy cattle industries. The pathogenesis is highly complex and involves many factors including various microbial etiologies, stress, management and environmental hygiene. Bovine mastitis has not been adequately controlled by vaccination or antibiotics. In many diseases, immunosuppression due to various stressors is responsible for increased susceptibility to bacterial colonization or growth. Over the past 50 y a considerable body of evidence of impaired neutrophil

and lymphocyte function in periparturient dairy cows has emerged that coincides with the high incidence of new intramammary infections 2 wk prepartum and clinical mastitis in early lactation. To overcome this immunosuppression, immunomodulatory agents have been and are being evaluated for their ability to prevent economic losses associated with periparturient diseases such as mastitis. Researchers have investigated immunomodulation as an approach to provide dairy farmers with a new tool to prevent infectious disease in their herds, although biotherapeutic products have not yet made it to the market place. The consequences of immune suppression are increases in infectious disease and premature loss from the herd, both of which add significantly to the cost of production and decrease the profitability of dairy farming. Simple solutions will not likely be found for something as complex as immune suppression; however, without additional significant research into this topic we can be assured that no progress will be made.

Production of milk from mastitis-free cows is quite simple, right? Keep your cows in clean, dry, and unstressful environments and feed them what they need, when they need it – far easier said than done! For years we have emphasized feeding cows optimal rations because the production and functional activities of leukocytes in combating microbial infection are complex and all involve expenditure of cellular energy, protein and other nutrients. The average cow has ~3500 neutrophils/µL of blood, this translates into ~1.4 x 10^{11} neutrophils in an 1800 lb Holstein cow. The circulating half-life of neutrophils is about 6 h, so the cow is replacing half of those cells every 6 h from bone marrow stores. Clearly, a significant component of the dietary energy and protein consumption for maintenance is spent on replenishment of immune cells. The negative energy and protein balance of dairy cows during the periparturient period and up to peak lactation undoubtedly influences immune function. We know that cows without the stress of lactation recover from periparturient immunosuppression within 1 wk after calving, whereas lactating cows remain immunosuppressed for 2 - 3 wk postpartum (Kimura et al., 1999a,b, 2002b). Today we have a new immune restorative to give transition cows. In combination with the best possible hygienic conditions and the best possible dietary management, we can further reduce the incidence of disease in early lactation and better enable cows to reach their full genetic potential.

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Ration Formulation Models: Biological Reality vs. Models

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ABSTRACT

Ration formulation programs are composed of basically 2 parts; the first is the model that represents nutrient requirements of the cow given her stage of life and level of production and the second is the algorithm that solves the ration to provide either the cheapest diet that meets the model (cow) requirements or maximizes milk income over feed costs. Early ration formulation programs used the simplex algorithm to solve the ration, which was based on maximizing or minimizing profit over cost based on linear model equations. The model, made up of linear, static nutrient relationships between milk production and nutrient inputs, was used to set nutrient requirements such as the tables in the Nutrient Requirements of Dairy Cattle (NRC, 1989 and earlier). At this level, the programs work, but are limited by the fact that life is not linear. As cattle eat more and produce more milk, the gain in milk production per unit of feed consumed gets smaller and smaller. As the focus changes from minimizing costs or maximizing profit to increasing efficiency, models and the algorithms used to solve them become more complicated. As the programs become more complicated, both the model and the algorithm influence the resulting ration solution. So to examine how well ration programs reflect reality or what nutrient inputs are really needed to formulate a diet, both the model and algorithm must be examined. The 2 main ration programs used today, **AMTS** (Agricultural Modeling & Training Systems, LLC) and **NDS** (Nutritional Dynamic Systems, RU.M.&N., Italy) both use the Cornell Net Carbohydrate and Protein System (**CNCPS;** Tylutki et al., 2008); but, because they use different solution algorithms and settings, will produce different rations.

INTRODUCTION

Models of dairy cow nutrient use are dependent on how nutrients are defined and how important those nutrients are to the nutritional physiology of the cow. Early ration formulation was based on nutrient definitions according to proximate analysis. However, proximate analysis had several problems including a non-homogenous category of nutrient, *Nitrogen Free Extract*, that had no relation to cow physiology and a lack of continuity between crude fiber (**CF**), and newer fiber analysis techniques, acid detergent fiber (**ADF**) and neutral detergent fiber (**NDF**). The basic idea of proximate analysis has stayed in nutrient analyses techniques through the use of total digestible nutrients (**TDN**) and more recently many analyses have been added to the basic framework of proximate analysis, and ADF, NDF through further development of CNCPS model. If all of the new analyses were needed to formulate a ration, laboratory costs would be extremely high. Therefore the goals of this paper are:

1) To use sensitivity analyses to determine the relative importance of a nutrient to the ration program,
2) To explore how changes in the nutrient affect the ration solution, and
3) To examine if ration program behavior would matter to the cow (reality).

The methods presented to evaluate the ration programs could be done by anyone and should be done before changing programs or upgrading to a new CNCPS model or algorithm.

Nutrient Descriptions

Chemical analyses of nutrients must be measurable with accuracy and precision, relevant to cow physiology, and must improve model predictions of production. Unfortunately none of the current systems meet all of these criteria. For instance, NDF was originally developed to quantify fiber from forages, but results for the same sample were not consistent. Due to the importance of feeds that contain both fiber and grain (i. e. corn silage), NDF was also used for high starch feeds. Because these feeds were nearly impossible to filter and complete the assay, the technique was modified to add amylase, noted as **aNDF**. But, since results were still not consistent (lack of precision), the ash content of NDF was removed (**aNDFom**). Then, because

whether a fiber was digestible in the rumen and therefore available to microbes for microbial growth would link NDF better with rumen physiology, digestible NDF (**dNDF as % NDF or NDFd as % DM**) was created. But these were determined chemically using an *in vitro* incubation system, which becomes more unlike rumen fermentation the longer it lasts. Consequently NDFd became defined according to length of incubation: **NDFd24** (24 h), **NDFd30** (30 h), etc. In recognition that some NDF is degraded more rapidly than others, NDF was also classified into undegradable NDF at 30 h (**uNDF30**), at 120 h (**uNDF120**) and at 240 h (**uNDF240**). These chemical analyses were used to define pool sizes in CNCPS for rapidly degrading NDF, slow degrading NDF, and unavailable NDF (lignin); respectively, to define how much NDF was potentially degradable (pdNDF = aNDFom - uNDF) and how much NDF was essentially not degradable at all in the rumen. While the development of these assays parallels how NDF has been observed to be degraded in the rumen, the nutrient NDF is not a substance that microbes degrade to produce specific products. Neutral detergent fiber is not unique and its components (cellulose, hemicellulose, lignin, and ash) are fermented through different pathways. Therefore NDF, while relevant to plant physiology, is not necessarily relevant to rumen physiology and so refining it further, according to rumen physiology, will not improve its representation of reality. It would be better to start with nutrient descriptions that were more homogeneous such as cellulose, hemicellulose, and lignin instead of trying to correct an already flawed nutrient description. This has been acknowledged by the developers of CNCPS and in a perfect world, the analyses to determine cellulose, hemicellulose, pectin, and lignin would already be developed and consistent with forage quality. Unfortunately this has not happened yet due to the focus on NDF.

METHODS

Evaluating the importance of a nutrient to the model and ration formulation

If a nutrient was measurable with accuracy and precision and a change in that nutrient supplied to the cow caused a change in cow health or production, the ration formulation program should reflect the importance of the nutrient. In modeling terms, the ration formulation should be sensitive to changes in the nutrient supplied by either changing the resulting ration or changing the requirements of other nutrients, or both. Essentially there are at least 2 questions that can be answered by this analyses:

1) "How important is it that I know that nutrient 's level in the feed (diet)?" or conversely "Should I spend the money for wet chemistry analyses?" and
2) "If I'm wrong about this nutrient's level in the feed, will it change the ingredient composition of the diet?"

The second question is impacted by both the nutrient requirement model and the algorithm used to solve the ration and may be different for different ration formulation programs. These analyses can be done by anyone and should be done before choosing which ration formulation program to use.

RESULTS AND DISCUSSION

The following are examples of these analyses using AMTS. Table 1 lists the baseline ration and ingredient constraints before any nutrients or nutrient variables were changed. The nutrient constraint column lists the nutrients that were constrained to get the ration solution. For each sensitivity analysis that compares changes in a model nutrient to ration changes, constraints were held constant and only the nutrient was changed.

Example 1.

Evaluate the importance of knowing physically effective (**pe**) factor in corn silage to meet the peNDF requirement for the ration. For a feed (corn silage), **peNDF = % NDF * pef** and pe factor is the percent of feed above the 1.1 or 4 mm screen of the Penn State Particle Sorter (**PSPS**). Physically effective NDF should be between 22 - 35 % according to constraints built into AMTS. Because corn silage is a major component of the baseline diet and pef is large for corn silage (82 %), pef was changed in 10 % increments to see the effect on ingredient content of the diet and peNDF. Figure 1 shows the impact of changing pef on peNDF. The dashed lines indicate the constraints for peNDF. For corn silage, there is not much impact on peNDF until pef is above 60 %. This makes sense because the amount of large fiber particles (above 4 mm) should be at least above 60 % of total corn silage. Figure 2 shows that as pef gets below 60 %, AMTS changes the ingredient composition of the TMR from corn silage to wheat silage. This also causes small changes in citrus, dried distillers grains (**DDG**), and corn to continue to balance the TMR. Above 60 % pef for an

Table 1. High milking cow ration solution (DMI 55 lb/d)

Ingredient	AMTS Ration (lb)	Min (lb)	Max (lb)	Nutrient Constraints
Corn silage	15	7	15	DMI
Wheat silage	0.3	0	6.5	ME
Corn	10	6	11	MP
Alfalfa	15	6	15	Rumen ammonia
Almond hulls	2	2	4.5	NFC
Dried distillers grains	3.5	2	3.5	peNDF
Wheat mill run	0	0	5	EE
Canola meal	0	0	6	Lys
Corn gluten	0.18	0	3.3	Met
Soybean meal	3.2	0	3.2	
Cottonseed	3.6	0	3.6	
Citrus pulp	0	0	1	
Molasses	0	0	0.65	

approximate 30 % change in pef, TMR peNDF changes by 5 %.

Reality Check

It is very difficult to get repeatable results with the PSPS. Results can commonly vary between 10 - 20 %. But, with only a 5 % change in peNDF of the TMR for a 30 % change in pef, getting good results from the PSPS is probably not an issue. However, it also implies that this number is not important for the ration (62 % pef is the same as 92 % pef) and could be excluded as a constraint and as a term in the program. In addition, particle size of the TMR can change greatly during mixing and feeding of the TMR due to mixing time, operating condition of the mixer wagon, and sorting of TMR by the cows (crowding, feeding frequency, etc.). Therefore including particle size as a constraint in a ration formulation program will not be a major contributor to impacting rumen function as it was originally intended.

Figure 1. Effect of changes in physically effective factor (pef) on peNDF. Constraints for peNDF is area between dashed lines.

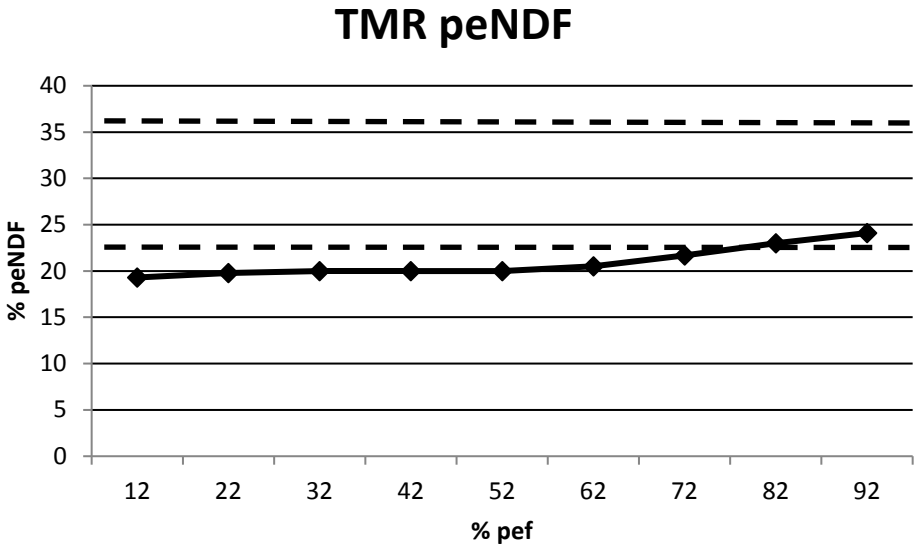
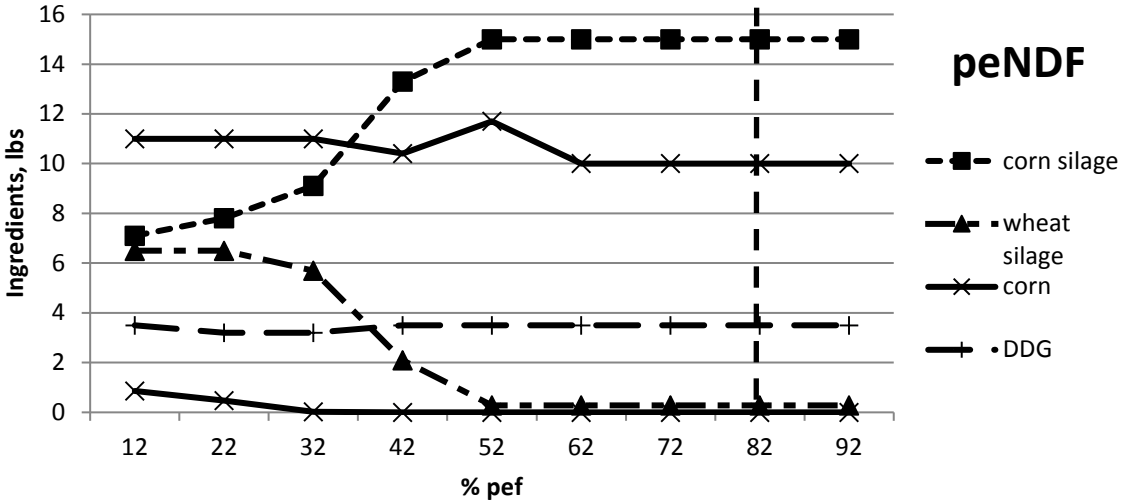


Figure 2. Changes in ingredient content of ration as pef is decreased. The pef for corn silage is depicted by the vertical dashed line.



Example 2.

How would the ration solution be changed if the starch content in corn was inaccurate?
Starch is a major component of non-fiber carbohydrate (**NFC**), which has a maximum limit of 40 % DM in the AMTS program. Corn was used to vary the amount of starch because it was the major contributor to starch in the diet. Changes in starch were counter balanced with changes in NDFom (Figures 3 and 4) and then sugar (Figures 5 and 6) to ensure the nutrient content of corn still summed to 100 %. Note that a decrease in corn starch content (about 10 %) replaced with NDFom caused a similar decrease in NFC (about 10 %) and large changes in the TMR, especially between corn and corn silage. But when starch was replaced with sugar, there was no change in NFC and very little change in the TMR. See Figure 6 where wheat silage is replaced with corn gluten (1:1 change by 0.13 lb).

Figure 3. Changes in NFC and TMR starch with replacing corn starch content with NDFom. Constraints for NDFom depicted by dashed line.

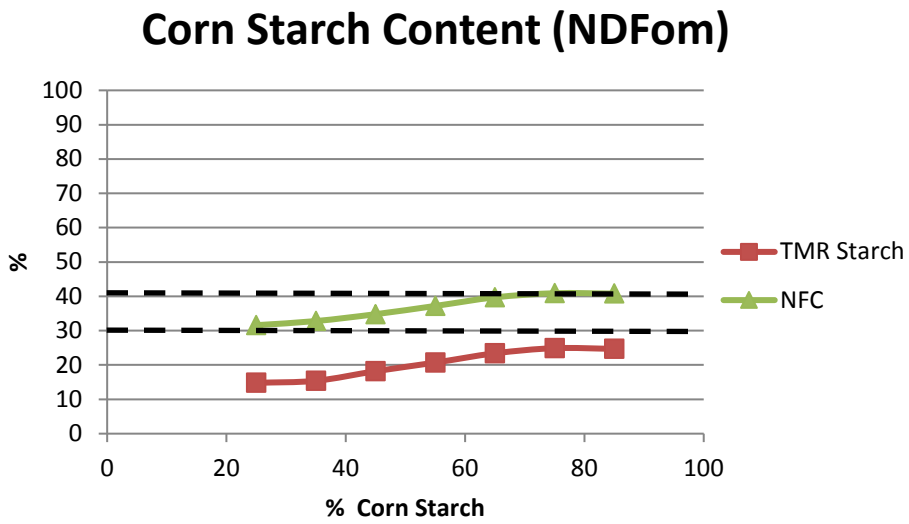
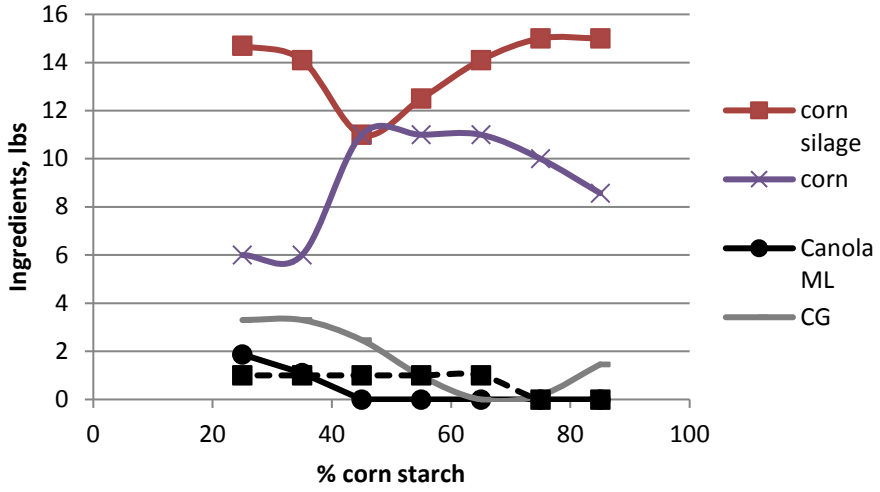


Figure 4. Changes in the ingredient composition in the TMR as a result of replacing starch percent in corn with NDFom.



Reality Check

Of all the macro nutrient analyses performed by laboratories, methods and results from starch analyses are the most variable. This analysis examines the impact on the ration solution if starch content in corn was wrong and either the *missing* nutrient percent ended up in NDFom or in sugars. If starch content is mis-identified as sugars, there is very little impact on the TMR ingredient composition; which also implies it may not be important to distinguish starch and sugars and sub-components of NFC. Knowledge of NFC may be enough. However, if starch content is mis-identified as NDFom, the impact to the TMR is much greater. Therefore it is important to know NFC and NDFom, but not-sub categories of nutrients within NFC.

Figure 5. Changes in NFC and TMR starch with replacing corn starch content with sugar. Constraints for sugar depicted by dashed line.

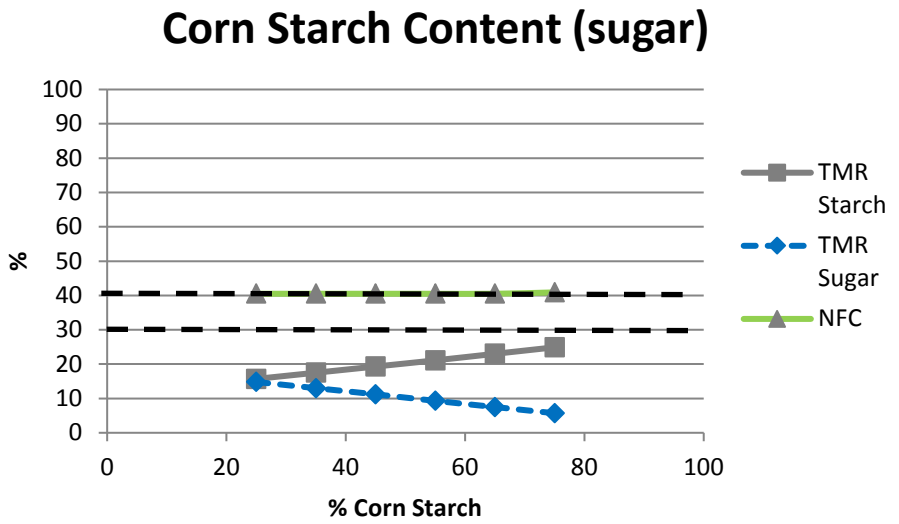
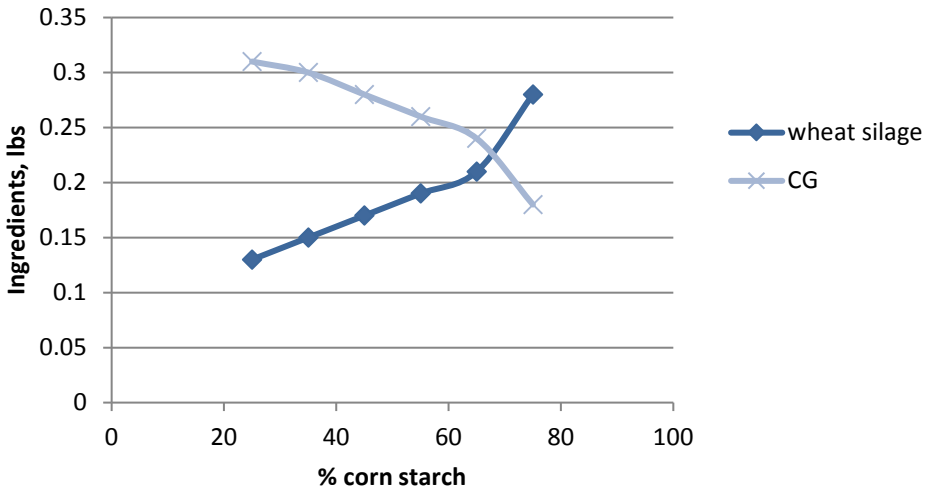


Figure 6. Changes in NFC and TMR starch with replacing corn starch content with sugar.



CONCLUSIONS

The Reality of Model Evaluation

Nutrient descriptions should be closely linked to how their nutrient inputs are described and measured. The CNCPS model has been very good at using well defined nutrient analyses to develop model concepts. However those nutrient definitions don't necessarily reflect differences in feed quality or changes in cow production. For the model, nutrient descriptions must adequately describe inputs for predicting cow physiology such as rumen function, ATP creation and use, and nitrogen and carbon for microbial growth. For the real cow, a change in a nutrient should result in a change in health or production. Unfortunately because cows are not usually managed or monitored individually, there is significant noise present in determining the impact of a nutrient in a real dairy herd. This makes model evaluation extremely difficult. For instance, glucose levels are extremely important in a transition dairy cow to prevent ketosis and the associated high economic costs of the disease. But until recently, subclinical ketosis, as defined by blood ketone (and glucose) levels, was largely ignored because cows generally did not show clinical signs and so the cost of the disease was thought to be inconsequential. However, once the associative effects of subclinical ketosis and their costs were estimated ($78/cow; Geishauser et al., 2001), prevention of subclinical ketosis (low blood glucose) through monitoring individual cows is becoming more common now. Using current nutrient descriptions, however, there is no way to predict glucose supply from a given diet with precision and accuracy. Even if we could predict glucose supply to the cow, there are many other health, stress, and management factors that would have a bigger impact than diet on glucose levels in cows at any one point in time. Therefore instead of trying to refine existing nutrients descriptions and analyses, it may be better to look to identifiers of feed quality that impact the production of the cow paying attention to methods of analysis that are precise and accurate.

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