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Diet Formulation

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Abbreviations that may be found in this publication include:

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

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

1.0 lb = 0.454 kg = 454 g
1.0 ft = 0.3 m = 30 cm
°F = (°C x 1.8) + 32

Abbreviations for metric units are:

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

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Nutrition and Claw Health

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Abstract

The health and function of the bovine claw is dependent upon sound nutrition and feeding practices. In this context, the avoidance of rumen acidosis, which is considered to be the predominant predisposing cause of laminitis, is believed to be of paramount importance. Acidosis in its acute form is a life threatening disease. In its subclinical form, acidosis contributes to decreased performance, poor body condition, and lameness most often due to laminitis and related claw disorders. In addition to being the single largest component of the dairy cow's diet, the one most often incriminated in rumen acidosis and laminitis is carbohydrate. The rapid fermentation rates of certain non-structural carbohydrates place desirable rumen microbes in jeopardy. Therefore, rations must be carefully formulated and fed to avoid potential problems. Not all studies reported in the literature have been able to demonstrate an association between rumen acidosis and laminitis. These inconsistencies substantiate the view of most people that laminitis is multi-factorial and likely complicated by many other factors. Rumen pH is a balance between the acid produced by carbohydrate fermentation and rumen buffering from saliva. Heat stress contributes to rumen acidosis by altering feeding behavior (encouraging slug feeding) and reducing salivary buffering. Although occasionally questioned as a cause of laminitis, the effect of elevated levels of dietary protein in dairy cattle diets has not shown conclusive evidence of contributing to laminitis. Research into the role of vitamins, particularly biotin, suggests significant benefits to claw health. Similar information exists on the role of minerals and trace minerals in dairy cattle diets. A claw healthy diet should include appropriate supplementation of both vitamins and minerals to support the proper growth and development of claw horn. Laminitis results from disrupted blood flow in the corium that leads to damage of the dermal-epidermal junction and the underlying connective tissue matrix of the corium. Inflammation predisposes to the activation of matrix metalloproteinases which break down the strong collagen fiber bundles of the suspensory apparatus of 3rd phalanx (**P3**). This permits sinking and rotation of P3 and predisposes it to the ulcers of the toe, sole, and heel. There are, however, alternate theories that suggest hormonal changes associated with calving may be major contributors to weakening of the suspensory apparatus. If these observations are correct, it may help to explain those inconsistencies in the literature and those observed clinically that do not show a clear relationship between laminitis and nutrition.

Introduction

The management of feeding and nutrition are the primary areas of interest when attempting to reduce lameness problems. This may or may not be the correct approach depending upon the specific types of lameness experienced. For example, it would be hard to influence the incidence of infectious foot diseases (foot rot, interdigital dermatitis, or

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digital dermatitis) by manipulation of the diet alone. Laminitis and claw disorders share a closer relationship to metabolic disease disorders which are often linked to nutrition and/or feeding issues. Cow comfort considerations are also critical factors in sorting out lameness problems and must be evaluated in herd problem situations as well. However, for the purposes of this discussion, our attention will be on nutrition and claw health.

Rumen Acidosis

Acidosis is generally associated with the ingestion of large amounts of highly fermentable carbohydrate-rich feeds which ultimately result in the excessive production and accumulation of lactic acid in the rumen. In it's acute form, the disease is characterized by severe toxemia, ataxia, incoordination, dehydration, ruminal stasis, weakness, and recumbency. The mortality rate is high. The subclinical form of rumen acidosis (better known as **SARA**, for Sub-Acute Rumen Acidosis) is far more common than the acute form of this disease. Major clinical manifestations would include variable feed intake, depressed fat test, poor body condition despite sufficient energy intake, mild to moderate diarrhea, and occasional cases of epistaxis (nose-bleed) or hemoptysis (the expectoration of blood from the mouth). Conditions such as laminitis or undefined lameness, abomasal disorders, and liver abscesses are generally secondary observations (Nocek, 1997; Nordlund, 2002).

Although few studies have been able to establish a direct link between rumen acidosis and laminitis, most assume that the feeding program is a major underlying factor. In reality, much of the information ascribed to cattle is based on information from studies of starch overloading models in horses (Garner et al., 1975; Vermunt and Greenough, 1994). Recent work suggests that an oligofructose overload model may be appropriate for the study of acute bovine laminitis. Researchers were able to successfully create classical symptoms of rumen acidosis and laminitis in cows treated with an alimentary oligofructose overload (Thoefner et al., 2004). The following is an attempt to identify some of the more important predisposing factors relative to nutrition and feeding of dairy cattle.

Nutrition and feeding considerations

Rumen fermentation disorders that result in acidosis are typically traced to diets with excessive levels of highly fermentable carbohydrates and inadequate levels of effective fiber (Nocek, 1997). Even with high quality ingredients and proper formulation of the diet, what ends up in front of the cow is still at the mercy of those responsible for mixing, delivery, and management of the feed bunk. Add to these selective eating or feed sorting behavior of cows (Leonardi and Armentano, 2000) and it's easy to see that there's ample room for error. Equally important are dietary changes that naturally occur during the cow's lactation cycle. In recent years, nutritionist's have concentrated their attention on feeding programs during the transition period in an attempt to ease the adjustment of cows to higher energy rations necessary to sustain milk production. A Florida study concluded that large differences in the fiber and net energy content of closeup and early lactation diets can contribute to an increase in the incidence of rumen acidosis and subclinical laminitis (Donovan et al., 2004).

Carbohydrate

Feeding rations high in non-structural carbohydrates to animals that are not sufficiently adapted has the potential to result in a lowered rumen pH. Lowered rumen pH is associated with a change in the rumen microflora from predominantly gram-negative to predominantly gram-positive lactic acid-producing bacteria. Coincident with this change in rumen pH and microflora is the release of endotoxin from the outer cell walls of dying and disintegrating gram-negative bacteria. Aided by a damaged and dysfunctional rumen mucosa, lactic acid, endotoxin,

and possibly histamine, are absorbed into the blood stream. These products are rapidly dispersed to the micro-circulation of the corium, where directly or indirectly (through vaso-active mediators), blood flow is disrupted leading to the lesions observed in laminitis (Nocek, 1997; Vermunt and Greenough, 1994).

While there is little dispute that rumen acidosis may occur as described above, it's not clear that laminitis will inevitably occur as a consequence. Three studies observed no correlation between laminitis and the feeding of rations high in carbohydrate (Smit et al., 1986; Frankena et al.,1992; Momcilovic et al., 2000). Despite conflicting information in the literature, one would still have to conclude that there seems to be an association (albeit complex) between carbohydrate nutrition, rumen acidosis, and laminitis, but more research is needed to sort out the details of these relationships.

Protein

Feeding high levels of protein in the diet of dairy cows and the potential to cause laminitis or lameness is surely less well understood. Outbreaks of laminitis in calves fed milk replacer and starter rations containing 18% digestible protein are reported from Israel (Bargai et al., 1992). Calves affected were 4 to 6 months of age and had lesions in their claws consistent with severe acute laminitis. Although this is an interesting observation, most would view the suggestion that high protein was the cause of this problem with significant skepticism, since milk replacers and rations containing 18% protein (or higher) are commonly fed to calves and young stock throughout North America without incident. On the other hand, results of a Canadian study found no relationship between the level of protein fed and lesions associated with laminitis (Greenough et al., 1990; Greenough, 1990). In consideration of the above information, one must conclude that there is simply insufficient information to know what effects, if any, protein may have on foot health.

Vitamins

Vitamin deficiencies sufficient to cause obvious disease are relatively rare under modern feeding conditions. More common are those conditions where vitamin levels are sufficient to prevent the occurrence of clinical disease but possibly insufficient to support optimum growth and performance. For example, rickets from a deficiency of Vitamin D is extremely uncommon since hay and exposure to sunlight normally provide the cow with ample quantities of this vitamin. On the other hand, sporadic instances of white muscle disease associated with Vitamin E and selenium deficiency occur in un-supplemented animals raised in areas where soils are normally deficient in selenium. Sudden death or calves exhibiting a generalized weakness or stiffness of the legs may be observed in animals affected. Vitamin A has important roles in the maintenance of epithelial tissues, including claw horn.

The B-Vitamins are synthesized by rumen micro-flora, and therefore, until recently, rarely fed to dairy cattle. The one exception in recent time is biotin. Biotin is essential for keratin-protein synthesis and the formation of long-chain fatty acids that make up the intercellular matrix of claw horn (Mulling et al.,1999). Canadian research suggested that cattle fed high grain diets are subject to potential biotin deficiency since the rumen microbes responsible for biotin synthesis are sensitive to low rumen pH (Girard, 1998). Since then, several feeding trials with biotin supplemented at a rate of 20 mg/day have shown benefits to claw health, including: an improvement in the healing rate of sole ulcers (Lischer et al., 1996; Koller et al., 1998), a decrease in the occurrence of vertical wall cracks in beef cattle (Campbell et al., 1996), an improvement in white line health (Midla et al., 1998), a decrease in the incidence of lameness in pastured dairy cattle in

tropical Australia (Fitzgerald et al., 2000), reduced the incidence of sole hemorrhages and increased milk production in biotin-supplemented cows (Bergsten et al., 2002), improved horn quality and strength (Koster et al., 2002), and improved white line health (Hoblet et al., 2002). While cost and a lack of scientific information were once reasons to question the value of biotin supplementation, current cost and a growing body of scientific information suggests that biotin is worthy of consideration in the diets of lactating dairy cattle.

Minerals (including trace minerals)

Minerals have at least 3 broad functions in the animal's body: 1) as structural components of body organs and tissues, 2) as constituents of body fluids and tissues where they function to maintain proper osmotic pressure, acid-base balance, and membrane permeability, and 3) as catalysts in enzyme and hormone systems (Underwood, 1981). The specific role of minerals with respect to foot health have been reviewed previously (Socha, et al., 2002; Tomlinson et al., 2004).

One of the macro-minerals of greatest interest relative to claw horn integrity is calcium (**Ca**). The differentiation of keratinocytes in claw horn epithelium requires Ca for the proper function of enzymes in biochemical pathways that ultimately result in the proper keratinization of horn cells (Nocek, 1997). Any deficiency that may occur, such as with hypocalcemia during the peripartum period, would have the potential to negatively influence normal maturation of keratinocytes and thus affect the integrity of horn produced during this period (Mulling et al., 1999). In view of the fact that hypocalcemia and lameness are both common disorders in dairy cattle, this would seem an area of interest for further research.

The trace minerals zinc and copper play important roles as enzyme catalysts in keratin synthesis. At least 2 studies have reported an improvement in foot health from the feeding of a zinc methionine complex or organic zinc in a corn and grass silage-based diet (Moore et al., 1988; Reiling et al., 1992). The role of copper in keratin synthesis is through the enzyme thiol oxidase, a key enzyme in the biochemical pathways necessary for the cross-linking of keratin filaments within the keratinocyte. Cross-linking of keratin filaments impart strength to the cell, making it more resistant to mechanical and physical forces (Socha et al., 2002).

Selenium and Vitamin E are known to have important functions with respect to the resistance of animals to infectious diseases. Selenium functions within the cytosol of the cell as a co-factor for the enzyme glutathione peroxidase to protect cells and tissues from oxidative damage. Vitamin E serves as a specific lipid-soluble antioxidant in the membrane of the cell where it protects the cell from chain reactive auto-oxidation of membrane lipids. While specific data on foot health and selenium supplementation are lacking, one might expect increased resistance to infectious foot diseases in animals whose selenium and Vitamin E requirements are met.

Heat stress and rumen acidosis

The primary avenues for heat loss during periods of hot weather are sweating and panting. In severe heat, panting progresses to open-mouth breathing, characterized by a lower respiratory rate and greater tidal volume. The result is respiratory alkalosis caused by the increased loss of carbon dioxide. The cow compensates by increasing urinary output of bicarbonate (**HCO_3**). Simultaneously, the salivary HCO_3 pool for rumen buffering is decreased by the loss of saliva from drooling in severely stressed cows. The end result is rumen acidosis because of reduced rumen buffering and an overall reduction in total buffering capacity (Dale et al., 1954).

The effect of ambient air temperature on rumen pH was evaluated in lactating Holstein cows fed either a high roughage or high concentrate diet in both a cool (65°F with 50% relative humidity) and a hot (85°F with 85% relative humidity) environment. Rumen pH was lower in cows exposed to the higher temperatures and those fed the higher concentrate diets (Mishra et al., 1970). These observations have been corroborated by others (Bandaranayaka and Holmes, 1976; Niles et al., 1998), supporting the current view that increasing the energy density of rations to compensate for reduced dry matter intake during periods of hot weather is not without significant risk.

Connection Between Rumen Acidosis, Laminitis, and Lameness

The dermal-epidermal junction is a highly specialized region within the claw that serves as the interface between the vascular and non-vascular tissue. It is also the specific site of the lesion of laminitis characterized by sinking and rotation of the P3 and the accelerated production of poorer quality claw horn. For the purposes of understanding the lesions as they occur at the cellular level, it is important to have at least a mental picture of this region.

Corium (or dermis) and epithelium

The corium consists of connective tissue with a rich supply of blood vessels and nerves. Adjacent to the corium (moving in the direction of the claw horn surface) is the basement membrane, germinal epithelium, stratum spinosum, and finally, the stratum corneum, otherwise known as the horn layer. Although they have no direct blood supply, cells within the lower layers of the epithelium (germinal epithelium and lower layers of the stratum spinosum) are "living cells" by virtue of nutrients and oxygen received from the underlying corium by diffusion across the basement membrane. The germinal layer is an active region of cellular proliferation and differentiation. Cells within this layer that differentiate into keratinocytes (cells capable of producing and accumulating keratin) will gradually move outward into the stratum spinosum. As they do, they continue to produce and accumulate keratin proteins. Eventually, cells migrate sufficiently away from the corium that they no longer receive an adequate supply of nutrients and oxygen. At this stage, they begin to undergo the process of death and cornification (formation of cells into horn). Clearly, any condition resulting in a disruption in the flow of blood to the corium not only affects the corium, but also the epithelium and thus, the integrity of claw horn.

Laminitis - lesions at the cellular level

The pathogenesis of laminitis is believed to be associated with a disturbance in the micro-circulation of blood in the corium which leads to breakdown of the dermal-epidermal junction between the wall and P3. As described earlier, rumen acidosis is considered to be a major predisposing cause of laminitis and presumably mediates its destructive effects through various vasoactive substances (endotoxins, lactate, and possibly histamine) that are released into the blood stream in coincidence with the development of rumen acidosis and the subsequent death of rumen microbes. These vasoactive substances initiate a cascade of events in the vasculature of the corium, including a decrease in blood flow caused by veno-constriction, thrombosis, ischemia, hypoxia, and arterio-venous shunting. The end result is edema, hemorrhage, and necrosis of corium tissues, leading to functional disturbances including the activation of matrix-metalloproteinases (**MMP**) that degrade the collagen fiber bundles of the suspensory apparatus of the P3 (Boosman et al., 1989). This is complicated still further by the activation of horn growth and necrosis factors that result in structural alterations involving the basement membrane and capillary walls (Mulling and Lischer, 2002).

Changes occurring in the epidermis are secondary to vascular disturbances that result in reduced diffusion of nutrients from the dermis to the living layers of the epidermis. This interrupts cellular differentiation and proliferation in the germinal layer, and the keratinization of epithelial cells in the stratum spinosum. The quality of claw horn is dependent upon keratinization which gives the horn cell structural rigidity and strength. In conditions resulting in vascular compromise, such as laminitis, the keratinocyte may become injured or inflamed from being deprived of nutrients. The end result is the production of poorly keratinized (weak or inferior) horn that weakens the claw horn capsule's resistance to mechanical, chemical, and possibly even microbial invasion. Thus, the term *claw horn disruption* has been proposed as possibly a more appropriate term for laminitis and particularly subclinical laminitis (Logue et al., 1998).

Laminitis - sinking and rotation of the third phalanx

The weakest link between the attachment of P3 to the basement membrane of the epidermis (referred to as "the locus minoris resistentiae") is at the dermo-epidermal junction (Mulling and Lischer, 2002). This region is also referred to as the "suspensory apparatus" and includes all structures between the surface of the bone and the inner aspect of the cornified claw capsule (that is, the inner layers of the epithelium up to and including inner portions of the stratum corneum). The interface between the dermal and epidermal components of the suspensory apparatus are the interdigitating dermal and epidermal laminae. The crucial part of this suspensory apparatus is the series of collagen fiber bundles that run from the surface of P3 to the basement membrane. It is the weakening of this tissue that is believed to be responsible for the displacement of P3 which predisposes the claw to disorders in cattle.

The "supporting tissues" within the claw capsule are made up of 3 parts: 1) connective tissue, a part of which encloses the digital cushions and extends into, and becomes part of, the interdigital ligaments which support the axial side of P3, 2) vascular tissue, and 3) adipose tissue which comprise the digital cushion. Collagen fiber bundles which comprise connective tissue in the supporting structure of the claw are believed to be affected similarly to those in the suspensory apparatus during bouts of laminitis.

Destruction of the dermal-epidermal junction has particular consequences in cattle as it permits weakening of the suspensory apparatus within the claw. As the suspensory apparatus weakens, P3 begins to "sink" or "rotate" within the claw. The result is compression of the corium and supporting tissues that lie between P3 and the sole. When this "P3 sinking phenomenon" involves severe rotation of the toe portion of P3 downward toward the sole, a toe ulcer may develop. If, on the other hand, sinking of the P3 is such that the rear portion sinks furthest, compression and thus a sole ulcer is more likely to develop in the area of the heel-sole junction (known as the "typical site" or the site most commonly associated with the development of sole ulcers). Sole ulcers are very common claw lesions in dairy cattle and constitute one of the most costly of lameness conditions (Mulling and Lischer, 2002; Lischer et al., 2002).

Alternative mechanisms responsible for damage and/or weakness of the suspensory apparatus

Researchers from the United Kingdom suggest there may be a combination of biochemical and biomechanical mechanisms responsible for weakening of the dermal-epidermal segment between the wall and P3 (Tarleton and Webster, 2002). Their work suggests that weakening of the suspensory tissue at the time of calving may be a result of the activation of matrix metalloproteinases

by a gelatinolytic protease they refer to as "hoofase". Levels of this enzyme were highest in the claws of heifers from 2 weeks pre-calving to 4 to 6 weeks post-calving. These researchers also propose another factor responsible for weakening of the suspensory apparatus that is not associated with the inflammatory changes normally observed with laminitis. Hormones, responsible for relaxation (such as relaxin) of the pelvic musculature, tendons, and ligaments around the time of calving, may have a similar effect on the suspensory tissue of P3 as well. Their data further suggest that although this weakening of the suspensory apparatus may be a natural occurrence, housing of animals on soft surfaces during the transition period may be sufficient to reduce or alleviate the potential for permanent damage to these tissues (Webster, 2002). Others suggest that sinking and rotation of P3 is associated with unexplained structural alterations occurring on the surface of P3 where the suspensory tissues are anchored (Mulling, 2002). Regardless of the actual mechanism, the result is a predisposition to claw disorders that often result in permanent damage to the suspensory and supporting tissues within the claw and Lischer, and a higher risk of lameness. These studies also support the view that laminitis is complex and multi-factorial.

Summary

Nutrition has significant influences on claw health in dairy cattle. Damage to the dermal-epidermal junction as occurs with laminitis interferes with the diffusion of nutrients across the basement membrane into the living layers of the epidermis. Furthermore, disruption of the basement membrane and germinal epithelium restricts normal differentiation and proliferation of keratinocytes destined to become claw horn. The end result is weaker, less resistant claw horn. Rumen acidosis predisposes to laminitis. It is most often associated with the ingestion of large amounts of highly fermentable carbohydrate-rich feeds in combination with fiber sources low in effective fiber. Some degree of acidosis seems unavoidable since what ends up in the cow's rumen is not totally determined by the ration formulation, mixing, or delivery to the feed bunk, but to some extent by the cow and what she elects to consume. The levels of protein in rations are often questioned relative to their potential for causing laminitis-like problems. To date, there is no convincing evidence that high levels of protein are responsible for laminitis. Vitamins and minerals have important roles in claw health as they support keratinocyte proliferation and differentiation. They are also necessary for proper keratinization within horn cells. There is strong evidence of a relationship between rumen acidosis and laminitis; however, this has not been documented by all studies reported in the literature. Recent development of a bovine research model may help to establish a clearer understanding of this relationship in the future. Current information suggests that laminitis is a disease affecting tissues at the cellular level. "Claw horn disruption" is the phase preferred by some who believe that this more accurately describes the lesion of laminitis. Reduced keratinization is a major complication of laminitis and results in the production of soft weak horn that is less resistant to physical or mechanical forces. Sinking and rotation of P3 is a secondary consequence of the damage caused by metalloproteinase enzymes released during the course of the disease. These enzymes are responsible for degradation of the collagen fiber bundles in the suspensory apparatus of P3 which creates laxity in this support system and permits sinking and rotation of P3. Recent work suggests that a novel enzyme termed "hoofase" may also play an important role in the activation of metalloproteinase enzymes. Hoofase was found to increase significantly in animals at or near the time of calving. A second mechanism is believed to be associated with the hormonal changes that occur around the time of calving. It is proposed that the same hormones responsible for relaxation of the pelvic musculature (e.g., relaxin) near the time of calving have a similar effect on the suspensory apparatus of P3. These researchers have also found

that housing of animals on soft surfaces throughout the transition period permitted recovery of these tissues, thus preventing permanent damage.

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Performance Monitoring of Dairy Nutrition and Feeding

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Introduction

Feed is the single largest operating expense on dairy farms, while feeding and nutrition should be considered one of the most important variables behind successful production, animal health and profitability of a dairy. Annual feed costs per milking cow can average $1000 to $1200 per year, or $100,000 to $120,000 for every 100 milking cows. Despite this fact, only a minority of dairy farms closely monitor feed quality variation, feed mixing, inventories, feed bunk delivery, shrink, feed costs, and corresponding animal performance. The result is lost opportunity to improve cow performance and to better management expenses.

Feeding and nutrition is much more than just balancing a good ration, mixing and delivery of the feed, and removal of feed refusals. In a paper previously presented at this Conference (Barmore, 2002) discussing the fine-tuning of the mixing and feeding of high-performing dairy farms, there where four key goals identified. The fourth fine-tuning feeding goal addressed the need to have ***on-going monitoring and use of records***. So, as a follow-up to the 2002 presentation, this paper will discuss specifics of "performance monitoring" that can be used to track and evaluate dairy nutrition and feeding.

On many dairy farms, the manager or employees responsible for feeding don't fully understand or appreciate the impact their role has on the overall profitability and success of the dairy. The feed manager is responsible for handling over 50% of the variable costs of the dairy, which account for well over $1,000,000 for dairy farms larger than 1000 cows and often equipment worth several thousands of dollars.

Clearly, implementing proper changes or improvements to a nutrition and feeding program first require that good timely data and information can be collected and interpreted. Historically, the primary focus of nutrition tracking and data collection have been done from a perspective of ration balancing "nutrient specification" and feed laboratory testing. In other words, the industry has given a lot of attention to tracking whether the ration is properly balanced for different nutrient pools, such as protein, rapidly degraded carbohydrates, and effective fiber, using accurate feed lab analyses. Although very important to a successful nutrition program, this might be considered too narrow of a perspective of the overall opportunities to monitor the nutrition and feeding program.

The concept of performance monitoring isn't new, but most of the discussions to date have centered on monthly, quarterly or even annual measurements by outside nutritionists, veterinarians, lenders, Extension, and other consultants. Although valuable, periodic performance monitoring does not usually sufficiently provide the timeliness of good daily data to optimize the management of a dairy. By gaining the interest and cooperation of on-farm

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employees and management to engage in daily monitoring, the success of a dairy typically improves.

As illustrated (Figure 1), performance monitoring of the nutrition and feeding management should focus on four key areas, including: 1) **cow evaluation**, 2) **impact of facilities and environment on nutrition**, 3) **records evaluation and interpretation of data,** and 4) **feeding and feed costs**.

Ration Balancing and Nutrient Specification

Understanding and tracking the nutrient specifications balanced for in a ration are key components of performance monitoring of dairy nutrition and feeding. However, there have been other proceeding papers (VandeHaar, 2002; Weiss, 2004) that have addressed this, and the topic will not be considered in this paper. An area of ration monitoring rapidly coming to the forefront due to environmental considerations is phosphorus and nitrogen management. Although phosphorus monitoring of rations has received considerable attention, better nitrogen management and monitoring of the ration nitrogen input/output must become a higher priority of all nutritionists. This will require a better understanding of the existing research on different nitrogen and amino acid pools, and how nitrogen can be managed through nutrition and feeding adjustments.

Monitors Versus Report Card

As an industry, we have utilized the computer to process and calculate a wealth of data that pertain to the dairy. We have developed many benchmarks, and have typically provided a "report card" that suggest past success or failure. In general, report cards do little to predict future outcomes, and more importantly, are often too slow to let us know there is a serious problem. Aggressive and successful businesses are more interested in where they are going rather than where they have been. Still, our industry is overloaded with benchmarks that show past performance and historical perspective. Although benchmarks and report cards have value in certain instances, they do not necessarily provide meaningful information to help a dairy navigate and improve the business over the upcoming weeks and months.

As opposed to a report card, we try to develop "***monitors***" to assess dairy performance. What does the word "monitor" mean as applied to dairy records? As a verb, it means the process of tracking parameters to detect change or lack of progress. As a noun, it is a specific parameter that is routinely measured. Why should we monitor records on a dairy or heifer operation? There are really 3 reasons to monitor:

1. Evaluate the impact of a management change,
2. Detect an undesirable trend or result, and
3. Motivate change.

Management changes include feeding changes, grouping changes, environment changes, etc. Before any management change is implemented, the business should know how to evaluate the response. The business should have knowledge of past performance and the ability to measure future performance with the appropriate parameter.

It is important that questions are asked first before data parameters are utilized. For example, a question may be, "Is fertility in my herd declining this summer?" Which parameter(s) would appropriately answer this question? It makes little sense to monitor a parameter and then decide what questions it may answer.

Monitoring data requires time and effort. Someone must collect the data, and then the data must be analyzed and interpreted. If this process does not result in discussion and/or action, then why

bother? Indeed, the goal of monitoring is to find areas where changes can be made to improve the dairy business. Monitoring is a waste of time and effort if decisions or management interventions do not result.

In summary, monitors should:

1. be proactive,
2. be readily measurable,
3. impact improvement and profit,
4. minimize variation, bias, lag, and momentum, and
5. result in discussion and action.

Records Evaluation and Data Interpretation

The computer has created a business world that is overwhelmed with information and data, yet often there isn't a clear understanding of how to properly collect and interpret good data, with the net result being bad decisions being made. This happens even though there are "lots of data". Before deciding to collect "more data", there are three steps that are recommended:

1. Clearly define what you are trying to measure, specifically defining the numerator and denominator if a calculation is involved.
2. The need is for "good" data versus "more" data; good data only can be generated if it's easily compiled, it is actually the proper data for the question being addressed, and is it timely.
3. There must be appropriate interpretation and discussion of the data, in a timely fashion, with the appropriate employees and advisors having agreement on management adjustments that will be taken because of the data interpretation.

There are several important principles of data interpretation and performance monitoring that must be considered to minimize misinterpretation of the data. Specifically to managing a dairy, the phrase "numbers don't lie" might be better rephrased as "numbers don't lie if properly interpreted in the context of normal biological and process variation, and they are the correct numbers relative to the question at hand".

Averages versus distribution (variation)

The fundamental rule of nutrition and feeding is that "you never know the true value of anything" (Weiss, 2004a). There are reasonably accurate estimates of the nutrient requirements of production, good accuracy of the average dry matter **(DM)** intake for groups of cows, and for the average nutrient composition of the feeds being fed. However, there will always be biological and process (i.e. mixing and sampling feed) variation that will occur that can cause the actual situation to be different from what the "averages" are indicating. Does this mean that due to normal variation we should give up on monitoring nutrition and and feeding management ....absolutely not! However, variation, and proper interpretation of data must be understood and addressed. As a starting point, Weiss (2004a) does an excellent job of discussing how to understand and manage feed ingredient variation.

We first need to think of feeding and nutrition in terms of the probability of an outcome rather than an absolute number. In other words, how confident are you that the number you are working with actually represents the true situation? In simple terms, knowing the distribution of data around an average allows the distribution to be used to determine how much confidence you should have when using an average value. The more variation, the greater the distribution and the less confidence that the average might truly represent the current situation. For another perspective on how distribution can be used in monitoring nutrition, one might also think of "***manufacturing a ration***" rather than balancing a ration, given that variation

and process control systems are much better recognized and understood in manufacturing industries.

Variability, or ***lack of consistency***, is a dimension of risk and must involve monitoring of the nutrition and feeding on dairy farms (Fetrow, 2001). There inherently always will be some variation in outcomes on a dairy when we are dealing with biological units...or cows! Making milk is a manufacturing process. In any manufacturing process, there will be some degree of variability when inputs are put through a process. Cows fed the same ration will differ in their milk production, with an individual cow varying in production from day-to-day. Variation makes operating a dairy more difficult and less profitable because the outcome of a process (e.g. mixing feed) is not precisely known.

The unpredictability of a process (caused by variation) makes troubleshooting and planning of future outcomes more difficult. For example, either not having any mixing or feed intake records or having records with a tremendous amount of day-to-day variation makes the monitoring of the impact of the nutrition program on cow health and production very difficult. Variation in the predicted feed intake or other nutritional parameters can be thought of as deviation from the target points or goals, which obviously impacts the outcome. Without records, or a monitoring system, the variation cannot practically be measured or managed.

Lack of consistency in the day-to-day feeding and bunk management creates challenges associated with normal healthy rumen function and animal health. The idealistic rumen environment to maximize production and feed efficiency would be "steady-state" conditions. Biologically and practically speaking, striving for steady-state rumen conditions isn't realistic, but the point to be made is reducing variation in the feeding can significantly improve cow performance by improving rumen function and digestion.

The best-managed, and typically most profitable, dairy farms seek ways to reduce variation and to better understand what is "normal variation and patterns" in daily processes. Dairy farms that can create consistency through better processes will improve their ability to plan and improve management. Daily monitoring of several aspects of the feeding and cow performance will allow quicker adjustments to be made as needed. The answer to getting started with improving variation in the feeding lies in implementation of good management plans with supporting monitoring systems. **Day-to-day consistency and monitoring of the cows, feeds, mixing, bunk management, and feed costs are key drivers of profitability on well-run dairy farms!**

Meeting specifications versus risk management

Producing milk and running a dairy means dealing with a biological manufacturing system (i.e. cows, people, and weather). It's unrealistic to say that with a biological manufacturing system that we're going to consistently meet exact specifications like might be considered in the manufacture of a car, textile, or other similar object. Rather, a preferred method of monitoring on a dairy is to collect and interpret data that will allow a better probability of predicting a positive outcome and allow doing this on a more frequent basis. Simply said, through the use of daily monitoring, we want to increase the number of times and probability of making good decisions through the use of good data and minimize the number of errant or bad decisions. Completely eliminating the bad decisions and unpredictable events (having to feed lots of low quality corn silage because of excessive rains) due to the biological nature of the dairy industry isn't possible, regardless of the level of monitoring implemented. We aren't trying to meet exact specifications as are other industries, rather trying to maximize the probability of making good decisions through the use of monitoring.

Accuracy versus precision

Using data to monitor performance generates discussion on how close to the target goals should a manager expect performance to be in feeding, fresh cow performance, milk production, and other measurable parameters. When working with cows and people, and dealing with the unpredictability of weather, it's important that performance be evaluated in the context of being "accurate" relative to the target goals, versus trying to be "precise" or exact. Lets use an actual "bullseye target" analogy, with circles that constrict towards center and hitting the bullseye being the indicator of greatest repeatability and accuracy. Accuracy can best be represented as consistently hitting within or near the bullseye, with no stray hits outside the inner-most circle. Precision on the other-hand could be represented as time and time again hitting the exact same spot on the target. Expecting to hit dairy performance targets with precision simply isn't realistic. Rather the focus when monitoring nutrition and feeding performance should be to have excellent accuracy and not be concerned that data repeat with precision.

Normal versus abnormal variation

There will always be variation around an outcome; the key is to establish what is considered "normal" variation and monitor for the outliers or data that signal there is something abnormal going on. An example of this might be the normal daily variation that will be seen in fat test when taken daily on multiple loads of milk from the same dairy. We probably shouldn't concern ourselves with a fat test bouncing around from 3.4 to 3.6% between daily loads due to normal variation associated with time of day of milking and analytical variation with testing milk fat. However, if a pattern over multiple days of average daily milk fat tests had been consistently running from 3.50 to 3.55% and suddenly the daily average drops to 3.40% for three consecutive days, this clearly would be a signal that something needs attention. The key is knowing the variation pattern and watching for "outliers" to the pattern. There will always be biological variation, and the pattern of this normal biological variation must be established. This can only be done with daily monitoring and collection of good data.

With good data, upper and lower limits can be set when data falls outside normal variation. These outliers are often referred to as signals or "flags" that intervention may be needed. An example might be the number of days that animals spend in a close-up group prior to calving. With proper monitoring, we can focus on average days in the pen, distribution of the average number of days in pen, and most importantly, the metabolic incidence rates associated with the animals that fall outside the targeted upper and lower limits (i.e. 18 to 24 days target distribution with the average days in the pen target being 21 days). Days in the pen will vary, looking at abnormal variation is the key!

The average, or central tendency of the data, likely is not the only acceptable outcome, but rather a range within normal variation. Often if three data points are near the upper or lower limits, this might be considered a signal that further investigation or intervention is needed. Usually, intervention based on a single outlier must be carefully considered when working in a biological system. One more key point on abnormal variation - remember that "abnormal variation or data" might actually be a good indicator, such as a cow being in heat thus her walking pedometer activity for a given day is very high and becomes manageable outlier data.

Statistical process control

There currently is a lot of interest and discussion of how to apply well proven statistical process control (**SPC**) principles on-farm to allow better monitoring and interpretation of farm generated data. Statistical process control is a method of interpreting time-series data using a

statistical process, which has been widely adopted across other industries and is commonly used in poultry and swine businesses. The general principle of SPC is to have ample good data collected on a regular basis that generates a historical perspective and "normal" pattern to the data. Statistical process control then is looking for irregular data patterns or "outlier data" that might be interpreted as a management issue that may need addressing. The underlying concept behind using SPC is to create more reliable processes and outcomes, with the intent being the ability to generate consistent results under all circumstances. Herein lays the potential blind spot of the dairy industry trying to fully embrace SPC type management on dairy farms. Let's remember, we are dealing with a biological manufacturing system (cows, people, and weather).

The tradeoff of aggressively striving for more realiable systems when dealing with a biological based business is that these same systems may become less accurate or valid to what is trying to be accomplished. Just because a process is very reliable, or repeatable over and over, doesn't mean it is necessarily meaningful or accurate. Adding "gut feel" and utilizing the craft and skills of employees to interpret the often changing situations of the cows and feeds may actually deliver more "accurate" results. Think of this as "reliability versus accuracy".

Yes, dairy farms will benefit from more reliable processes, such as feeding where the results are more consistent (ration crude protein varies very little from day-to-day). But, what if the cows are suggesting based on observational factors that the accuracy of the ration relative to rumen function, milk production, and manure consistency isn't very accurate (simply put "not getting the job done"), then what good is having very reliable results? Accuracy and reliability are a constant "push-pull" concept in data management. Producing accurate and repeatable results on a dairy requires that both qualitative, as well as quantitative, data be utilized, and dairy farms would be wise to think this through before implementing a SPC monitoring system. A good example of this might be fresh cow monitoring and how utilizing temperature monitoring (quantitative) along with visual appraisal for "attitude and appetite" (qualitative) might be the best system. Standard process control systems typically address only the quantitative side of the picture.

Too much data versus relevant data

Too much aggregated data, from too many animals, summed over too many pens will tend to limit the value and relevancy of the information. The net result is the question at hand might not be correctly answered. An example of this might be knowing average DM intake for a herd, rather than knowing the DM intake for a specific pen. If looking at herd feed intakes, rather than pen intakes, because the denominator includes fresh cows, 1st calf heifers, possibly sick cows, and cows of all stages of lactation and production, the data are too broad and really doesn't tell you anything about feed intake and energy balance for the cows in early lactation. With any data, it's critical that both the numerator and denominator be known and appropriate for the question being asked.

Two dots don't make a line

The opposite of too much data is not having enough data, yet falling into the interpretation trap of over-analyzing limited data, implying that it actually means something. Simply stated, it takes at least three data points to create any resemblance of a line with specific direction. If there are only two data points, the information could be completely misleading as to the true direction. An example of this might be having two displaced abomasums (**DA**) in a row...does this really mean there is a pattern or an issue with DA? Maybe or maybe not. However, if there are 3 to 4 DA in a row, this is a data line that is likely pointing in a direction that warrants investigation and/or intervention into what might be causing the DA.

Benchmarking versus monitoring

Benchmarking is a very common term and practice used across industries, including the dairy industry comparing peer results to performance at a given location. Benchmarking is always of interest because it looks at the "competition" and helps assess where a business stands relative to its peers. This will always be an important aspect of business analysis. However, there is big watch out with using benchmarking to monitor performance on a dairy.

The only time that benchmarking should really be used to make specific management decisions and changes is when clearly the benchmarks being compared have been calculated with the same exact definition for the numerator and denominator. A simple example might be comparing the retained placenta (**RP**) rate between three different dairy farms, where the dairy farms all use a different time period and/or method to define what actually constitutes a RP. Dairy A might only have a RP incidence rate of 6%, while Dairy B has a RP incidence rate of 9%. Knowing this information may not accurately indicate which dairy actually has the better fresh cow program. Clearly, this might have very limited value on a given dairy versus daily monitoring of fresh cow performance and taking timely and appropriate action for each and every RP that does occur.

Monitoring versus on-farm experiments

There is a common fallacy that if a dairy runs a feeding trial or experiment on their farm that the data and information will provide better insight to whether the feeding practice should be implemented. The fallacy of this is that relatively imprecise data measurements (always the case on individual data gathered on-farm due to all the biological normal variation) when added to a set of relatively precise (controlled research data) will actually improve the accuracy of the overall data set. This is simply false!! This is not to imply that on-farm implementation of new practices and changes shouldn't be monitored...of course they should be! However, the monitoring should be focused on determining if the implementation of the technology or change is a good fit for the dairy, and whether by adopting the technology, there is a trend and pattern towards a more improved cash flow and long-term profit. When trying to answer whether the biology and science is sound behind an adopted technology or management change, only controlled research should be used to answer the "why and how does it biologically work" questions. Use on-farm monitoring to answer the "does it fit" and "does it appear to be improving cash flow and long-term profitability" questions.

Problems With Parameters

No parameter is perfect, although some are better than others. Parameter problems can be categorized as follows (Fetrow et al., 1997; Eicker et al., 2002):

1. Variation,
2. Momentum,
3. Lag and
4. Bias.

Variation results from one number having a large impact on the result. Data analysis for small herds is often limited for this reason. For example, suppose in one week that a group of 10 cows were palpated for pregnancy, and 4 were checked pregnant. Suppose the next week that another 10 cows were palpated, and 3 were pregnant. The numbers would suggest that palpation pregnancy rate dropped from 40 to 30%. This is a 25% reduction in palpation pregnancy rate. Did the dairy really get 25% worse?

Momentum is when too much time goes into the calculation, making changes difficult to detect. Large changes in performance are not detected quickly if there is too much momentum.

Rolling herd average, days open, calving interval, and average milk peaks are examples of parameters with too much momentum. Rolling herd average is the classic example of a number that is very slow to change, since a years worth of data goes into the calculation.

Lag is the time between when an event occurs and when it is measured. Age at first calving is a parameter that has significant lag. By measuring age at first calving, we are measuring an event that happened 9 months ago (conception). Although a heifer grower may want to record age at first calving for a report card or for marketing purposes, it has no value as a monitor.

Bias occurs when data are ignored or not included in the calculation. This includes using a subset of the herd or not accurately recording data. Conception rate is a good example of a parameter with bias. Suppose a dairy has 100 cows come into heat in a give 21 day period. The dairy farmer is confident that 50 of the cows are in good heat and will conceive, but they are not sure of the other 50. If only 50 are bred and 40 conceive, the records would indicate an 80% conception rate (40/50). If all 100 cows were bred and 60 conceived, then conception rate is 60%. If conception rate were the parameter used to monitor success, the first alternative would be optimal. However, the latter example with a lower conception rate resulted in 20 more pregnancies!

What Should Be Monitored?

Traditional monitors include rolling herd average, milk peaks, days open, calving interval, age at first calving, etc. Previous discussion tells us that these parameters are worthwhile as report cards but of limited use as a monitor. If these numbers get worse, the dairy has likely had a problem for some time.

We need to monitor parameters that will quickly tell us when a management intervention is warranted. As suggested earlier, there are four key areas that should be considered for performance monitoring of the nutrition and feeding management, including: 1) **cow evaluation**, 2) **impact of facilities and environment on nutrition**, 3) **records evaluation and interpretation of data, and** 4) **feeding and feed costs**.

To begin with, what questions should we be asking when we walk on a dairy? What questions address whether the feeding program and nutrition are working? Here are some questions and thoughts pertaining to each question:

1. Are the fresh cows doing well?
2. Are cows getting pregnant?
3. What are culling patterns telling us?
4. How is fresh cow and overall herd health?
5. How are the "good" cows performing?
6. How many "bad" cows are there?
7. How are the first lactation heifers doing compared to older cows?
8. By pen, are feed intakes meeting targets and how much variation is occurring?
9. What is the pattern for milk fat and protein?

Are the fresh cows doing well?

Monitors of limited value include average milk peaks in the herd, or any other "average" that applies to cows that calved over different time periods. Better monitors include calving disorders as a percent of calvings, milk weights during specific time periods during the first 60 days fresh (requires daily milk weights), first test milk weights from last test day, and 30- and 60-day cull rate [number of cows left less than 30 and 60 days-in-milk **(DIM)** divided by calvings].

Are cows getting pregnant?

Monitors including days open, percent of herd pregnant, and calving interval are of limited value. In asking the question, we are most concerned with the open cows in the herd, and the rate at which they are conceiving. The most appropriate monitor is 21-day pregnancy rate, which is the number of pregnant cows every 21 days divided by the pregnant-eligible pool [cows beyond the voluntary waiting period that are not Do Not Breed (**DNB**)]. The rate at which cows are resynchronized is also important.

What are culling patterns telling us?

Overall cull rate is a poor monitor to answer this question. Two additional questions further refine the issue: are too many fresh cows leaving and why, and are the cows that need to be culled leaving? Calculating a 30-day (or 60- or 90-day) culling rate, as previously described, will answer the first question. Quantifying the number of "bad" cows or "DNB" cows will address the second question. Any cow that is open >100 DIM and with less than 35 lb/day of milk is a "bad" cow in our estimation when other animals are available to trade-up and fill a necessary stall.

How is fresh cow and overall herd health?

This is a somewhat vague question that can encompass many areas and will vary depending on the dairy farmers ability to detect, define, and record incidence of disease on a consistent basis. Number of cows in the hospital pen, death loss, cows shipped, and disease incidence rate will provide some insight. Visual observation of the herd, including general appearance and condition of the cows, locomotion status, manure appraisal, and cud chewing, may provide additional insights. Percent born dead (dead on arrival; **DOA**) for cows and heifers calving over a given time period is a useful monitor of calving problems and the work being done in the maternity area. Other more subjective measures may be useful for some dairy farms, such as scoring calving difficulty and assistance provided.

Metabolic disorders should be tracked as a percentage of calvings over a give time period. For large dairy farms, this time period may be a week or month. For small dairy farms, this time period may be quarterly, semi-annually, or annually. It is useful to compare first lactation disorders separately from older cows. All dairy farms do not record metabolic disorders in a similar manner, so they are difficult to compare or benchmark. For example, what is the definition of an RP? Is it a retained fetal membrane soon after calving, 24 hours after calving, 48 hours after calving, or only when a cow goes to the hospital? Incidence of DA is more straightforward. Milk fever incidence can be impacted by the aggressiveness of the herdsperson in the fresh pen. Ketosis is very subjective and most difficult to benchmark. Having said this, some reasonable goals are less than 3 to 4% DA, less than 10% RP, and less than 1 to 1.5% milk fever. Season and environment will obviously impact these numbers.

Are the "good" cows performing?

Which are the "good" cows? Recent milk peaks or production for cows in the earlier stages of lactation are worth monitoring to evaluate how the "good" cows are milking. The percentage of cows over 100 lb/day of milk may be meaningful, along with the "ceiling level" of milk production or the top level that cows are achieving under current feeding and management conditions.

How many "bad" cows are there?

Every dairy should have its own definition of a "bad" or unprofitable cow. If not, they should. Once the criteria for a "bad" cow are established, is the dairy removing these cows from the herd or are they holding onto them? For most dairy farms,

cows that are >100 DIM, open, and <35 lb/day of milk would be "bad" cows. Criteria for a cow to come a DNB should be clearly defined by the management team.

How are the first lactation heifers doing compared to older cows?

Mature equivalent (**ME**) production is an attempt to correct milk production for age, among other factors. Comparing 305-day ME for heifers and cows provides a report card for how heifers have done. First or second test 305-day ME projections provide more timely data and provide a sense of direction of how fresh cows are doing relative to previous points in time. Both reproduction and health data should always be evaluated based on lactation number, specifically looking at differences in 1st lactation heifers relative to cows.

How are feed intake levels and variation by pen?

Knowing DM intake and the variation around the average intake by pen have several advantages to nutritionists and others managing herd health. Typically, higher intakes will result in better milk production and energy balance of the cows. However, feed efficiency may actually suffer with higher intakes, indicating the importance of knowing intake along with milk production by pen (Linn, 2004; Hutjens, 2005). Possibly more important than knowing the average DM intake by pen might be knowing the amount of variation in intake within a pen. Dry matter intake will vary from pen movements, weather, forage quality, and numerous other factors. Consider that feed intake is not static even when these variables are relatively constant, and the "normal variation" must be established as the criteria in which the monitor is being measured against. In a commercial dairy setting, we don't believe it always is accurate to impose our human "24-hr day" system of evaluating a cow's DM intake pattern. It might be more telling to evaluate intake patterns in slightly longer intervals, such as 48 hrs, to assess normal versus abnormal variation.

What is the pattern of milk fat and protein?

Milk fat might be considered a "standard" in the industry for monitoring nutrition and feeding. Although valuable, it's of both authors belief that this is often misinterpreted and misused in the industry in terms of evaluating the true status of rumen health and energy status of cows and would best be carefully interpreted. The ease of milk fat data collection clearly suggests that it should be used as a monitor on all dairy farms, but with careful interpretation. Milk protein and milk urea nitrogen as monitors have been well discussed in many other papers and will not be addressed here.

Cow Evaluation

Considerable time is spent in the industry walking pens and evaluating what we see, smell, feel, and hear. In part, we want to determine if the cows are healthy and productive and to find problems that may exist with the cows. Each person has specific things they like to see when walking pens, along with subjective measures of rumen and cow health. Probably the most subjective of monitors recommended, these parameters and monitors combined with experience are valuable in performance monitoring of the nutrition and feeding program.

Cud chewing

This may be one of the most overrated monitors used in the industry because of the subjective nature. While widely adopted, many advisors to dairy producers promote the importance of monitoring cud-chewing as an indicator of normal rumen function. The limits of using cud chewing as a valued monitor comes from the subjective nature of how it's measured and the limited accuracy of the "data". Cud chewing can vary tremendously

throughout the day in relation to time of feeding, milking, lockup, and other activities that may interrupt their routine. Is "more" cud chewing always a good thing? One way to really get cows chewing more is to force them to consume some really low quality forage!

Just because a predetermined percentage of a group is not chewing their cud during a single walk-through, does this mean they are not healthy or productive? A good approach to consistently monitor cud chewing is to choose a spot and time to monitor and compare over different visits to the dairy. Another way to improve the accuracy of the data is to make an assessment of cud chewing on the entire herd, even though multiple pens may be involved. The milking parlor is an under-utilized place to monitor cud chewing – consider the location standardized across pens and all animals. In the parlor, within a few minutes of the machine being attached, cows should be relaxed and prone to chewing. In our experience, consistently high performing herds will achieve in excess of 50 to 60% of the cows in the parlor chewing at any given time post machine attachment. This figure often will approach 90 to100% of the cows on a given side of the parlor, including during periods of heat stress if ample cow cooling is being provided.

Manure

This subject has been a popular topic in recent years, and a thorough discussion could fill an entire paper (Hall, 2003). Although a very subjective monitor, most nutritionists consider manure evaluation important, looking for consistent manure within a pen and little variation across the herd. Normal variation within a pen might be considered as 2 to 3% "too loose" and 2 to 3% "too stiff", although every nutritionist has a different definition of "loose" and "stiff". Loose manure can result from protein imbalances, irregular feeding patterns, forage moisture swings, acidosis, moldy and/or mycotoxin contaminated feeds, and sorting among other items. Loose manure with bubbles, off-color, greasy appearance, or strong smell is a cause for concern and further investigation. It is not unusual for "just fresh" pens to have a higher percentage of animals with loose manure. Presence of mucus or small amounts of undigested feed in the manure is disconcerting to many nutritionists, but in practicality, it is not always a cause for concern. Some ingredients, such as whole fuzzy cottonseed or cracked soybeans, will almost always result in 1 to 3% of the seeds (by weight fed) passing into the manure undigested, yet these ingredients are staples in many successful dairy farms.

The key to manure monitoring is to realize that we are looking for "outliers" more so than the average composition. Washing of manure is of limited value to the authors, given the highly subjective nature of interpretation (Stone, 2005). Compared to low producing herds, high producing herds often have more mucus and small amounts of "undigested" feed in the manure, potentially from higher rate of passage.

Locomotion

The purpose of locomotion scoring is to evaluate foot health in a herd. Without formally scoring every cow, it is useful to watch cows walking to and from the milking parlor to evaluate foot health. Cows with a normal gait should place their rear foot in nearly the identical place the front foot just vacated. Cows should also walk and stand with a straight back. Quantifying foot problems is difficult in many situations, but overall as a monitor, this has a lot of merit.

Behavior

Understanding normal comfortable cow behavior is key to monitoring the performance of nutrition and feeding. Cows should always be relatively calm without getting restless or excited from someone walking in the pen. Pens of 1st calf

heifers will be more likely to become anxious from someone walking the pen. Cows should always be able to move about freely without slipping or falling. Cow behaviors in the pen that are appropriate include resting, eating, cud-chewing, drinking, exhibiting estrus, and walking to and from these activities, with all of these being done in a calm non-combative or competitive way. Other activities, including standing around, fighting, and nervous reaction to stimulus, can impair production and foot health. Normal cow behavior, regardless of temperature conditions or other factors, is key to success of a nutrition and feeding program.

Monitoring Facilities and Environment

Ever feel frustrated having a well-balanced ration being delivered and consumed by the cows, yet cow performance is not meeting expectations? Cow performance and health require excellent nutrition, as well as minimizing a cow's exposure to stress. Dairy facilities can have a dramatic impact on milk production. A dairy facility must create an environment that is ideal for cow comfort and normal cow behavior, while allowing the employees operating the dairy to produce consistency in day-to-day tasks.

Facilities should be designed to minimize travel distances, time standing, and slippage and poor footing. A good cow-friendly environment must also minimize heat stress, allow the cow the opportunity to rest comfortably in a stall when desired, deliver clean abundant supplies of water, and maximize the cow's opportunity to consume fresh feed without competition from other cows in the pen. Clearly, there often are bottlenecks in one or more of these facility-related areas that prevent the full expression of a quality ration and feeding program. **Don't ever overlook the impact that facilities might have on the performance of cows consuming a high quality ration!**

Research continues to help us better understand the interactions of facilities, cow environment, and cow behavior (Smith et al., 2002). A better understanding of how a high performing cow spends time eating, ruminating, and resting, and how these are impacted by environmental conditions allows development of better rations and feeding practices. Realizing there are distinct differences in cow behavior and needs with primiparous and multiparous cows in itself is important when evaluating rations and facilities. From an evaluation perspective, there also needs to be a better understanding of how much cow-to-cow variability there is in the key behaviors that comprise a cow's time budget.

Grant and Hill (W.H. Miner Agricultural Research Insitute, Chazy, NY; 2005, personal communication) are finding large ranges in resting and rumination times of animals. This might suggest that evaluating the "average" cow behavior might provide limited information versus maybe looking closer at the "outliers and "signals" that small groups of underperforming animals within a group or pen might be showing. When these researchers stratified animals into two groups, those producing over 100 lb/day of milk and those producing less than 100 lb/day, the average resting time for the higher producing animals was 12.5 +/- 1.4 hr/day compared to 10.6 +/- 2.4 hr/day for the lower producing animals. **The resting time was nearly two hr/day greater for the higher producing cows.**

In a preliminary analysis of the data, regressing resting time against milk yield indicated that every extra hour of resting was associated with an increase in milk production of approximately 3.3 lb/day (Grant and Hill, W.H. Miner Agricultural Research Insitute, Chazy, NY; 2005, personal communication).

Key areas of facility and environmental monitoring are listed below. Each of these areas, if

not properly managed, will hinder normal feed intake and amplify body maintenance requirements, with the net effect being lower feed intake and low milk production relative to the energy intake. Hutjens (2005) and Linn (2004) nicely discussed the concept of feed efficiency and environmental factors that can limit the conversion of consumed digestible energy to milk production.

Cow comfort and facility monitoring encompass much more than just the freestall beds and the bunk space. Consider the entire pen and milking center as the "environment".

Facility and environment monitoring

- Proper air exchange and flow, with key areas being over stalls, in the holding pen, and parlor.
- Heat abatement is a must on all dairy farms, which should include proper shading, use of forced air movement, and water cooling. Cows must be encouraged to maximize eating and resting time during warm conditions.
- Waterers must be readily accessible, providing abundant clean water. Ideally each waterer should allow three or more cows to drink simultaneously without competition. Cow traffic should move freely behind the cows that are drinking in cross-overs. Provide water in route to/from the parlor when possible, providing 2 linear feet of breezeway water space per parlor stall for each side returning from milking (i.e. for a double-16 parlor, provide 32 ft of water trough space when possible).
- Alleys, cross-overs, and walking surfaces must allow normal locomotion, while minimizing slippage. Improper concrete finish, lack of proper grooving, ice, slippery rubber surfaces, and excessive sloping can all cause locomotion issues. Don't underestimate the importance of proper grooving or newer rubber surfaces that can be overlayed on concrete to improve locomotion and foot health.
- Freestalls should encourage maximum resting time and ease of rising, while properly positioning cows to minimize soiling of the beds. Design and management of freestalls should consider the following:
  - Leveling of the bedding and refilling schedule,
  - Depth and dryness of bedding to ensure cleanliness and cushion,
  - Forward and side lunge space and ease of rising,
  - Neck rail placement,
  - Brisket board height and placement,
  - Loop design, mounting structure, and dimensions, and
  - Front and rear of freestall, head space and obstructions, and curb height.
- Bunk space, manger height, headlock opening dimensions, and cow-side feed alley widths have a large impact on intake and nutrition performance.
- Bedded packs must be kept clean at all times, providing adequate square footage per animal. Minimizing time on a bedded pack should be the goal for every cow, whether using a calving pack or sick cow pack. Lack of proper cooling, inadequate supply of cool water, and lack of fresh feed often are bottlenecks when managing bedded packs.

Stocking density and grouping are other aspects of facilities and the cow's environment that can have big impacts on performance. There are detailed discussions of these topics that can be referred to separately (Barmore, 2003; Robinson, 2004).

Monitoring Mixing, Feed Delivery, and Bunk Management

The process of taking feeds from storage, accurately weighing and mixing the feed, and then delivering the proper ration to the correct pen of cows seems rather straight forward. That is, until

we consider the moisture variations that can occur in forages (Stone, 2005) and other feeds stored outside, the changes that can occur regularly with forage quality, the difficulty in accurately weighing some ingredients, ease in which feeds can either be over or under-mixed, and the human errors that can occur throughout the feeding process for various reasons.

A high plane of nutrition consumed on a consistent basis has a tremendous impact on the overall success of a dairy. A key component of nutrition is obviously feeding and bunk management. Given the high variable costs associated with feeding and the impact of nutrition on herd performance and health, it hopefully becomes obvious that establishing a daily nutrition and feeding monitoring program will be financially beneficial.

Monitoring of the feeding program can be broken into two distinct areas, the first area being the parameters that the feeder and nutritionist closely monitor, and the second area being parameters that the owner/manager and nutritionist typically monitor (Barmore, 2001). Although there certainly will be overlap between these, it has been helpful to establish specific responsibilities with many of the monitors better suited for the person actually doing the daily feeding.

Parameters Monitored by Feeder

Mixing feed, delivery of feed, and bunk management can be quite comprehensive, including all aspects of determining the batch size, frequency of feeding, timing of feeding, feed delivery to the bunk, feed push-ups, feed stability and bunk-life, actual intake and recordkeeping, feed sorting, feed weigh-back management, and the bunk environment, including stocking density and manger design. Stated a lot more simply, ***the goal is to provide a fresh, high-quality, non-sorted ration at all times, where cows can get feed when they want, in unlimited quantities, without competition from other cows with both feed and water available in a comfortable environment.***

One of the greatest areas of feed variation that requires monitoring is with forages, whether ensiled or dry hay being fed (Stone, 2004). There are several parameters of forage and feed quality, along with total mixed rations **(TMR)** bunk management, where a feeder and nutritionist should work together to establish a monitoring system of these parameters that uses both a subjective and quantitative analysis, including:

- Moisture content of forages, other wet feeds, and the blended TMR,
- Smell and fermentation quality of ensiled feeds before feeding,
- Excessive wet or otherwise bad forage that needs to be isolated or discarded before mixing,
- Identifying feeds which are heating prior to coming out of storage,
- Particle length of forages from storage, after mixing, and in the bunk,
- Proper kernel processing of corn silage,
- Baled hay coarseness, stem texture, and mixing properties of the baled hay,
- Grain particle size.,
- Ingredient inventories adequate to complete the next day feedings,
- Proper appearance of blended protein or grain mixes based on the actual formulation,
- Occurrence of moldy feeds that need to be discarded,
- Level of refusals in each pen requiring removal before feeding,
- Accurate cow pen counts to determine batch sizes needed,
- Level of sorting assessed by comparing the fresh TMR relative to the refusals removed,
- Heating and secondary fermentation of the TMR that may occur in the bunk, and
- Frequency of TMR pushup and adequacy of

having TMR available the full length of the bunk at all times.

Have we as consulting nutritionists and veterinarians truly invested in training the proper people that have a key role in feeding management? Although several years ago, Bucholz (1999) pointed out the gaps in understanding recommendations between nutritionists and the feeders that were encountered in their Extension feeder training programs. Something as key, and relatively straight forward, as moisture determination had several breakdowns due to lack of understanding and clarity on the behalf of many of the feeders. This lack of understanding still exists on many dairy farms as we speak.

Accuracy of mixing

Knowing the accuracy of how ingredients are loaded into a mixer is important to minimize future mixing errors. From an expense management perspective, knowing the accuracy of loading and mixing is key. Some of the common tools used to determine the accuracy of loading and mixing are: 1) TMR nutrient analysis, 2) particle size evaluation, 3) marker or tracers blended and tracked, 4) hand-recorded feeding logs, and 5) use of software programs which interface with mixer scales.

A big potential advantage of implementing a monitoring program is the ability to better manage the consistency of the day-to-day rations being delivered. The key to improving mixing accuracy, feed inventory control, and reducing shrink and variation is setting up a well-understood and effective monitoring system for measuring feed disappearance charged against inventory. Many examples can be cited of a dairy that experienced a significant health challenge with fresh cows, or a dairy that lost a large amount of milk production and income over time because of errors that were being made in the mixing or feeding program, yet essentially no records were available to quickly and accurately determine specific causes or to allow implementation of a better management plan.

There are several methods to monitoring and tracking the actual loading, mixing, and feeding process. Neither will one system fit all dairy farms, nor are any systems 100% accurate. Essentially, there are three ways to approach setting up a monitoring system, including: 1) using a simple "pencil and paper" system of recording, 2) using a combination of #1 and spreadsheets, or 3) using a computerized software program specifically developed for tracking and monitoring feeding and inventories that integrates with the scale on the mixer. Each of the systems has its own advantages, with clearly the future being with the radio frequency scale integrated feed management software programs that allow extensive data evaluation of the feeding system. For any of the systems used, determining forage inventories can be one of the more difficult steps. Forage storage capacity charts can be used to fairly accurately determine how much forage is in inventory based on measured compaction density and the size of the bunker or bag.

Feeding Parameters Monitored by Management

Are the feed costs acceptable?

Feed cost per cow per day is often used as the primary monitor of feed costs, but it is limited as a monitor for obvious reasons given that higher producing cows eat more feed. Feed cost per hundred weight of milk is a better measure of feeding economy and has some use as a report card but limited use as a monitor (Bethard and Stokes, 1999). Income over feed costs (**IOFC**) is a better monitor for short term decisions. As an example, consider two herds with varying production and feed costs but similar milk price ($15/cwt). Herd A has low feed costs ($2.95/day) and low milk production (65 lbs/day), while Herd B has higher feed costs

($3.40/day) and milk production (75 lb/day). Feed cost per hundredweight is $4.54 for Herd A and $4.53 for Herd B. However, IOFC is $6.85 for Herd A and $7.85 for Herd B.

This example illustrates several points. First, feed cost per hundredweight is not necessarily a good monitor. Second, benchmarking between herds can be very misleading. Feed cost per hundredweight is not adjusted for fat and protein content of milk, so herds with higher components will often have a higher feed cost per hundredweight, all else being equal. Some dairy farms will also include dry cow feed cost in the feed cost per hundred weight calculation, while other dairy farms will not. This can be a significant source of error when benchmarking feed costs among dairy farms. Generally, using both IOFC and feed cost per hundredweight of milk will provide a more accurate assessment of feed costs than either one alone, and certainly both of these monitors are better than feed costs per cow per day.

Since protein and commodities typically represent a large majority of purchased feed costs, closely monitoring and managing these costs can represent very large contributions to the year-end bottom-line. Without ever compromising quality, risk management strategies should be utilized in feed cost management that includes bids, contracting, and other price protection vehicles where appropriate. Cost of inventory and shrink are often underestimated when considering the types of ingredients and storage that best fit a given dairy. Regular monitoring of purchased feed costs should be implemented at every dairy.

There are other feed cost related questions to ask, depending on the goals and structure of the dairy. Many nutritionists want to know if cows are efficiently converting feed to milk. The milk:feed ratio (pounds of milk per pound of DM intake) is typically monitored to answer this question. This number does have some value as long as the context of how it's interpreted is understood. Feed efficiency will vary considerably (Linn, 2004; Hutjens, 2005) depending on herd make-up (portion of herd that is heifers, days in milk for the herd, etc.), accuracy of measuring true intakes versus feed delivered, and actual milk, etc. shipped by pen.

Summary

Feed costs represent the single largest variable expense of producing milk. Many dairy farms have the ability to monitor and track inventories, mixing, and feeding but lack a well thought out system and plan. The economic incentives for creating such a plan are large. Often, when data are available, it's under-utilized or almost equally as bad misinterpreted. Collecting feed quality and ration variation information, along with feed intake and feed inventory information, allows a dairy team to more quickly uncover areas of needs to avoid issues that otherwise would arise with cow health, lost production, or higher than expected feed costs.

Experiences have shown that by establishing as part of a feeder's job description the expectations for monitoring feeding and mixing, and at the same time giving the feeder the monitoring tools, that significant reductions can be made in the variation that occurs from load-to-load or day-to-day. Reducing the variation in the rations delivered, while reducing feed shrink, are real opportunities available to the dairy producer for better managing a significant area of risk. Records and monitoring are always a key to improving and must be considered a key to building a better feeding management plan and reducing risk exposure.

Begin by making a commitment to improving the mixing and feeding management and monitoring the feeding process on a daily basis; speak to this commitment with employees and other professionals supporting the dairy. Understand the areas which contribute to the greatest variation. Clearly

communicate that feed inventory, feed removal from storage, mixing, and shrink along with bunk management are part of the feeder's responsibilities, including writing it into the job role and description. Provide on-going training for these same employees. Develop an organized, yet simple, monitoring program that will be embraced by the feeder, nutritionist, veterinarian, ag lender or accountant, and management team alike. Recognize the significant costs associated with variation and feed shrink that occurs in a feeding program, deploying the proper amount of resources in labor and capital to allow improvements to be made. Investment and changes in feeder training, proper feed handling equipment and mixers, storage facilities and bins, along with computer feeding software, often are solid investments with relatively quick returns. Set clear expectations with the entire dairy management team as to what the goals and commitments are for improving mixing, feeding variation, and feed shrink.

And don't forget to celebrate the success and improvements along the way!

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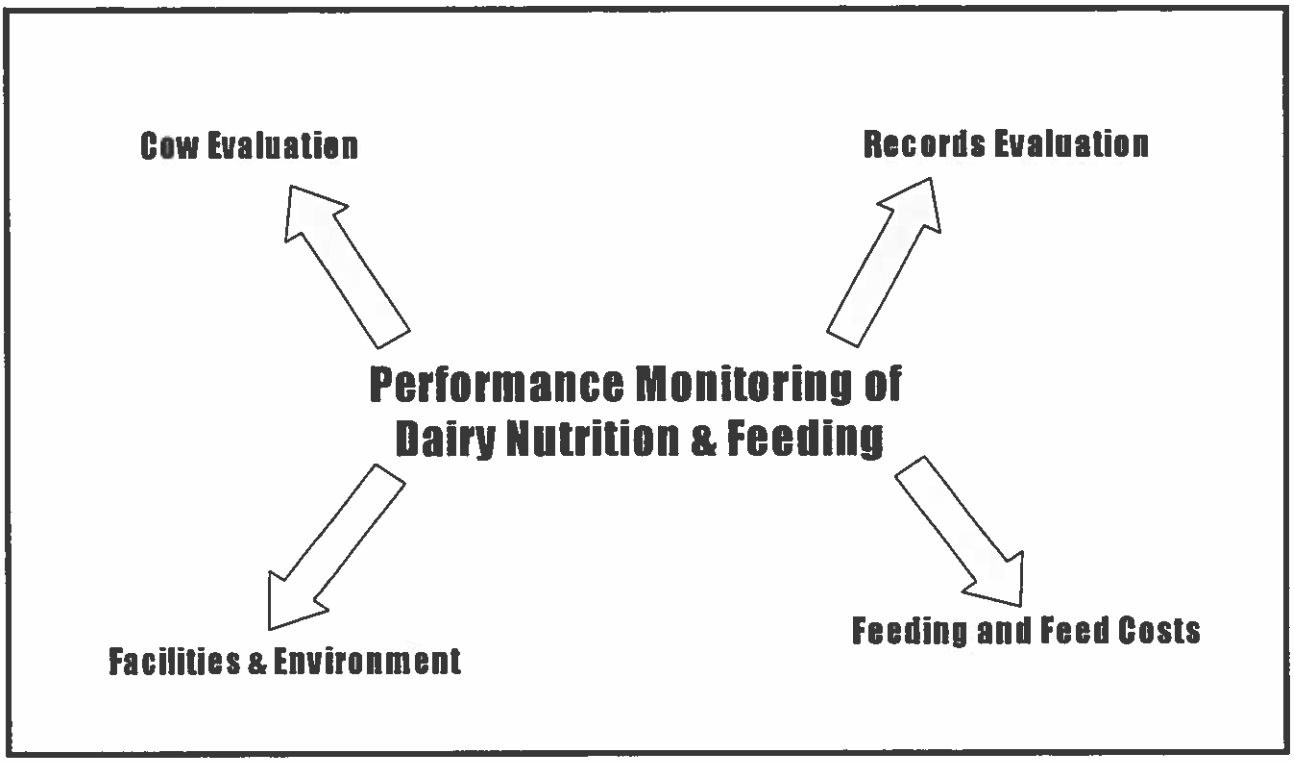

Figure 1. Four key areas for performance monitoring of dairy nutrition and feeding.

Risk Factors for Metabolic Disease

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Abstract

Metabolic disease is the most commonly recognized disease on dairy farms. While the pathogenesis is well known, metabolic disorders continue to occur. Metabolic diseases are associated, with one disease predisposing to another. Evidence suggests that metabolic disease affects host defense, and therefore, impacts the common infectious diseases of dairy cows. Risk for metabolic disease is affected by dietary formulation but is modified by cow behavior and intake. Regardless of dietary formulation, the cow and management factors on a given farm may determine the impact of metabolic disease.

Introduction

Metabolic diseases are those associated with the chemical processes necessary for maintenance of life. In cattle, metabolic diseases include errors in electrolye / mineral metabolism, of which parturient hypocalcemia (milk fever) is most common, or errors associated with energy metabolism, including ketosis and displaced abomasum. Metabolic diseases are associated in that the occurrence of one increases the risk of another. These associations tend to leverage the impact of disease on the animal (Correa et al., 1993).

Parturient hypocalcemia and ketosis can present in either clinical or subclinical states. Clinical disease implies that cows exhibit physical abnormalities. Subclinical disease is one where cows do not exhibit clinical signs, but the biochemical condition is present. Most producers have been content to estimate the impact of metabolic disease as a function of occurrence of clinical disease. While clinical disease occurs at a modest rate, subclinical disease has become recognized as common.

Occurrence of Metabolic Disease

Clinical parturient hypocalcemia affects an average of 6% of cows and has been associated with a 3-fold increased risk of dystocia, retained placenta, and displaced abomasum, and a nearly 9-fold increased risk for clinical ketosis and mastitis (Curtis et al., 1983; Kelton at al., 1998). Subclinical hypocalcemia, defined as plasma calcium of 5.5-8.0 mg/dl within 48 hours of parturition, has been preliminarily reported to occur in 25.3, 43.9, and 57.8% of lactation 1, 2, and 3+ cows (Reinhardt et al, 2004).

Clinical ketosis is estimated to affect about 6% of cows (Kelton et al., 1998; USDA, 1996). However, subclinical ketosis, defined by postpartum serum beta hydroxybutyrate $\geq$1200 µmol/L, affected 59% of cows (Duffield et al., 1998). Ketosis is associated with a decrease in milk production and increased risk of other postpartum diseases (Rajala-Schultz et al., 1999). It is known that the risk of displaced abomasum is increased as a consequence of subclinical ketosis in lactation

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(Geishauser et al., 1997) or in the 2 weeks leading up to calving (LeBlanc et al., 2005).

These data may be interpreted several ways. They do suggest that there are a high proportion of cows very near "the edge" of clinical disease. This further suggests that any limited stressor, acting to tip the balance in favor of disease, may cause a very considerable proportion of cows to be clinically affected.

In the most parsimonious terms, metabolic disease, both electrolyte related and energy related, may be considered a problem associated with diet formulation, diet consumption, and/or individual (i.e., genetic) factors. Of these, diet consumption is probably the most variable. Therefore, if a single risk factor "root cause" of metabolic disease is to be considered, that "root cause" would focus on the factors associated with dry matter intake (**DMI**) in late gestation/early lactation cows. This is particularly and directly the case for the energy related diseases.

Energy Associated Disease

Ketosis, fatty liver disease, and displaced abomasum are the common energy related metabolic diseases. Energy related disease is generally thought to occur as a result of excessive lipolysis (fat breakdown) that leads to ketosis/fatty liver. Lipolysis is stimulated when energy output exceeds intake. Endocrine drivers of lipolysis include decreased insulin (low insulin allows lipolysis to continue), increased glucagon (which increases lipolysis), increased glucocorticosteriods (cortisol - which increases lipolysis), and catecholamines (epinephrine/norepinephrine – the so called "fight or flight" hormones that are powerful lipolytics). While some of these mediators are beyond direct control, the glucocorticosteriods and catecholamines are important mediators that are, to at least a partial degree, dictated by and within control of management.

Energy related disease occurs as a consequence of energy distress. Energy distress can be pictured as a non-adaptive or inappropriate cow response to negative energy balance. Since all cows are expected to go through a period of acute negative energy balance postpartum, the key to health is really how the cow responds to the total environmental stress. Negative energy balance occurs prior to calving, and lipid mobilization pre-partum is extremely rapid (Goff and Horst, 1997). Therefore, energy distress is initiated before calving. Classically, much focus has been placed on improving energy intake of cows through activities aimed at increasing voluntary DMI. The importance of maximizing dry period DMI has been recently questioned, and there has been some thought that stabilizing dry period DMI may be of principle concern (Grummer et al., 2004). Irregardless of whether maximizing or stabilizing DMI is found to be of primary importance, factors that contribute to acutely decreased DMI must still be identified and controlled.

Risk Factors for Altered DMI

Body condition, social interaction, and concurrent disease are a few of the many factors affecting DMI. It is well known that over-conditioned cows [body condition score (**BCS**) ≥4.0] have a greater decline in DMI around calving, putting them in a position of susceptibility to energy related disease. It has been suggested that adipose cells of over-conditioned cows are more sensitive to signals to initiate fat breakdown, and fat cows may exhibit insulin resistance. Over-conditioned cows tend to have increased fat breakdown, increased liver lipid concentration, and a shift toward ketogenesis. It appears that cows near calving with BCS ≥ 4.0 have a marked propensity toward lipid mobilization, and cows with BCS ≤3.0 have little propensity to mobilize fat (Duffield et al., 1999). Therefore, the recommendation that late dry cows be in a BCS range of 3.25 to 3.75 probably represents a good tradeoff between subsequent milk

production and risk of metabolic disease. However, careful managers may be able to maintain health and gain high production in cows with greater BCS if environmental conditions are optimal and energy distress is avoided (Contreras et al., 2004).

Social (or grouping) stress can result in alterations of cow behavior and may affect energy balance. The effects may be mediated through decreased feed intake or through the stress induced lipolysis pathways. Pen moves result in observed social disorder for 2 days, with a milk yield depression of 2 to 5% for the average cow (Hasegawa et al., 1997). While this is a modest effect, social stress can effect the non-dominant cow to a much greater degree. Dominate cows (usually older, larger, more senior, and gaining weight) are largely unaffected by a group change. However, non-dominate cows (typically younger, smaller body size, and/or cows losing weight) may be targets of aggressive social behavior, with resulting less opportunity for feed and rest. Clinical ketosis and fat infiltration of the liver in late pregnant cows has been observed following feed restriction of 30 to 50% or fasting for 4 to 6 days (Gerloff and Herdt, 1984). Therefore, coupling the natural decline in DMI with social stress lasting more than two days, especially in non-dominate animals entering a marginal housing situation, a significant proportion of animals could be placed in acute negative energy balance leading to energy distress and clinical disease.

Social effects are accentuated in larger cow groups/herds, so they assume more importance as herds grow in size. The ability to measure cow interaction, and the effect it has on feeding behavior, is only beginning to be addressed. Social interaction is dependent on the constitution of the group, as well as housing, feeding, and other environmental factors. Therefore, the relationships can become complex and difficult to predict. In general, minimizing re-grouping at key times has been under investigation. These times include the period of 5 days prior to calving and 1 to 10 days after calving (Cook and Nordlund, 2004).

Relationships of Energy, Disease, and Host Defense

Three other related diseases, retained placenta, endometritis, and mastitis, are prevalent conditions that have been putatively associated with energy deficiency in cows. Endometritis and mastitis affect 17% and 13 to 45% of lactations, respectively, and are infectious in origin, but the bacterial agents are considered opportunists so that these diseases are largely determined by cow defense (Hogan et al., 1989; Epperson et al., 1993; USDA, 1996; LeBlanc et al, 2002). Neutrophils are very important in bacterial defense, and it was shown that neutrophil function declines in late gestation, reaching a nadir near calving (Kehrli et al., 1989). Additionally, neutrophils are important in placental release, and cows with retained placenta had a deficiency in neutrophil function in the prepartum period (Kimura et al., 2002). Ketone bodies appear to decrease neutrophil response (McMurray et al., 1990; Sartorelli et al., 1999). Cows that exhibited hepatic lipidosis, a lesion consistent with energy distress, took longer to clear experimental intramammary infection and had blunted response to vaccination (Hill et al., 1985;Wentik et al., 1997). In addition, *in vivo* work suggests that improvements in energy balance in late gestation tended to decrease retained placenta (Duffield et al., 2002). While it is unclear how negative energy balance affects host defense, it is important to recognize that diseases of the mammary gland and uterus may be associated with energy distress. Energy balance should be considered a potential contributor to these energy related diseases if antioxidant vitamins and minerals are adequate.

Summary

Metabolic diseases are interrelated, so that one disease increases risk for another. The energy

associated diseases include ketosis, displaced abomasum, fatty liver, retained placenta, metritis, and possibly mastitis. The root cause of these conditions is an energy distress situation, where cows respond inappropriately to the negative energy balance of early lactation. It is likely that the negative energy balance of early lactation will be accentuated as milk production rises.

Providing an environment for an adaptive cow response will remain key to health. Dairy advisors must take an active role in promoting quantitative monitoring to assist the producer. In addition to tracking average DMI, monitoring energy balance using milk or blood NEFA or ketone assays may be essential, and may provide an early warning of problems to come. Since disease represents failures (those cows who could not negotiate stress), analysis of disease incidence records must be conducted and compared to known risk factors, including BCS, DMI, pen moves, and concurrent disease. These areas are obvious points where nutritionists and veterinarians can interact in a cooperative relationship.

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Water Quality for Calves

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Physiology of the Pre-ruminant Calf

Water makes up 85.8% of the body weight (**BW**) of a neonatal calf (Lewis and Phillips, 1978). Prior to birth, the developing fetus is surrounded by amniotic fluid that is 92% water. In the uterus, the developing calf is supplied with water by diffusion from maternal plasma, and at birth, the calf is at its greatest water content having developed in a water based media where water has borne the nutrients required to allow rapid growth and development. The uterus supplies an environment where water containing fluids shelter the fetus, mitigating the effects of jolting and gravity on the developing fetus. Upon birth, the mammal is suddenly exposed to light, temperature extremes, and wind, beginning the processes of drying and dependence on water contained in milk and the intake of free water by the calf.

While milk is the primary source of water for the calf, consumption of additional free water is required to support optimal growth and health in the bovine. Feeding supplemental water to pre-weaned calves is of particular importance to encourage consumption of dry feed. Kertz et al. (1984) demonstrated that when supplemental water was not provided, this resulted in a 31% decrease in dry matter (**DM**) intake and a 38% reduction in weight gain. For each extra liter of water consumed, there was a corresponding increase of 82 g/day of dry feed intake and an increase in weight gain of 56 g/day. These data powerfully emphasize the importance of providing access to supplemental water of high quality for young calves from a very early age. Housing arrangements which provide easy access to water and dry feed for calves and the importance of keeping feed and watering equipment accessible to human care givers for routine cleaning are discussed in detail by Davis and Drackley (1998, Chapter 18).

Mineral Content in Water

Mineral content of well water has been shown to be variable across and within regions of the United States by survey (Socha et al., 2001). A database of more than 5000 water samples from rural areas across the United States has been developed by Zinpro Corporation (Eden Prairie, MN), with assistance from Agri-King, Dairy One (Ithaca, NY), and Dairyland Laboratories, Inc. (Arcadia, WI). This database has been made available for use in this paper by the Zinpro Corporation. Average, maximum, minimum, and standard deviation of mineral concentrations in ppm from 238 water samples from Indiana, Michigan, and Ohio are shown in Table 1. In addition, samples have been divided by state and zip code of water sample origin, these data are summarized in Table 2.

The most basic measure in this database is that of total dissolved solids (**TDS**), this with addition of total soluble salts (**TSS**) and pH are initial considerations in determining the suitability of

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drinking water for calves. Water hardness is a physiochemical property of water based primarily on Ca, Mg, and Fe concentrations. Water turbidity, partially dissolved solids, acid/base balance, and mineral content are all factors that may affect water acceptance, palatability, and final intake of free water. Minerals of particular concern when in high concentrations are cobalt, copper, iron, hydrogen sulfide, manganese, and sulfur. The form in which sulfur is present depends on water pH and the concentrations of anions and cations present in the water. Hydrogen sulfide, which is the "rotten egg" odor that some water contains, is volatile, and no accurate measure of it can be made without special equipment that allows a sample to be taken without exposure to air prior to determination. Hydrogen sulfide has been shown to decrease water palatability, acceptance, and intake in adult cattle (Loneragan et al., 2001), but in my reading, I was not able to find a specific reference to the effects of hydrogen sulfide concentration on free water intake of pre-weaned calves. On the other hand, total sulfur in water of less than 500 mg/L has been recommended for calves from research by Linn and Raeth-Knight (2002). High but still safe concentrations and maximum tolerable concentrations of minerals for dairy cattle are shown in Table 3. These values are based on nutrient recommendations made in the NRC (2001) and from several other sources (Socha et al., 2003).

Mineral Interactions and Associated Metabolic Problems

Elemental Cu interacts with manganese and several other elements. Acid/base balance and anion/cation ratio influence the magnitude of these interactions (Xin et al., 1991; Hemken, 1993). In the state of NY, the influence of elevated Mg in veal calf diets was investigated by supplementing veal milk replacer with magnesium oxide to mimic problems seen in the field with calves developing kidney stones when fed milk replacers reconstituted with water containing high levels of Mg (Petersson et al., 1988). Four diets were fed containing 0.1, 0.3, or 0.6% Mg and the fourth diet, 0.6% Mg plus 2% NaCl. The 0.6% concentration of Mg supplementation resulted in 70% of the calves developing renal calculi (kidney stones). Addition of 2.0% NaCl to the 0.6% Mg replacer diet, over the 112-day feeding period, reduced presence of kidney stones to 30% as determined by autopsy after euthanasia. Increased free water intake prompted by the addition of NaCl was suggested to have been the causative factor in reducing stone formation.

Iodine is used as a disinfectant for dairy equipment, as an ingredient in teat dips, and as a compound to allow sterilization of the umbilical cord of calves. Jenkins and Hidirglou (1990) investigated the effect of adding 0.57, 10, 50, 100, or 200 ppm iodine to calf milk replacer from 3 to 38 days of age. This study revealed typical signs of iodine toxicity at 100 and 200 ppm of iodine, including nasal discharge, excessive tear formation, and saliva production. While digestibility of milk protein was reduced only at the two highest doses of iodine, even at 50 ppm of supplemental iodine resulted in greater iodine in blood plasma, bile, and non-thyroid tissues after a 5 week feeding period. This led researchers to set 10 ppm of iodine as the practical limit as is reflected in the NRC (2001). Milk replacer diets fed to rapidly growing veal calves are a good example. The NRC (2001) states that the Cu requirement for calves is 0.2 ppm; however, practical water and replacer diets for rapidly growing veal calves are often limited to 0.05 ppm Cu because of clinical Cu toxicity problems which occur when the water and replacer mixture contain greater Cu concentrations (Dr. Jeffrey Pyle, North Manchester Veterinary Clinic, North Manchester, IN; personal communications, 2005).

The solubility of minerals and mico-minerals in the calf digestive system is important for absorbability. An example is the element aluminum. Experimentally, aluminum chloride added to calf

diets, even at low levels, has been shown to decrease DM intake, weight gain, bone ash weight, and bone P composition (Crowe et al., 1990). In addition, these authors mentioned that soil aluminum content and ingestion of aluminum containing soils by grazing ruminants in New Zealand has been shown to reduce P digestibility. However, the practical importance of this toxicity or mineral interaction in the Midwest and Great Lakes areas of the U.S. is unknown. Most clay containing soils in this area are composed of a 2:1 particulate ratio of alumina to silica. Solubility of the aluminum fraction is so poor that little practical problem with aluminum toxicity in the United States or Canada is seen.

Temperature

The influence of milk or supplemental water temperature on health and performance of dairy calves has been reviewed by Davis and Drackley (1998. Chapter 15). Veal calves fed cold milk replacer ad libitum had decreased intake of milk as compared to veal calves fed replacer at room temperature (Filpot et al., 1972). In several studies with female dairy calves, restricted amounts of replacer and dry calf starter were fed; calves fed the cold milk replacer exhibited similar performance to calves fed warm replacer (Appleman and Owen, 1975). Seasonal dairy producers often practice "mob feeding" of grouped dairy calves. Nipples of hardened rubber are put mid-way on the outside of 55 gallon drums, and tubes to the nipples are kept at the bottom of the barrel to increase suckling activity and saliva production by the calf (Gratehouse, 1996). Nipple barrel calf feeding systems work best if calves are fed milk or replacer twice each day. Using this system, milk is usually consumed in 20 to 30 minutes; after the milk is consumed, water is fed by placing about 20 gallons of fresh water in the drum. This allows partial drum cleaning and gives the calves access to free water which, as in more traditional calf feeding systems, provides the calves extra water that promotes maximum DM intake and growth. Data from many feeding systems have shown that there is an extremely strong positive correlation between intake of water and intake of DM from replacers and from supplemental concentrates and forages Kertz et al., 1984).

Organic contaminants

Presence of E. coli, coliform, and total bacteria, as well as presence of organic toxicants in water on Ohio dairy farms was reviewed by Mancl and Eastridge (1993). In addition, the presences of bacteria (E. coli, coliform, and salmonella), as well as protozoal and fungal contaminants, have undergone an extensive survey on dairy operations in the pacific northwestern U.S. (LeJeune et al., 2001). The most readily available source for testing of fecal coliform bacteria is measurement by local health departments. Fecal coliform levels are reported in colony forming units (**CFU**) per ml. Bacterial numbers are reported on a $\log_{10}$ scale/ml of the liquid sample. It should be noted that this number only predicts the present number of microbial CFU and ignores potential growth under different environments and temperatures. It is possible that even low levels of coliform, E. coli, or salmonella bacteria (< 10 CFU/ml) can quickly and exponential increase to dangerous levels. Organic contaminants also include non-living organic compounds, such as pesticides, fuel tank discharge, paints, sealants, and other contaminates. In the tri-state and great lakes regions, several commercial laboratories such as A&L Great Lakes Lab (Fort Wayne, IN), Dairyland Laboratories (Arcadia, WI), and Dairy One (Ithaca, NY) offer analytical services to test for some of these contaminants through high pressure liquid chromatography (**HPLC**), gas liquid chromatography (**GLC**), and liquid chromatography (**LC**). Some rarely encountered contaminants, such as organophosphates, may require testing by highly specialized laboratories.

Dr. Jeffery Pyle and his associates with North Manchester Veterinary Clinic (North

Manchester, IN) work with some small and several very large veal growers in northern Indiana. Veal producers have a great sensitivity to water quality problems. The preferred sources for mixing milk replacer on small operations is water treatment by long term storage of chlorinated water in raised tanks. Frequent sampling is performed to confirm complete bacterial kill. On very large commercial veal operations, operators often take mineral content of well water out of the picture by using distilled water and by the use of citric acid to reduce pH of the water to near neutral (pH 7.0). Well water in northern Indiana is often of pH 7.6 to 7.8 (Table 2). Nearly neutral pH is preferred on veal operations because coagulation of casein (milk clot) in the abomasums of calves can be limited if water pH and buffering capacity is not modified. On these veal operations, distilled water is often used to closely control mineral concentrations, particularly of Fe and Cu. Iron concentrations in water and replacer are limited for two reasons. First because salmonella bacteria thrive in water with a high Fe content; and second, there is need to produce the pale coloration and meat quality for a traditional veal product. Veal calves receive needed iron by injection rather than by an oral route. The potential for explosion of coliform bacteria in milk replacer has prompted many veal growers to further treat previously chlorinated water with an in-line supply of ultraviolet radiation to reach the goal of zero CFU of bacteria in the final replacer delivered to calves. While the lengths taken to control inorganic and organic components in water used on veal operations may seem too costly and time consuming for use with dairy calves, lessons can be learned and new ways of controlling water quality for calves can be implemented by learning from veal growers who are striving to bring healthy calves from about 100 lb of initial BW to a well finished 550 lb of final BW in less than 19 weeks (133 days).

Take Home Message

- Insure that your producers consistently have clean, fresh water readily available for their calves.
- Suggest that producers supply you with current water test information which includes TDS, pH, mineral and mico-mineral concentrations, and information on presence, CFU/ml, and speciation of bacteria.
- Know the least expensive and most efficient methods available to modify mineral and microbial concentration of water fed to calves.

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Table 1. Average concentration of macro- and micro-minerals in 238 rural water samples from IN, MI, and OH[1].

Item	TDS,mg/L	pH	Sulfates	Nitrates	Cl	Ca	P	Mg	K	Na	Fe	Zn	Cu	Mn	Mo
							ppm								
Average	598.82	7.46	79.30	5.29	82.53	77.09	0.11	27.97	4.26	69.71	1.08	0.09	0.03	0.14	0.02
Maximum	7664.00	9.20	1140.00	42.00	700.00	590.00	0.70	190.00	20.00	869.45	34.50	2.55	0.69	8.80	0.06
Minimum	20.00	4.40	0.58	0.00	1.00	0.00	0.00	0.00	0.00	2.00	0.00	0.00	0.00	0.00	0.00
±SD	587.69	0.56	137.38	7.49	148.43	65.25	0.19	21.58	3.95	123.66	2.47	0.23	0.07	0.57	0.01

[1]Data supplied by Zinpro Corporation (Eden Prairie, MN), with assistance from Agri-King (Fulton, IL), Dairy One (Ithaca, NY) and Dairyland Laboratories, Inc. (Arcadia, WI). TDS = total dissolved solids and SD = standard deviation.

Table 2. Number of samples and average pH and mineral concentration by zip code in Indiana, Michigan, and Ohio from the database of Socha et al, 2003.

State and Zip Code	Number of Samples	TDS (mg/L)[2]	pH	Sulfates	Nitrates	Cl	Ca	P	Mg	K	Na	Fe	Zn	Cu	Mn	Mo
									ppm							
Indiana																
46041	39	499	7.0	62.0	4.0	39.0	84.0	0.0	34.0	2.0	26.00	1.000	0.000	0.000	0.000	0.010
47339	56	588	8.0	40.0	9.0	30.0	60.0	0.0	21.0	2.0	109.00	1.000	0.000	0.000	0.000	0.010
Michigan																
48414	81	678	8.0	71.0	3.0	187.0	74.0	0.0	30.0	5.0	68.00	1.000	0.000	0.000	0.000	0.040
49008	40	595	7.3	148.0	4.1	42.9	109.2	0.3	29.9	4.2	54.00	0.566	0.059	0.053	0.044	0.010
Ohio																
43019	22	482	7.0	87.0	6.0	26.0	73.0	0.0	33.0	3.0	61.00	1.000	0.000	0.000	0.000	0.050
44021	89	612	7.0	92.0	6.0	34.0	74.0	0.0	26.0	6.0	75.00	1.000	0.000	0.000	0.000	0.020
46041	7	498	7.6	30.6	5.7	28.6	67.8	0.2	25.6	3.2	61.90	0.250	0.010	0.010	0.030	0.020

[1]Note: Water composition of samples are listed by zip code up to the next 1000 as summarized from Zinpro Corporation (Eden Prairie, MN).
[2]TDS = total dissolved solids.

Table 3. Guidelines for young stock water quality.[1]

Item	Upper Levels	Maximum Tolerable Limit
Aluminum, ppm	5.00	10.00
Arsenic, ppm	0.20	0.20
Barium, ppm	1.00	1.00
Bicarbonate, ppm	1000	1000
Boron, ppm	5.00	30.00
Cadmium, ppm	0.01	0.05
Calcium, ppm	100	200
Chloride, ppm	100	300
Chromium, ppm	0.10	1.00
Copper, ppm	0.20	0.50
Fluoride, ppm	2.00	2.00
Iron, ppm	0.20	0.40
Lead, ppm	0.05	0.10
Magnesium, ppm	50.0	100.0
Manganese, ppm	0.05	0.50
Mercury, ppm	0.01	0.01
Molybdenum, ppm	0.03	0.06
Nickel, ppm	0.25	1.00
Nitrate-nitrogen, ppm	20.00	100.00
pH	6 to 8.4	8.5
Phosphorus, ppm	0.70	0.70
Potassium, ppm	20.00	20.00
Selenium, ppm	0.05	0.10
Silver, ppm	0.05	0.05
Sodium, ppm	50.00	300.00
Sulfates, ppm	50.00	300.00
Total dissolved solids, ppm	960	3000
Vanadium, ppm	0.10	0.10
Zinc, ppm	5.00	25.00
Coliform, number/100 ml	0.50	0.50
Fecal coliform number/100 ml	0.1	0.1
Total bacteria, number/100 ml	1000	1000

[1]Taken from Socha et al., 2003.

Covering Bunker Silos

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Introduction

Bunker silos and drive-over piles offer several advantages for large dairy farms. Low initial cost, low maintenance, high storage capacity, and rapid filling are common advantages over upright silos or silo bags. However, proper management of these structures is key to optimizing forage preservation and animal productivity.

Covering the bunker or drive-over pile shortly after filling the silo is an essential step to proper preservation. Bolsen et al. (1993) reported that dry matter losses in the top 1 to 3 ft can exceed 50% when the silo is not properly covered. Plastic film and tires are the most common method of covering most large silos. However, this method has several disadvantages. First, several people are required to cover most large silos with plastic and tires. Labor is also required to remove the plastic and tires. Secondly, proper disposal of the plastic is a real concern in many states. Split tires are often required because whole tires make an excellent breeding ground for mosquitoes, thus increasing the risk of West Niles virus. Finally, deer, raccoons, and vermin can tear the plastic, allowing air to penetrate increasing localized spoilage. Holthaus et al. (1995) reported that organic matter losses in the top 18 inches of silos covered with plastic and tires averaged approximately 25%.

Because of these challenges, there are producers who have decided not to cover their silos. Kansas State researchers have estimated that the value of the silage lost from not covering bunker silos in the High Plains regions was between 5 and 10 million dollars per year. There are many factors that can affect the return on investment for plastic and tires. Bolsen (1997) estimated that the value of the lost silage averaged about four times the cost of the plastic and tires, and labor to apply and remove both.

Some producers are tempted to feed the spoiled silage, with the assumption that it will be diluted to the point of not affecting the animals. However, feeding silage contaminated with mycotoxins can cause reduced milk production, missed breeding cycles, abortions, increased veterinary fees, and require the feeding of additives to bind the mycotoxins. The exact cost of feeding mycotoxin-contaminated silage is difficult to determine, but Thomas et al. (1998) estimated that it cost the Vermont dairy industry between 4.5 and 9 million dollars per year. Kansas State data showed that feeding a 75:25 normal:spoiled corn silage mixture reduced organic matter, crude protein, NDF, and ADF digestibilities by 5.0, 4.1, 7.2, and 9.9 percentage units, respectively (Bolsen, 2004). These researchers reported that feeding 25% spoiled silage partially or totally destroyed the mat phase in the rumen.

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Previous Edible Coverings

Because of the challenges associated with using plastic and tires, there have been several attempts to develop an edible covering for bunker silos. Bolton and Holmes (2004) summarized the data evaluating alternative covers for bunker silos. These include lime, earth, a roof, candy, molasses and molasses-based products (Cargill Liqui-Seal)™, small grains, sod, Nutri-Shield™, sawdust, chopped straw, and composted manure solids. Savoie et al. (2003) evaluated apple pulp and peanut butter as alternative covers for laboratory silos. The bottom line is that of all the alternative coverings tested, none were as effective as the conventional plastic covering.

Criteria of a Plastic Replacement

The following criteria have been used in developing our alternative bunker cover: 1) provide effective protection, 2) be edible, 3) provide essential nutrients, 4) be palatable, 5) easy to apply, and 6) cost effective. For an alternative covering to be successful, it must be equal or superior to plastic in its ability to protect the silage and minimize surface spoilage. The product should be edible or significant cost will be incurred in the removal and disposal of an inedible covering. If the product provides essential nutrients, then a portion of the cost is offset by its feeding value. The product must be palatable so that when included in the total mixed ration (**TMR**) intake is not impaired. Ease of application is critical to acceptance by the end user. Finally, the total benefits must be greater than the cost.

The original idea for this product resulted from my wife who made home-made play dough for our kids. After observing the physical properties and ingredient composition, the first series of experiments were to evaluate its potential to protect large hay bales. We found that it shed water well and was consumed by the cattle when salt was removed from their diet. This lead to a series of experiments with bunker silos.

Initial Bunker Silo Experiments

The objective of the first experiment was to determine whether the starch-salt matrix could serve as an edible covering for bunker silos that would simultaneously reduce spoilage and serve as a nutrient source. Whole plant corn silage (40% DM) was chopped and packed into six side-by-side mini-bunkers (12 ft long x 6 ft wide X 6 ft deep). Equal amounts (3,455 lb of DM) of chopped whole-plant corn were weighed into each bunker, leveled, and packed with a small tractor. The three treatments were uncovered, covered with six-mil plastic, or covered with the starch-salt matrix. The starch-salt matrix was mixed in a motar mixer with boiling water added to gelatinize the starch. The matrix was applied by hand to achieve a 0.5-0.75 inch thick layer using a cement trowel. After 3 days of curing, paraffin wax was melted and a thin layer applied with a paint roller. The forage was allowed to ensile for 92 days. Hand separation was used to sort the spoiled and good silage prior to feeding. A wooden frame (1 ft by 5 ft) was used to measure the spoilage under a fixed area. The measurements were made at 3 locations on each silo. Surface spoilage under the frame averaged 31.5, 36.0, and 2.6 lb of DM ($P < 0.05$) for the uncovered, plastic, and starch-salt covering, respectively. Forty-eight Angus heifers were allotted by weight to 12 pens. Two pens of heifers were randomly assigned to each mini-bunker. Silage DM fed was 1549, 1951, and 2684 lb ($P < 0.05$) for the uncovered, plastic, and starch-salt covering, respectively. These are relatively low recovery rates because of the small size silos with a large surface area to volume ratio. In addition, the forage at harvest was drier than optimum for bunker silos. Animal days per bunker were 140, 152, and 212, respectively ($P < 0.05$). During the feeding study, the starch-salt matrix was removed from the silage prior to feeding. For the last 6-days, heifers fed the

starch-salt matrix silage were fed the covering at the rate of 2.0 lb/day (as-fed). After collecting the orts, it was determined that heifers consumed approximately 91% of the covering offered.

The ash content of the pre-ensiled forage was 5.8%, and for the spoilage from uncovered, plastic, and starch-salt matrix treatments, if averaged, 11.4, 8.7, and 18.3% ($P < 0.05$), respectively. These data suggest that a portion of the salt diffused into the silage immediately under the covering. Cai et al. (1997) showed that some strains of lactic acid bacteria are salt tolerant. A combination of the air-tight covering and preservative effects of the salt helped to minimize surface spoilage. Also, the salt containing silage did not inhibit intake when it was mixed with the normal silage below it.

This initial research showed promise, but there were several significant huddles to overcome. First, this product required boiling water to gelatinize the starch, a costly and awkward requirement on a large scale. Secondly, wheat flour was used as the starch source. A cheaper more easily obtained source of starch was needed. Finally, a more practical means of application was needed.

Several of these issues were addressed in the laboratory involving the testing of approximately 40 different formulations. All of the modifications still allowed us to meet the original criteria. We found that finely ground wheat could replace the flour. By adding additional feed-grade ingredients, we could eliminate the boiling water and still achieve a starch-salt matrix that was adhesive and flexible. Achieving a product that was able to be sprayed on and not crack upon drying required additional reformulations.

Alternative Application Methodology

The goal of this research was to develop a commercially feasible application method to cover bunker silos with an edible covering. The previous formulation had a bread-dough consistency and had to be modified so that it could be sprayed. After evaluating several pieces of equipment, a commercial CEJCO concrete pump (Model CSS 2489; Carl E. Johnson, Inc., 2171 Tucker Industrial Road, Tucker, GA 30084) with a vertical shaft mixer and screw pump was used. A 50 ft x 3 inch diameter hose was used to apply the product. On the end of the hose, a spray nozzle was connected to a 110 CFM Ingersoll-Rand industrial air compressor (Ingersoll-Rand, P.O. Box 0445, 155 Chestnut Ridge Rd., Montvale, NJ 07645) for atomizing the product as it was applied. Approximately 700 lb of dry ingredients were added to the mixing chamber and water was added to bring the final product to approximately 30% moisture. This unit was chosen because it could be powered by the hydraulic system of a farm tractor. This approach was used to cover mini-bunkers and small drive-over piles. The wax was applied as described above. When the silos were opened, surface spoilage was similar to what had been observed in the original experiment.

Protective Coatings for the Edible Covering

The objective of this research was to develop a protective covering for the edible starch-salt matrix that was easier to apply than the paraffin wax. A control 6-mil black plastic covered with 2 to 3 inches of soil was compared to the starch-salt matrix coated with a sprayable wax emulsion, molten paraffin applied with a paint roller, or wax paper. The wax paper is made by Georgia-Pacific Paper Company (Clatskanine, OR) and is food grade so that it can be fed to animals. The sprayable wax emulsion has the advantage of eliminating the need for equipment and fuel to melt the paraffin wax. The wax paper could be applied directly behind the spraying apparatus and bound to the starch-salt matrix by running small press wheels on top of the paper. The wax paper has the potential advantage of holding the starch-salt matrix in place on steep slopes of bunkers or drive-over piles.

Eight 7 ft wide X 24 ft long by 4 ft deep mini-bunker silos were filled with 21,330 lb of chopped whole corn plant (39.1% DM). The silos were sealed on September 11, 2003 and opened after 117 days of ensiling. The silage was packed with a tricycle International Harvestor (**IH**) farm tractor. Less weight on the rear wheels resulted in less compaction next to the walls and more spoilage along the walls. Spoiled and good silage were hand separated. The DM fed for the plastic control, sprayable wax, paraffin wax, and wax paper treatments were: 4759, 4378, 5861, and 5493 lb, respectively. Less DM was fed from the sprayable wax silos than the plastic controls ($P < 0.05$). The DM fed from the paraffin and wax paper treatments was 23 and 15% greater, respectively, than what was fed from the plastic control silos. Again, low DM recoveries are due to the high surface to volume ratio for these silos.

Current research is aimed at the development of a low-profile vehicle that could drive over the piles and apply the starch-salt matrix in swaths. A feeder hose would be hooked to the unit from a screw-type concrete pump. Research is being done to determine if the dry ingredients and water could be mixed in a typical feed mixing unit and unloaded into the screw pump powered by its own hydraulic pump.

Summary

There are three reasons why the starch-salt matrix sealed with wax is superior to plastic in reducing surface spoilage. First, the starch-salt matrix forms an air-tight seal. The starch-salt matrix doesn't just lay on top of the forage like plastic, rather it bonds to the forage particles without air-layer interface. In addition, the salt diffuses into the top 10 to 15 inches of silage and acts as a preservative to prevent mold growth. These qualities allow the starch-salt matrix to meet our first criteria of providing effective protection.

All the ingredients in the formulation are Generally Recognized as Safe (**GRAS**) and feed grade, making it totally safe to feed. The ingredients in the starch-salt matrix also provide essential nutrients that would normally be added to the diet. The covering will blend with the other ingredients in a diet in a normal feed mixer. At subzero temperature, there may be a few clods that don't immediately breakdown. But when combined with the "warmer" ingredients, they will break apart and not be easily sorted by the cattle. We have fed the covering at 2.5% of the diet (DM basis) and not observed any reduction in intake. Seldom will the covering be at a higher proportion of the diet because we are only applying it at 0.5 to 0.75 inches. If the silage is over three feet deep, the covering will be less than 2.5% of the mixture. In addition, usually the silage does not make up the total diet.

Ease of application is the focus of much of our current research. We see this being done on a custom basis where the same equipment can be used on numerous silos per year. The dry ingredients would be delivered in bulk and loaded into a feed mixing truck. Water would be added to achieve the desired consistency and then unloaded into a screw pump that would deliver the mixture to the spraying machine.

Obviously, the technology will only be adopted if it is cost effective. We are optimistic because most of the cost of the original ingredients will be recovered when they are fed. Thus, application cost is the main item that needs to be paid for by the reduced spoilage and avoidance of plastic disposal and tire handling problems. Although there are significant application issues that need to be solved, we have made real progress in addressing these issues and are optimistic that this product has a future in helping large dairy farms and feedlots manage their silage more effectively.

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Effects of Nutrition on Milk Composition: A 25-Year Review of Research Reported in the *Journal of Dairy Science*[1]

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Abstract

A number of major scientific advances have been realized the last 25 years in determining the opportunities and limitations of altering milk composition through nutritional manipulation. Because of the greater sensitivity of milk fat to dietary manipulation than either protein or lactose, nutritional control of milk fat content and fatty acid composition received a great deal of attention. New information emerged linking ruminal production of trans fatty acid isomers with milk fat depression. As a result, research on fatty acid biohydrogenation intensified, yielding new insight on the origin of specific trans fatty acid isomers originating from ruminal biohydrogenation and how these isomers were modified by the action of mammary enzymes. The discovery of conjugated linoleic acid (CLA) as a potent anticarcinogen also led to extensive work on enhancing its concentration in milk through nutritional manipulation and discovering the physiological effects of specific CLA isomers. New protected fats were developed in recent years that were designed to resist biohydrogenation and enhance the concentration of unsaturated fatty acids in milk. The nutritional factors receiving the most attention during the last 25 years for their influence on milk protein content were forage to concentrate ratio, the amount and source of dietary protein, and the amount and source of dietary fat. New insights were tested on modes of action whereby fat supplements caused a decline in protein concentration. Changes in milk lactose concentration occur only in extreme and unusual feeding situations, but the basic biology of lactose synthesis and regulation are still being explored using modern molecular techniques. This paper highlights the major advances in controlling milk composition by dietary manipulation and how it impacts the entire animal system from practical feeding studies to basic cellular work on mammary tissue metabolism.

Introduction

The basic driving forces for manipulating the composition of milk are much the same now as they were 25 years ago, and include 1) improving the manufacturing and processing of milk and dairy products, 2) altering the nutritional value of milk to conform to dietary guidelines set forth by governmental agencies, and 3) using milk as a delivery system for nutraceuticals with known benefits to human health. The period from 1980 to 2005 has seen efforts at trying to alter the content or composition of all three components - fat, protein, and lactose. As expected, the greatest changes were made in milk fat and fatty acid composition.

This paper was written with strict adherence to two limitations. First, it is not the intention of this paper to cite the vast scientific literature compiled over the last 25 years relating to manipulation of milk composition. The contributions have been too numerous, and an undertaking such as this would be better suited for a review article in a scientific journal where the merits of each study could be

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evaluated. Instead, this paper will focus on the major advances that have occurred over the last 25 years that are now recognized as significant steps forward in nutritional control of milk composition.

The second limitation was to maintain focus on nutrition. We know that a multitude of factors influence the final composition of milk, including genetics and breed of animal, environment, stage of lactation, parity, and nutrition of the cow. Although all of these factors work in combination with each other to determine the final composition of milk, the focus of this paper is on nutrition of the cow and how it impacts milk fat, protein, and lactose.

With these goals in mind, manipulation of each milk component is discussed separately below with emphasis on the changes desired, the advances in enhancing the absorption and delivery of the desired nutrient to the mammary gland, and utilization of the nutrient by the mammary tissue to achieve the desired objective. Taken collectively, the advances in altering milk composition by dietary manipulation have come from significant contributions of the entire animal system, from practical studies on feeding systems to basic cellular work on mammary tissue metabolism.

Milk Fat

Target

Nutritional control of milk fatty acid profile has received considerable attention over the last 25 years (Mansbridge and Blake, 1997). Whether the goal is to improve manufacturing properties of milk or to enhance the concentration of fatty acids having beneficial health effects in humans, the key objective was usually to increase one or more unsaturated fatty acids in milk. For instance, increasing oleic acid content in milk enhances the plasticity and softness of milk fat, which has interested processors attempting to improve the spreadability of butter. Also, market pressures continued over the last 25 years to find avenues for enhancing the concentration of the "healthy" unsaturated fatty acids in milk. As an example, the Wisconsin Milk Marketing Board in 1988 published recommendations of a Milk Fat Roundtable stating that an "ideal" milk would contain no more than 8% saturated fatty acids, less than 10% polyunsaturated fatty acids, and the remainder (82%) as monounsaturated fatty acids (Berner, 1993). In addition, information emerged about the health effects of unsaturated trans fatty acids produced in the rumen, which led to interest in enhancing their concentration in meat and milk.

Research then followed to determine the ability of different dietary formulations to reduce milk fat content or enhance the concentration of unsaturated fatty acids. Dietary factors receiving the most attention were the amounts of grain and fat fed to cows. Each of these will be discussed separately, with a greater emphasis on the more researched fat supplements. The control of milk fat and fatty acid composition by fat supplements is complex because the transfer of dietary unsaturated fatty acids to milk can be significantly lessened by several factors including their biohydrogenation by ruminal microorganisms, poor rates of intestinal absorption, and their deposition in adipose tissue rather than in mammary fat. Thus, major advances in using fat supplements to alter milk fatty acid profile included significant work in understanding and controlling fatty acid biohydrogenation by ruminal microorganisms and the uptake and utilization of unsaturated fatty acids by the mammary gland.

Grain feeding

Cereal grains are used liberally in dairy rations in the U. S. because they are a cost-effective source of digestible energy needed for maintaining high levels of milk production. In addition to stimulating milk yield, higher grain intakes can also depress milk fat percentage and alter fatty acid composition. Grain feeding typically reduces the proportions of milk fatty acids having 6 through 16

carbons, and increases the proportion of 18-carbon unsaturated fatty acids. Several theories to explain the cause for the grain-induced milk fat depression were under scrutiny in the early 1980s, but the exact cause was not clear. Two theories receiving most of the attention at the time were: 1) inadequate rumen production of acetate and butyrate to support milk fat synthesis, and 2) propionate from grain stimulates circulating insulin concentration, which redirects metabolites away from mammary tissue. Multiple studies have shown that both theories are unlikely. See Bauman and Griinari (2003) for a recent and thorough account of the theories for milk fat depression.

One of the major breakthroughs on the theories of milk fat depression during the last 25 years was the refocus on trans fatty acids as the causative agent of milk fat depression in dairy cattle. Although trans fatty acids were implicated in milk fat depression many years earlier, it was new studies done in the early 1990's by Dr. Richard Erdman with dairy cattle and mouse studies by Dr. Beverly Teter at The University of Maryland that redirected the attention on trans fatty acids. Studies performed at several locations showed an inverse relationship between trans fatty acids in milk and milk fat content. Several reports indicated substantial increases in milk trans fatty acids without reductions in milk fat content, which raised questions that not all trans fatty acid isomers were associated with milk fat depression. Later, work showed that milk fat depression was more closely associated with the production of trans-10 fatty acid isomers in the rumen than with all trans isomers in general. Grain feeding was shown to enhance the production of the trans-10 fatty acid isomers by ruminal microorganisms. An important study done at Cornell University by Dr. Dale Bauman and colleagues demonstrated severe milk fat depression in cows infused with trans-10, cis-12 CLA, but no depression following infusion of the cis-9, trans-11 CLA isomer. Further work with other conjugated dienes and trienes have failed to find any further inhibitor of milk fat synthesis. Thus, it appears that trans-10, cis-12 CLA is the most likely factor causing milk fat depression.

Fat supplements

Extensive work on feeding fat to dairy cattle occurred over the last 25 years. The emphasis in the early 1980's was on using fat to provide more energy for milk production. During this time period, extensive work was done on developing rumen-inert or bypass fats that minimized digestibility problems that often occurred when feeding unsaturated oils to dairy cows. This led to commercial development of a variety of bypass fats, including calcium salts of fatty acids and products enriched in saturated fatty acids. Analysis of milk fatty acid composition was usually done in the same studies providing a large databank of information on the extent that fat supplements could alter milk fatty acid composition.

Untreated vegetable oils high in unsaturated fatty acids have only limited ability to alter milk fatty acid composition. The reason for this was established decades prior to the 1980's and is attributed to the microbial population located mainly in the rumen that transform dietary unsaturated fatty acids. Therefore, delivery of unsaturated fatty acids to mammary tissue is limited even when their dietary concentration is high. The ruminal microorganisms transform unsaturated fatty acids in a process called biohydrogenation (Jenkins, 1993), where microbial enzymes add hydrogen across the carbon:carbon double bonds of the fatty acyl chain, converting the double bond from unsaturated to saturated (Figure 1).

There has been considerable interest over the last 25 years in finding ways to shield dietary unsaturated fatty acids from biohydrogenation in order to enhance their absorption and delivery to the mammary gland (Jenkins, 1998). Figures 2 and 3 show examples of changes in oleic and linoleic acid concentrations in milk fat when various forms

of rumen-protected fats were fed to dairy cows. Oleic acid concentration in milk fat varied from 18 to 24% of total fatty acids when control rations containing no added fat were fed to cows. When rumen-protected fats were fed to cows, oleic acid in milk varied from 18 to as much as 48%. The effects of fat source on milk linoleic acid concentration were less dramatic. Linoleic acid concentration in milk normally ranges from 1.5 to as much as 4% when cows are fed control diets with no added fat. Feeding rumen-protected fats increased the upper range of linoleic acid concentration to about 6.5%.

Another significant finding bringing a great deal of attention to biohydrogenation intermediates in milk fat was the discovery that CLA had beneficial effects on human health, most notably cancer-fighting properties. It was the cis-9, trans-11 CLA isomer in particular that received the most attention for its anticarcinogenic properties, which was known to arise from the biohydrogenation of linoleic acid. The recent interest in enhancing biohydrogenation intermediates in milk propagated research to determine the origin and possible enhancement of beneficial fatty acid isomers produced in the rumen.

Many of the advances in nutritional manipulation of milk fat content were made possible by enhancing our basic understanding of the principles of nutrient uptake and utilization by the mammary gland. Many of the advances during the last 25 years were focused on characterizing the regulatory steps in fatty acid synthesis and desaturation. Desaturase activity in the mammary secretory cell converts stearic acid arising from ruminal biohydrogenation to oleic acid that is secreted in milk. Thus, studies have been directed at enhancing activity of delta-9 desaturase in order to increase oleic acid at the expense of saturated fatty acids in milk.

An important discovery within the last few years was the observation that the delta-9 desaturase was the predominant source of the cis-9, trans-11 CLA isomer in milk, which has a number of benefits to human health (including anticarcinogenic properties). Trans-11 arising from biohydrogenation in the rumen is transferred to the mammary tissue and desaturated to cis-9, trans-11 CLA via the delta-9 desaturase. This has shifted attention to manipulating ruminal biohydrogenation to enhance the yield of the trans-11 isomer.

Milk Protein

Target

The nitrogen fractions of milk can be broadly divided into three categories: casein, whey, and nonprotein nitrogen (**NPN**). Casein comprises the majority of the nitrogen in milk (about 78%), with lesser amounts of whey N (17%) and NPN (5%). In cheese-making, curd structure, curd firmness, and cheese yield are directly related to casein content. The nutritional factors receiving the most attention during the last 25 years for their influence on milk protein content were forage to concentrate ratio, the amount and source of dietary protein, and the amount and source of dietary fat (DePeters and Cant, 1993; Bequette et al., 1998).

Forage to concentrate ratio

In most cases, reducing the proportion of forage in the diet of a cow increases both protein content and yield. Milk protein content can be increased 0.4 percentage units or more if forage proportion in the diet is reduced to 10% or less of the dietary DM. Because a minimum concentration of forage is needed in typical dairy diets (generally 40% or greater) to avoid digestive and metabolic disturbances, reducing the forage to concentrate ratio has not been a practical method of consistently enhancing milk protein content. Another issue has been to determine if forage is the direct cause of milk protein depression, or if it is an indirect effect of decreasing energy intake. Limited research on

this question during the last 25 years points to a greater role for energy intake, with fiber content of the ration having little direct influence on milk protein content.

Rapidly fermentable dietary carbohydrate has been associated with milk protein content. Several studies utilized a hyperinsulinemic-euglycemic clamp technique to examine raised insulin concentrations without the confounding effects of hypoglycemia. Results demonstrated a modest increase in milk protein unless casein was infused abomasally. When combined, insulin and casein produced substantial increases in milk protein content (10%) and yield (28%). Thus, when rapidly fermentable carbohydrate is fed, greater production of propionate and microbial protein is produced, leading to signals in the cow's body to produce more milk and milk protein.

Amount and source of protein

Unlike forage to concentrate ratio, the effects of amount and source of protein in the diet on milk protein content have been extensively investigated. However, it soon became clear that dramatic changes in either amount or source of protein caused only modest changes in the protein content of milk. The data in Figure 4 show a spread of milk protein from 2.85 to 3.27% as protein content in the diet varied from 15.0 to 19.5% and included a wide variety of protein sources, including rumen-protected amino acids. As pointed out by Dr. Roy Emery at Michigan State University in his 1978 review on feeding for increased milk protein, protein content of milk increases only about 0.02% for each 1% increase in dietary protein (Emergy, 1978).

Low transfer efficiency (25 to 30%) of dietary protein to milk is a major factor accounting for the inability of diet to markedly alter milk protein content. Blood flow through the mammary gland is implicated as a key cause of this poor capture, which is part of the overall process for the coordinated timing of nutrient delivery to the mammary gland. Contrary to this point, studies in cows undergoing a hyperinsulinemic-euglycemic clamp show that both mammary blood flow and amino acid extraction can adjust, leading to enhanced milk protein production. This suggests that the mammary gland has the capacity to alter the uptake of substrates from the arterial supply in response to changes in arterial amino acid concentrations, mammary blood flow, and metabolic activity to improve milk protein production.

Amount and source of fat

As fat supplements were being explored as energy sources for dairy cows, it soon became apparent that feeding additional fat was often accompanied by a decline in milk protein content. As a result, feeding fat had to be limited in markets where milk pricing gave an incentive to protein content. On average, protein content in milk declined 0.03% for each 100 g supplemental fat intake, or about 0.1 to 0.3 percentage units for most typical levels of fat feeding. When fat supplementation reduced milk protein content, the casein fraction declined the most. Fat effects on the whey fraction were inconsistent and NPN generally increased. Because fat supplements increased milk yield when properly fed, total daily production of milk protein remained the same or even increased when fat was fed, despite the decline in protein content.

Several important studies were done during the last 25 years to elucidate the mechanism whereby fat supplements cause this dilution effect, i.e., a greater increase in milk yield than protein yield. One proposal was by Casper and Schingoethe (1989) at the University of South Dakota. They proposed that elevated blood fatty acids from the fat supplement decreased the release of somatotropin, which reduced mammary extraction of amino acids. Work done by Cant et al. (1991) at the University of California led to an alternative proposal. They

showed that infusing casein into the abomasum of lactating cows fed 4% yellow grease increased arterial amino acid concentrations but failed to prevent the milk protein depression. In a later study (Cant et al., 1993), they observed a 7% drop in mammary blood flow when cows were fed fat, thus preventing increased removal of critical amino acids as milk synthesis increased. The University of California workers proposed that fat supplements reduced milk protein concentration by reducing blood flow through the mammary gland causing reduced extraction of blood amino acids. In their explanation, milk volume is increased by the higher fatty acids inhibiting mammary de novo fat synthesis, causing a sparing of acetate for oxidation and more glucose available for lactose and milk synthesis.

Milk Lactose

As stated earlier, few studies have detected any significant change in lactose content of milk in cows fed diets in the normal range. Studies using mice have evaluated the impact of low lactose content on milk production. Using gene knockouts of α-lactalbumin, these studies have determined that lactose synthesis requires α-lactalbumin. This may not be advantageous to the dairy industry, as the milk produced was too viscous to be removed by the nursing pups. Therefore, it is likely that postharvest technology will be required to reduce lactose content of milk.

Summary

To the extent that milk pricing is linked to milk components, producers will continue to exploit nutrition of the cow as a means to modify milk composition for maximum economic return. With the complete mapping of the cattle genome not far away, opportunities will be explored to genetically manipulate or develop lines of cows that produce milk with a specific composition. Nutrition will remain an integral part of expressing this modified genetic potential. The greatest opportunities on the horizon for manipulating milk composition will be directed at using milk for delivery of nutraceuticals to enhance human health (Department of Health, 1994; Dixon and Ernst, 2001) and to combat clinical diseases, such as obesity, lactose intolerance, or osteoporosis. Fatty acid profile of milk will continue to receive attention in these areas, as it is a reservoir for many of the unique, and yet unknown, trans isomers of ruminal origin having a wide range of physiological responses. Enhancing specific proteins in milk to enhance human health will also be important, but because milk protein composition is less responsive to diet than fat, postharvest manipulation by processors and food scientists will play a major role.

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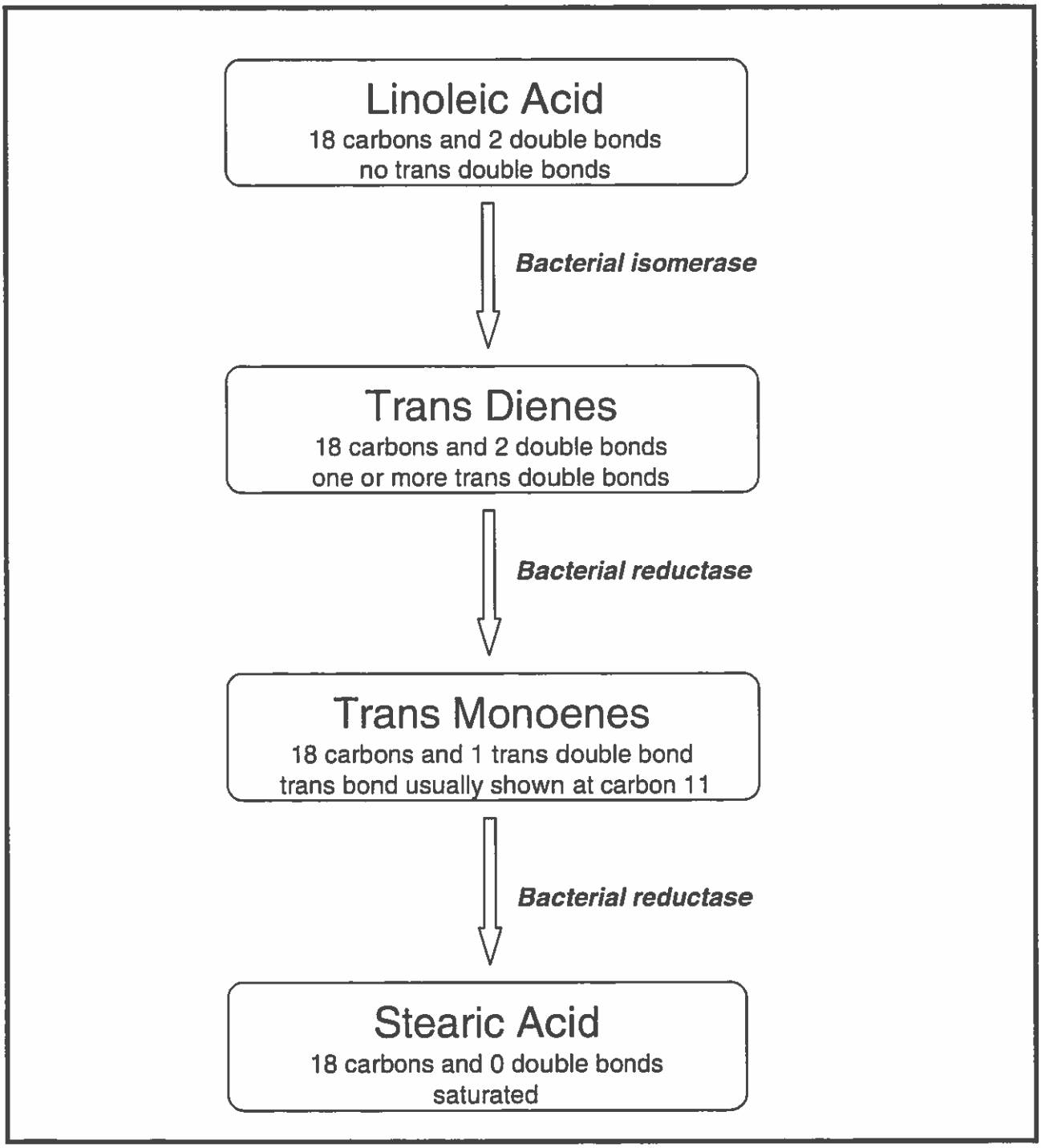

Figure 1. Major steps in the biohydrogenation of linoleic acid by ruminal microorganisms. Depending on conditions in the rumen, various proportions of stearic acid and trans intermediates are produced from linoleic acid. The trans diene intermediates usually include various conjugated isomers or conjugated linoleic acid.

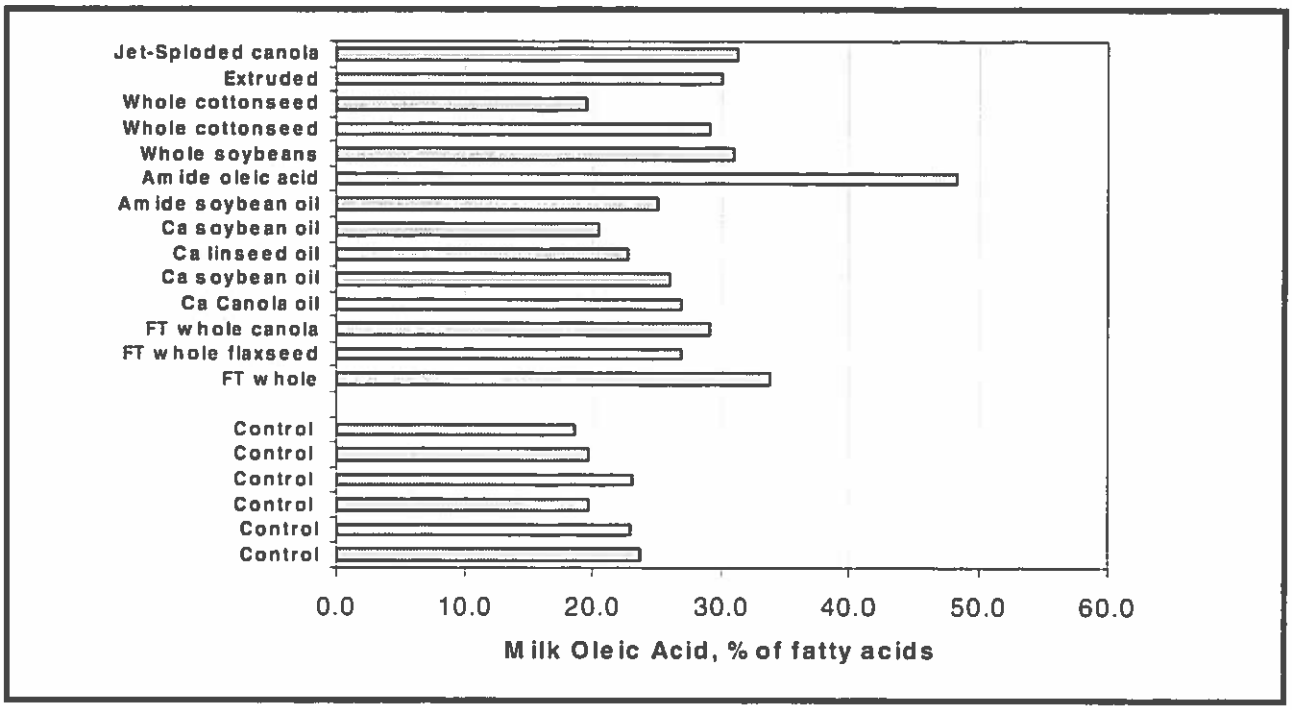

Figure 2. Samples of data from published studies showing the extent that oleic acid concentration in milk varies when lactating cows are fed control diets with no added fat or diets containing various sources of rumen-protected fat. Rumen-protected fat sources included whole oilseeds, amides of fatty acids, calcium (**Ca**) salts of fatty acids, and formaldehyde-treated (**FT**) fats.

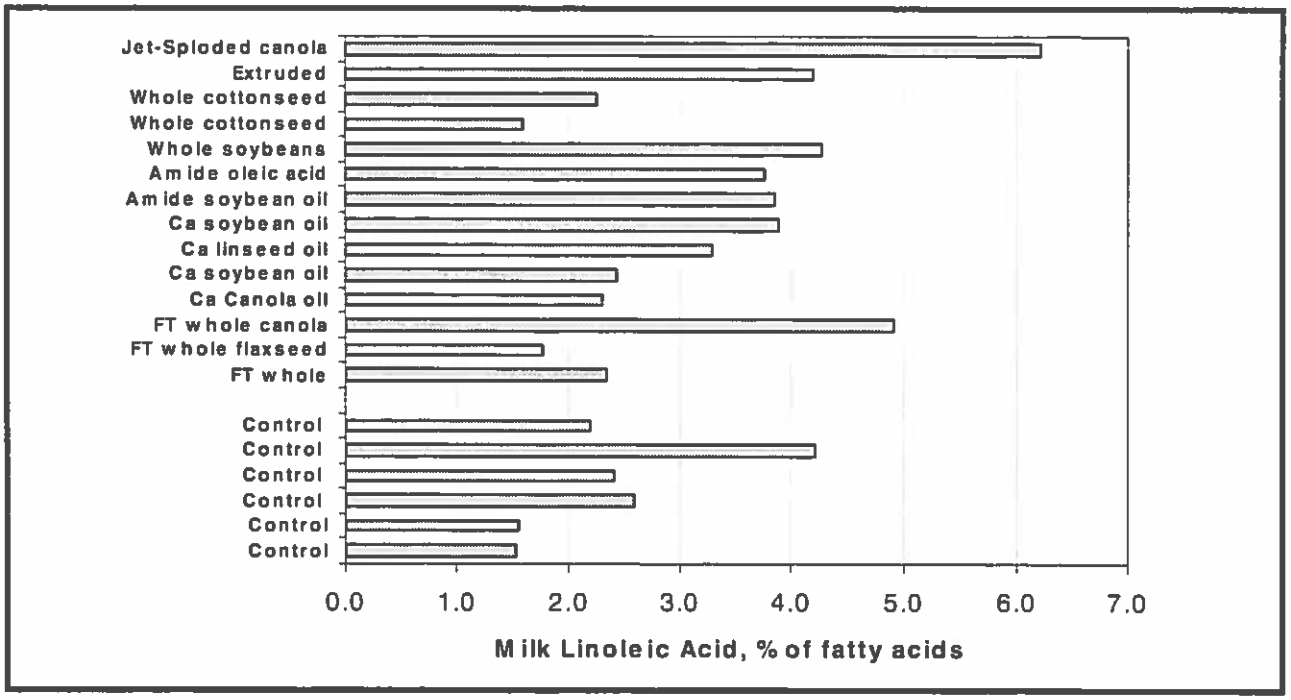

Figure 3. Samples of data from published studies showing the extent that linoleic acid concentration in milk varies when lactating cows are fed control diets with no added fat or diets containing various sources of rumen-protected fat. Rumen-protected fat sources included whole oilseeds, amides of fatty acids, calcium (**Ca**) salts of fatty acids, and formaldehyde-treated (**FT**) fats.

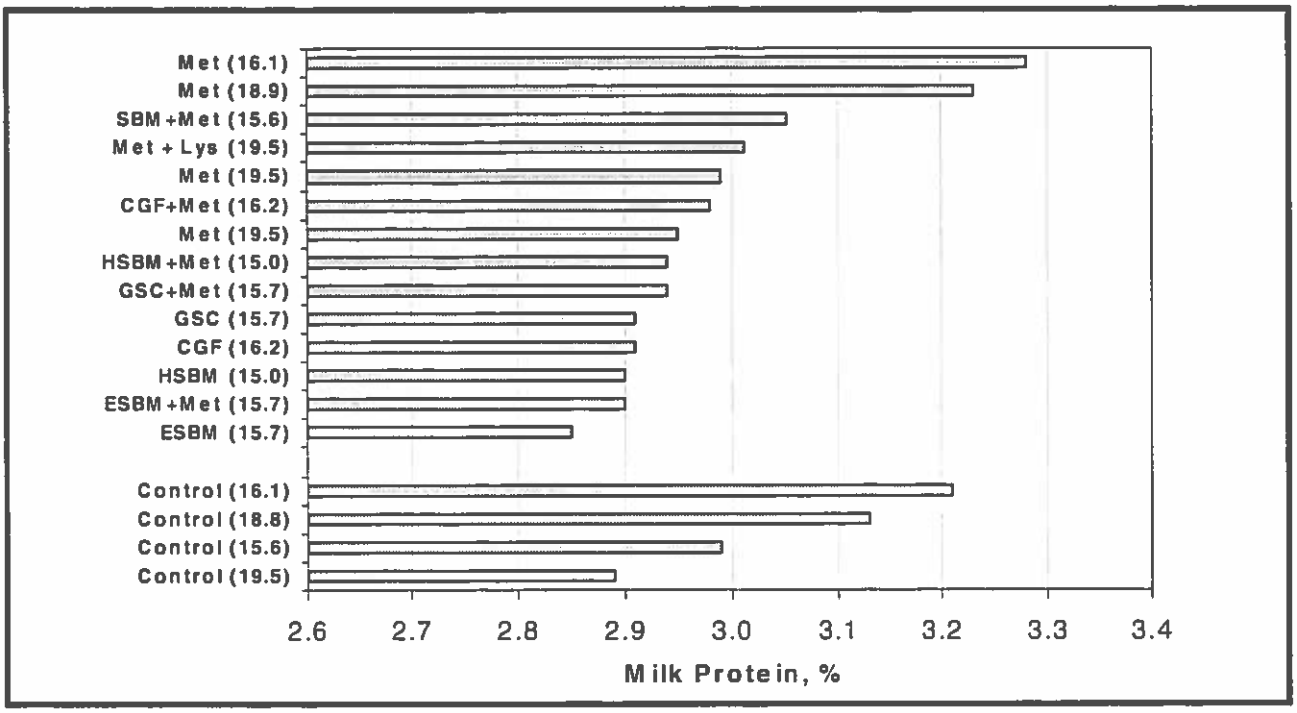

Figure 4. Samples of data from published studies showing the extent that milk protein percentage varies with amount and type of dietary protein. Dietary protein percentage is shown in parenthesis following source of protein (CGF = corn gluten feed, ESBM = extruded soybean meal, GSC = ground shelled corn, HSBM = heated soybean meal, Lys = rumen protected lysine, Met = rumen protected methionine, and SBM = soybean meal .

Selenium Sources for Dairy Cattle

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Abstract

Inorganic selenium (selenite and selenate) and selenium yeast (Se-yeast) are the only approved sources of supplemental selenium **(Se)** in the U.S. The predominant form of Se in Se-yeast is selenomethionine (Se-met). The mechanism of intestinal absorption is completely different for inorganic and Se-met; therefore, factors that reduce absorption of inorganic Se are unlikely to influence absorption of Se-met. The metabolism of inorganic Se and Se-met within a cell also differs. Inorganic Se is used almost exclusively in the synthesis of selenospecfic enzymes; whereas, Se-met can be used in the synthesis of those enzymes, but it can also be incorporated into any protein that contains methionine. Clinical data comparing health effects of inorganic Se and Se-yeast are lacking, but cattle fed Se-yeast have higher concentrations of Se in whole blood (average = 20% more) and milk (90%) and activity of glutathione peroxidase (16%) than cattle fed inorganic Se. Feeding Se-yeast during late gestation also greatly increases the Se concentration in tissues of the newborn calf. Based on available data, the bioactivity of Se from Se-yeast is probably about 20% higher than inorganic Se, but that difference could be greater when absorption of inorganic Se is reduced because of antagonists.

Introduction

Almost 50 years ago, Se was shown to be an essential nutrient for mammals (Schwarz and Folz, 1957) and that a Se deficiency led to white muscle disease in ruminants (Muth et al., 1958). Over time, research identified several beneficial effects when Se intake by domestic animals was increased; however, it was not until 1979 that the U.S. government permitted supplemental Se to be added to diets of domestic animals. Both the concentration (0.1 ppm at that time) and the source (sodium selenite or selenate) of supplemental Se were regulated. The regulation was amended in 1987 and allowed 0.3 ppm of supplemental Se to be added to ruminant diets, but the allowed sources (sodium selenite and selenate) did not change. In September, 2003 (FDA, 2003), the regulation was amended again to allow the use of selenium yeast (Se-yeast) in diets for dairy and beef animals based on data from cattle fed Selplex (Alltech, Inc, Nicholasville, KY). The maximum allowed supplementation rate was maintained at 0.3 ppm of Se. The approval of Se-yeast for dairy cattle greatly expanded the Se supplementation options available to nutritionists, but it also made Se supplementation a more complicated matter.

Selenium Yeast - What is it?

The definition of Se-Yeast according to FDA (2003) is "a dried, nonviable yeast (*Saccharomyces cerevisiae*) cultivated in fed-batch fermentation which provided incremental amounts of cane molasses and selenium salts... and allows for optimal incorporation of inorganic selenium into cellular organic matter. Residual inorganic selenium

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... must not exceed 2% of the total selenium content in the final selenium yeast product." During fermentation, the yeast consume Se and incorporate it into various organic compounds. The most prevalent Se endproduct is seleno-methionine (**Se-met**). Although differences are likely among commercial sources of Se-yeast, on average, approximately 90% of the Se is Se-met (Schrauzer, 2003). Seleno-cysteine (**Se-cys**) is produced in much lesser amounts. Those two seleno-amino acids are identical to the regular amino acids, methionine (**met**) and cysteine, except that Se replaces the sulfur atom (Figure 1). The predominant chemical form of Se in Se-yeast makes organic Se different from all other organic trace minerals. All other organic trace minerals are complexes or chelates. The metal is 'associated' with an organic compound, but it is not part of the compound's molecular structure. The Se in Se-met and Se-cys is part of the molecule; the Se cannot be removed without breaking covalent bonds.

Numerous other Se-compounds are produced by yeast, but identifying and quantifying all the different Se compounds found in Se-yeast is extremely difficult and requires very sophisticated techniques and instruments. Although the concentrations of these other Se compounds will be quite low, they may be important biologically. Some of these 'minor' selenium compounds have been shown to have potent anti-carcinogenic properties in laboratory animals, and clinical data are accumulating showing similar effects in humans, especially with respect to prostate cancer (Combs et al., 2001). Essentially, nothing is known regarding biological activity of these minor Se compounds in cattle. Therefore, the rest of this paper will consider only the Se provided by Se-met and Se-cys.

Selenium Absorption

The most prevalent forms of Se consumed by dairy cows in the U.S. are selenate and selenite (from inorganic Se supplements), and Se-met and Se-cys (from Se-yeast and basal feedstuffs). Ruminal metabolism and intestinal absorption of these Se compounds differ. Most of the selenate (SeO_4) consumed by a cow is reduced to selenite (SeO_3) in the rumen, but some of the selenate leaves the rumen and is absorbed as selenate in the small intestine. Based on studies with rats, intestinal absorption of selenate is probably via an active (energy-requiring) transport system. Absorption of selenate by ligated intestinal loops of rats was about 80% (Vendeland et al., 1992). In the rumen, selenite (either that consumed in the diet or produced from selenate) can be converted to low molecular weight insoluble forms of selenium. These compounds have not been chemically identified but most likely are not well-absorbed or utilized by the host. Some of the selenite is used to synthesize seleno-amino acids (predominantly Se-cys) that are incorporated into microbial protein. The remaining selenite leaves the rumen and reaches the small intestine where it is absorbed probably via a passive mechanism. Intestinal absorption of selenite was about 35% using ligated rat intestines (Vendeland, et al., 1992). Because it is so difficult to quantify the various Se compounds, reliable data on distribution of Se in ruminal contents are limited. Reasonable estimates when selenite is fed are 30 to 40% is converted to insoluble forms, 10 to 15% is found in microbial protein and 40 to 60% remains as selenite (Serra et al., 1994). I could not find any information regarding ruminal metabolism of Se from Se-yeast. An in vitro experiment found that about 60% of Se-met (not Se-yeast) was incorporated directly into bacterial protein as Se-met (Paulson et al., 1968). Although data are limited, a much higher percentage of Se leaving the rumen is in the form of seleno-amino acids (predominantly Se-met) when cows are fed Se-yeast than when fed selenite or selenate. Seleno-methionine is absorbed from the intestine by the same mechanism as methionine and is quite efficient (>80%). However, because Se-met and met use the same intestinal absorption system, increasing the intestinal flow of met will decrease absorption of Se-met because of competition.

True absorption of Se from diets containing supplemental inorganic Se, calculated from Se balance studies, averages about 50% in dairy cows, goats, and sheep (Harrison and Conrad, 1984; Aspila, 1988; Koenig et al., 1997; Ivancic and Weiss, 1999). True absorption will be lower if the diet contains appreciable quantities of antagonists to Se absorption (discussed below). Data on the true digestibility of Se from Se-met or Se-yeast are very limited and variable. True digestibility of Se from Se-met (measured in goats) was 65% (Aspila, 1988), and the calculated true digestibility of Se from Se-yeast (measured in sheep) averaged about 44% (Koenig, et al., 1997). Because of the method used to produce the Se-yeast in the sheep study, the proportion of Se that was inorganic was probably greater than that found in the currently available Se-yeast products. Even though data are very limited, based on known absorption mechanisms, Se from Se-yeast is probably absorbed with greater efficiency than Se from selenite. Assuming Se-met from Se-yeast has an escape value of 60% (based on in vitro studies with Se-met) and that 90% of the Se in Se-yeast is Se-met, approximately 55% of the Se from Se-yeast that leaves the rumen is in the form of Se-met. Assuming the digestibility of the Se from Se-met is 80% (average digestibility of ruminal microbial protein) and the digestibility of the 45% of total Se that is not Se-met is the same as for selenite (50%), the true digestibility of Se from Se-yeast would be about 66%. This is about 30% higher than the true digestibility of Se from selenite.

Selenium Metabolism

The reason Se is an essential nutrient for animals is because certain enzymes (selenoenzymes) must contain a Se-cys residue in their active sites. The most familiar selenoenzyme with respect to dairy cattle nutrition is glutathione peroxidase (**GSH-px**), which is an important component in cellular antioxidant systems. Cells have developed a simple, but elegant, method of ensuring that Se-cys is inserted into the proper location in enzymes (Figure 2). Selenite that is absorbed goes to cells where it is reduced to selenide and then the selenide is used to synthesize Se-met from a serine molecule that is linked to a specific tRNA (UGA codon). The synthesized Se-cys-$tRNA_{UGA}$ complex is then put in the right place during protein synthesis. If Se-cys from the diet is absorbed, it cannot be inserted directly into the active site of the enzyme during protein synthesis because it does not have the correct tRNA. Dietary Se-cys must be catabolized and then the Se can be reduced to selenide and a Se-cys-$tRNA_{UGA}$ can be synthesized. Absorbed dietary Se-met can be used in place of met in protein synthesis. Cells do not appear to be able to differentiate between regular met and Se-met. Therefore, Se-met can be found in all proteins in the body in direct proportion to the amount of met found in the protein and the relative pool sizes of regular met and Se-met. The Se-met can also be catabolized and its Se be converted to selenide and then put into Se-cys-$tRNA_{UGA}$. The bottom line difference between inorganic (selenite) and organic Se (Se-met) is that inorganic Se is used almost exclusively to produce selenoenzymes, but organic Se can be used to produce selenoenzymes and also result in general labeling of all proteins that contain met. This difference has implications when interpreting Se concentration data.

Se-yeast versus Selenite: The Data

When comparing sources of nutrients, the most important question is, "Which source will result in the greatest net return?" To answer this question, you need to know the cost of the supplement (per unit of nutrient) and the value of the response. For Se, the response is usually health-related. Numerous studies have shown that supplemental Se (usually from inorganic sources) improve immune function and mammary gland health and reduce the prevalence of retained fetal membranes (Weiss, 2003; Weiss and Spears, 2005). Therefore, the best method to compare Se sources is with clinical

trials that measure prevalence and severity of certain diseases when cows are fed different sources of Se. I could find only one study (Malbe et al., 1995) in which selenite and Se-yeast were fed and clinical measures were taken, and because of the experimental design, the effects of Se source could not be statistically compared. Cows were fed diets with 0.2 ppm Se from selenite or Se-yeast and milk somatic cell count (SCC) and prevalence of infected quarters were measured. Following 8 weeks of supplementation, infected quarters decreased 60% for cows fed selenite and 43% in cows fed Se-yeast compared with day 0 values. The SCC decreased 37% and 30%, and NAGase activity in milk (a measure of inflammation) decreased 21 and 45%, respectively, for cows fed selenite and Se-yeast. All measures of mammary gland health were improved in Se supplemented cows, whereas no changes occurred in cows not fed supplemental Se. Based on these data, source of Se did not appear to have a large effect.

The effects of Se source (inorganic vs. Se-yeast) on concentrations of Se in blood and milk and activity of GSH-px have been compared in numerous experiments (Table 1; Figures 3, 4, and 5). The median increase in whole blood Se when Se-yeast was fed was 20% (Figure 3). Whole blood GSH-px activity was numerically higher in all studies when Se-yeast was fed, but only two studies reported statistically higher values (Figure 4). The median increase in activity was 16%. The relative response in GSH-px activity when Se-yeast is compared with selenite might be a function of Se intake. The two studies with the greatest difference between Se-yeast and selenite in GSH-px activity fed the lowest concentration of supplemental Se (approximately 0.1 ppm Se). Knowles et al. (1999) reported no difference in GSH-px activity between cows fed selenite and Se-yeast when cows consumed 4 mg/day of supplemental Se (approximately 0.2 ppm), but when cows were fed 2 mg/day of Se (approximately 0.1 ppm), GSH-px activity was about 50% higher when Se-yeast provided the supplemental Se (Figure 4).

The median increase in milk Se was 90% when Se-yeast was fed (Figure 5). The vast majority of the Se in milk when Se-yeast is fed is in the form of Se-met. Milk Se concentrations increase linearly as intake of Se from Se-yeast or from feeds that are high in Se increase, but milk Se does not change greatly as intake of selenite increases (Figure 6). One factor considered by FDA during the Se-yeast approval process was the concentration of Se in milk and meat. Based on human health concerns, FDA set the maximum allowable concentration of Se in milk at 0.14 mg/L. Based on the equation in Figure 6, an intake of approximately 25 mg/day of Se from Se-yeast and basal ingredients will produce milk that exceeds the legal limit in Se concentrations (approximately 3.5 times the legal dietary limit for lactating cows).

Selenium is transferred to the fetus in utero. The concentration of Se in plasma of newborn Holstein calves was 42% higher when cows were fed Se-yeast during the last 60 days of gestation compared with cows fed selenite (Weiss, unpublished). In studies with beef cows, whole blood from newborn (or very young) calves was 35% (Pehrson et al., 1999) and 42% (Gunter et al., 2003) higher in Se concentration, and activity of GSH-px activity in the calves was 32 and 75% higher, respectively, when dams were fed Se-yeast. Awadeh et al. (1998) reported only an 18% increase in whole blood Se and no effect on GSH-px in newborn beef calves when dams were fed Se-yeast.

Based on blood concentrations and GSH-px, Se-yeast is about 1.2 times 'better' than selenite, and based on milk concentrations, it is 1.9 times better. The relative response in milk Se concentration is much higher than the response in blood because milk protein has about twice as much methionine as do proteins in whole blood; therefore, it is twice as likely that Se-met will be incorporated into milk protein than blood protein. Milk protein is synthesized constantly and removed from the cow two or three times a day. Therefore, Se-met

concentrations in milk reach steady state within a few days after Se-yeast supplementation has begun. Once a red blood cell is made, it does not synthesize protein and red cells live 100 to 130 days. Therefore, it would take 3 or 4 months of supplementation for whole blood concentrations to reach steady-state. Many of the experiments that measured whole blood Se did not last that long, so the measured difference probably was less than maximal differences. Lastly, a substantial portion of the Se in whole blood is in selenoenzymes, which based on GSH-px is less responsive to source of supplemental Se than other proteins. This would dilute the response in whole blood Se concentrations when Se-yeast is fed. Good clinical data are needed to determine the true difference in bioactivity of Se from selenite and Se-yeast. In lieu of those data, the best estimate of relative difference between selenite and Se-yeast available currently is GSH-px activity because it reflects biological activity of Se, not availability of met. Based on those data, Se from Se-yeast, on average, is about 1.2 times more bioactive than Se from selenite.

Factors to Consider When Choosing a Se Source

Antagonists to Se absorption

Selenite and Se-met are absorbed from the intestine by completely different mechanisms. Factors that antagonize absorption of selenite are not likely to have the same effect on absorption of Se-met. Diets with 0.2% added sulfate-sulfur reduced true absorption of Se from selenate by 20% (Ivancic and Weiss, 1999). When sulfate is present, Se from Se-yeast would be about 50% more available than Se from inorganic sources (compared with 30% when sulfate is not excessive). Sulfate is unlikely to have an effect on Se-met absorption. Although this is not a likely problem, diets that provide high concentrations of digestible met will reduce availability of Se from Se-yeast because of competition for absorption sites in the intestine.

Body retention of Se

Cows fed Se-yeast have higher concentrations of Se in almost all tissues than do cows fed selenite. Much of this Se is in proteins as Se-met. As proteins in the body are turned over, Se-met is released and if broken down can provide Se for selenoenzyme synthesis. Cows fed selenite have a much lower body reserve of Se than cows fed Se-yeast. This could be beneficial in periods of high Se demand and in unexpected periods of low Se supply. Increased body reserves may be especially beneficial for newborn calves. Calves borne from cows fed Se-yeast have higher concentrations of Se in tissues and often much higher GSH-px activity than when cows are fed inorganic Se. In addition, colostrum from cows fed Se-yeast contains more Se than colostrum from cows fed selenite, thereby increasing the difference in Se status of the calves. Feeding cows some Se-yeast during the last 60 days of gestation may have beneficial effects on calf health by improving the Se status of the calf.

Costs of supplement

Diets with 0.3 ppm of supplemental Se provided by Se-yeast will cost about 5 cents/day per lactating cow more than will diets with selenite and 2 or 3 cents/day more for dry cows (approximately $17 annually for each cow, assuming a 305 day lactation). If supplementation rate was reduced 20% to account for higher bioactivity of Se-yeast, the annual cost is about $14. The cost of an ingredient should not be the primary concern; return on investment is what matters. Unfortunately data are not available to determine whether return on investment (via improved health) differs between inorganic Se and Se-yeast.

Recommendations and Conclusions

The benefits and disadvantages of each type of Se supplement are summarized in Table 2. The

Se-yeast has numerous advantages over selenite, but the question remains, "Is it more profitable to use Se-yeast?" In situations where antagonists are not a concern, inorganic Se is probably the most cost-effective option for lactating cows. If antagonists are present, some or all of the Se should be provided by Se-yeast. To ensure adequate Se status of calves, providing a portion of the supplemental Se as Se-yeast in dry cow diets is a good idea. Current regulations permit using a combination of Se sources as long as the total supplemental Se does not exceed 0.3 ppm in the total diet. Usually using a combination of nutrient sources is better than relying on a single ingredient. Some data with other trace minerals show benefits when a combination of inorganic and organic sources are used compared with either all organic or all inorganic. The same may be true for Se. In my opinion, if antagonists are not present in feed or water, lactating cows should be supplemented with Se that is predominantly from inorganic sources. If antagonists are present, the predominant Se source should be Se-yeast. Because of potential benefits to the newborn calf, a larger proportion of Se (maybe 50%) in dry cows diets should come from Se-yeast, even when antagonists are not present.

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Table 1. Sources of data used in Figures 3, 4, and 5.

Experiment Code on Figure				
Figure 3	Figure 4	Figure 5	Animal Type	Citation
A	A	A	Beef cows	Awadeh et al. (1998)
B	...	B	Dairy cows	Fisher et al. (1995)
C	C	C	Dairy cows	Knowles et al. (1999) (2 mg)
D	D	D	Dairy cows	Knowles et al. (1999) (4 mg)
E	E	E	Dairy cows	Malbe et al. (1995)
F	...	...	Beef heifers+steers	Nicholson et al. (1991)
G	...	...	Dairy heifers	Nicholson et al. (1991)
...	H	...	Combined	Nicholson et al. (1991)
I	I	...	Growing beef	Nicholson et al. (1993)
J	J	J	Dairy cows	Ortman and Pehrson (1997)
K	K	K	Dairy cows	Ortman and Pehrson (1999)
L	L	...	Dairy heifers	Ortman et al. (1999)
M	M	M	Beef cows	Pehrson et al. (1999)
N	N	N	Beef cows	Gunter et al. (2003)
...	O	...	Dairy heifers	Pehrson et al. (1989)
...	...	P	Dairy cows	Weiss (unpublished)

Table 2. Benefits and disadvantages of inorganic and Se-yeast.

Benefits	Disadvantages
Inorganic selenium	
Cheap	Absorption can be affected by antagonists
Provides adequate Se in many situations	Provides limited body reserves of Se
Se-yeast	
Probably 20 to 30% more available	More expensive
Builds up body reserves of Se	
Increases milk Se (human health benefit)	
Increases colostrum Se (calf health benefit)	
Increased transfer of Se to fetus	
Not affected greatly by absorption antagonists	

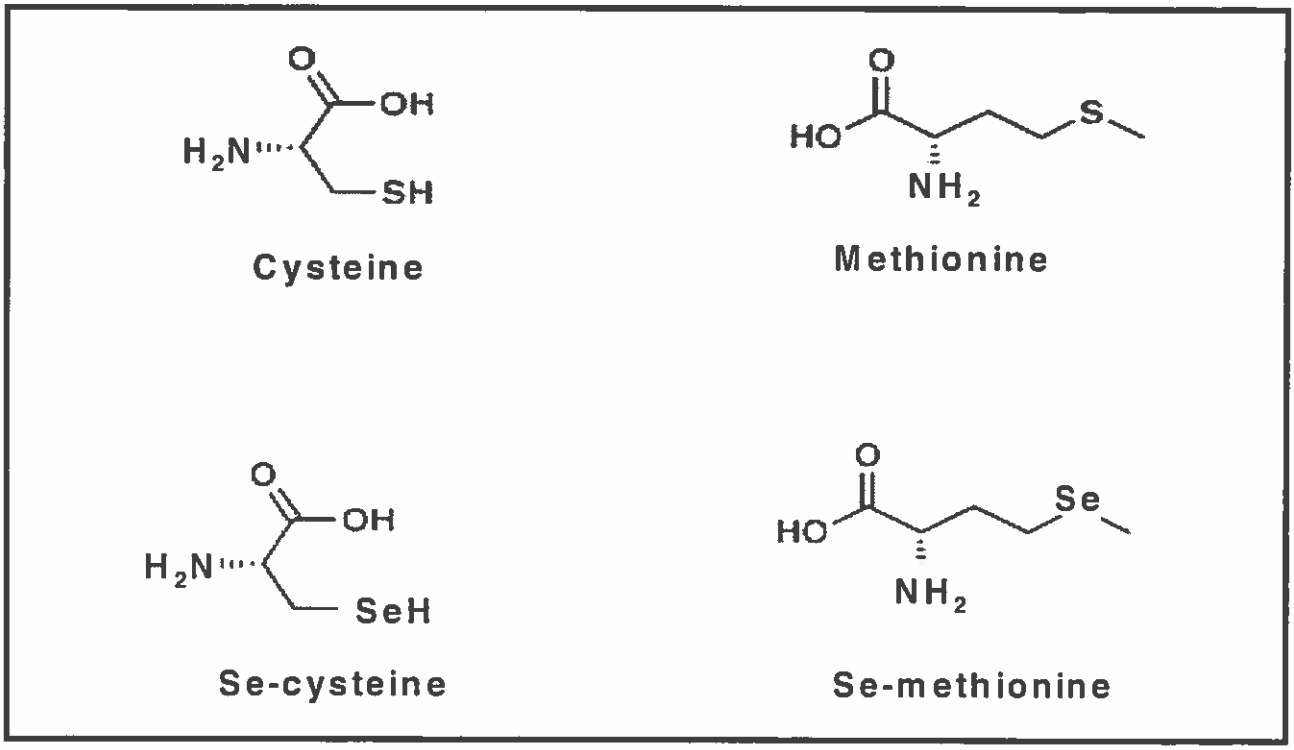

Figure 1. Chemical structures of the amino acids, methionine and cysteine, and the comparable seleno-amino acids.

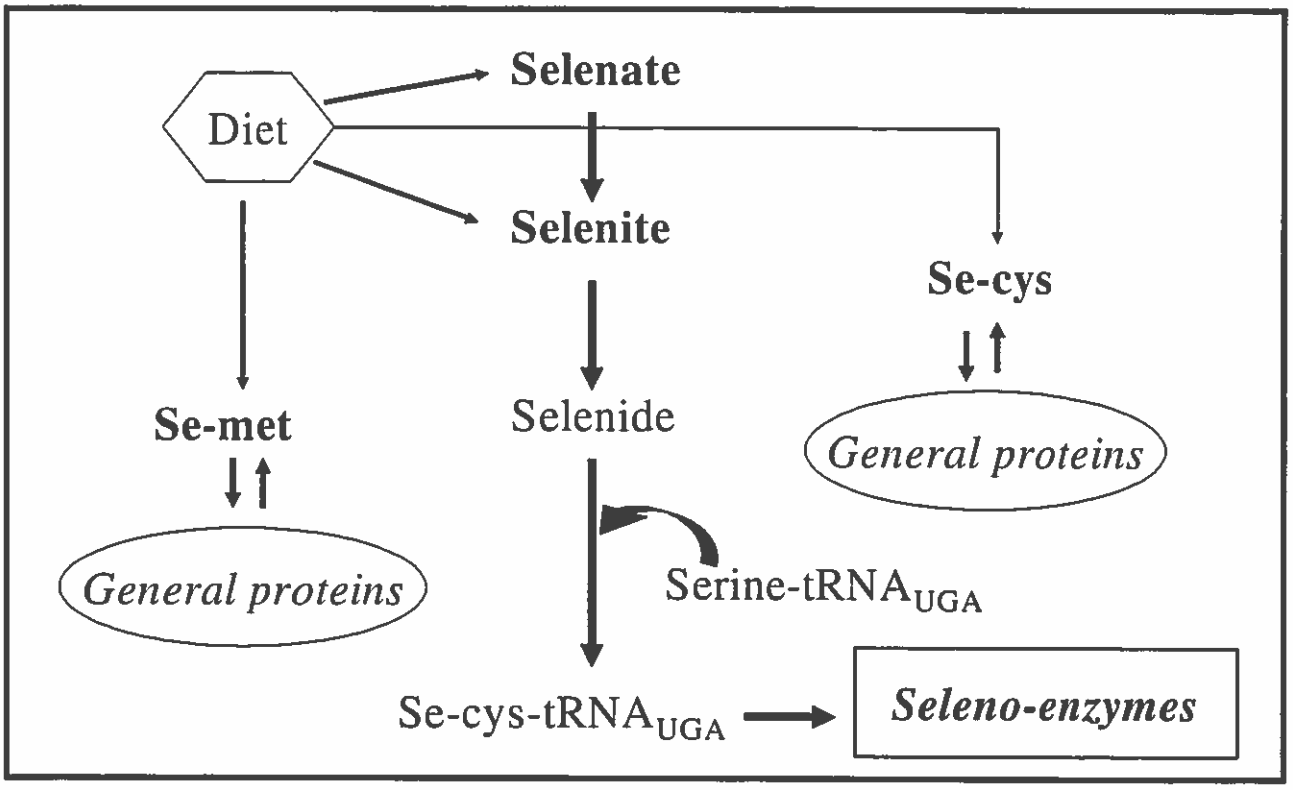

Figure 2. Simplified pathways of selenium metabolism.

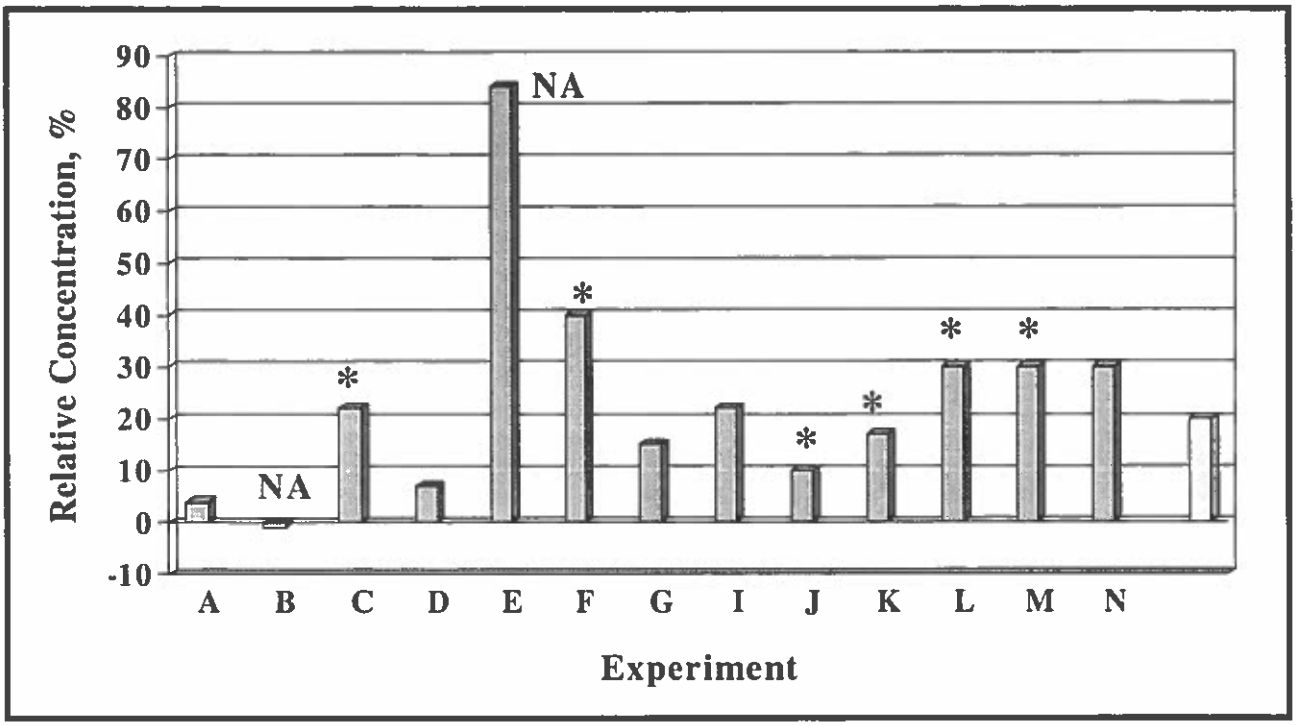

Figure 3. Relative increase in concentration of Se in whole blood when cattle were fed Se-yeast compared with selenite. Relative increase calculated as (Se-yeast minus selenite)/selenite x100. A value of 0 means that concentrations were equal when Se-yeast or selenite was fed. The hashed bar is the median response. NA = data not statistically compared; * = $P < 0.05$.

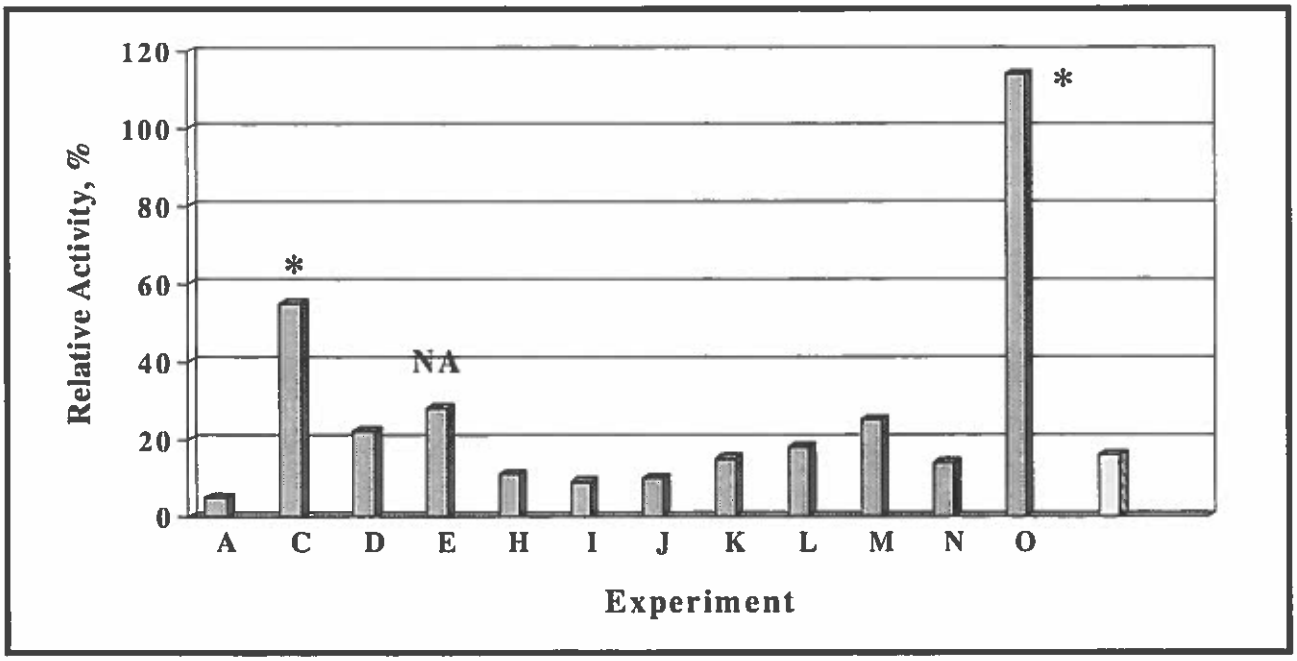

Figure 4. Relative increase in activity of glutathionine peroxidase activity in whole blood when cattle were Se-yeast compared with selenite. Relative increase calculated as (Se-yeast minus selenite)/selenite x100. A value of 0 means that activities were equal when Se-yeast or selenite was fed. The hashed bar is the median response. NA = data not statistically compared; * = $P < 0.05$.

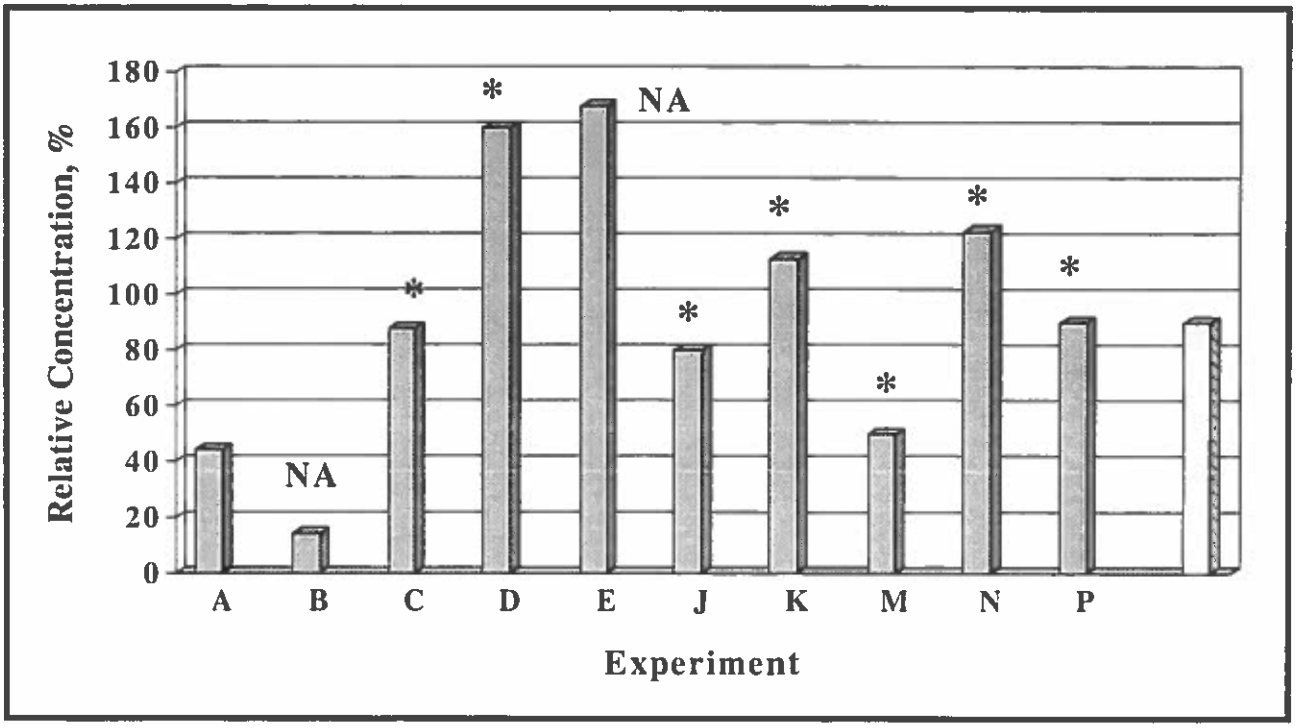

Figure 5. Relative increase in concentration of Se in milk when cattle were fed Se-yeast compared with selenite. Relative increase calculated as (Se-yeast minus selenite)/selenite x100. A value of 0 means that concentrations were equal when Se-yeast or selenite was fed. The hashed bar is the median response. NA = data not statistically compared; * = $P < 0.05$.

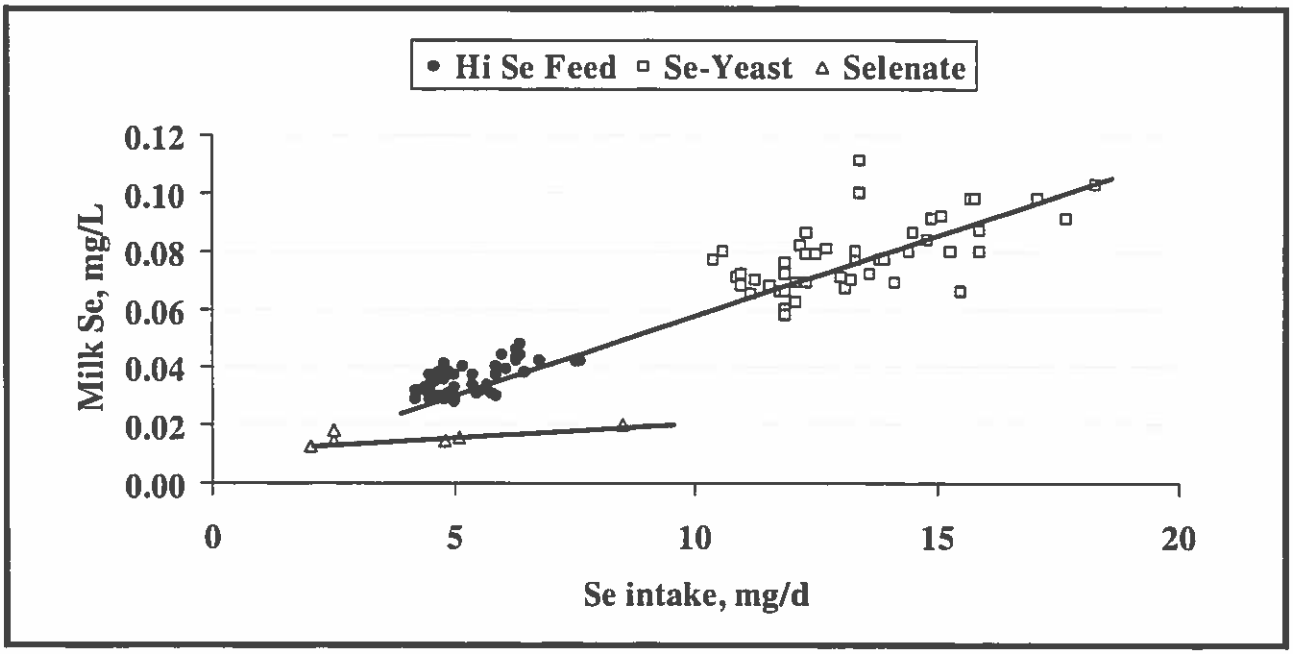

Figure 6. Concentration of Se in milk when fed: A) a basal ingredients with low concentrations of Se plus supplemental selenite (△), B) a diet with basal ingredients that contained high concentrations of Se and no supplemental Se (•), or C) a diet with basal ingredients that contained high concentrations of Se plus supplemental Se from Se-yeast (□). Treatments B and C fit the same line with a slope of 0.0052. Treatment A had a slope of 0.0007.

Optimizing Starch Concentrations in Dairy Rations

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Abstract

Currently, many nutritionists consider only the total nonfiber carbohydrate (**NFC**) fraction when formulating rations for lactating dairy cows. Increasingly, we need to measure the components that comprise NFC (starch, sugars, soluble fiber, and β-glucans) and formulate rations that optimize the concentration of each component in the diet. Starch is the major NFC fraction in dairy cattle diets, and some research has attempted to determine optimal dietary concentrations of either NFC or starch. However, an optimal amount of dietary starch will be a function of several factors, including the inherent degradability of the starch source, processing method, amount of soluble protein, neutral detergent fiber (**NDF**) content, feeding method, and environment. Commonly, dietary starch recommendations range between 23 to 30% of ration dry matter (**DM**) depending on forage content of the diet. The basis for this range in recommendations is a combination of some research but mostly anecdotal and experience-based observations in the field. The purpose of this paper is to explore some of the key factors that influence the optimal content of dietary starch, particularly considering diets high in fibrous byproducts.

Introduction

We cannot define an optimal dietary concentration of starch without considering other nutrient fractions in the diet. We need to define any optimal starch concentration in relation to the concentration of other carbohydrate and protein fractions. Additionally, we must consider the ruminal degradability of the starch and other dietary carbohydrate fractions. In other words, we must optimize the entire carbohydrate profile, pool sizes and digestion rates, to optimally formulate a ration. Diets that contain appreciable quantities of fibrous byproduct feeds will be lower in starch content and higher in content of digestible NDF than typical diets for lactating dairy cows. As these diets become more commonly fed, particularly in the Midwestern US, we need to determine the optimal carbohydrate and protein fraction and rate profiles for these types of diets. Starch and fiber will be key components in determining the success of feeding diets high in nonforage sources of fiber, such as soybean hulls, corn gluten feed, distillers grains, beet pulp, and others.

We also need to consider the feeding environment and its potential impact on cow response to any particular amount of dietary starch. Management and housing factors that encourage abnormal feeding behaviors, such as slug feeding or sorting, will increase the risk of ruminal acidosis and associated problems for any concentration of dietary starch.

This paper will focus on the interactions among starch and other carbohydrate fractions, particularly NDF, although other factors are certainly important in determining cow response to

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starch, such as protein solubility (Hoover and Stokes, 1991).

Dietary Starch Improves Energy Content of the Diet

Starch represents a substantial fraction of dairy cattle diets, ranging from less than 20% (dry cow diets) to greater than 35% of lactating cow diets. Most of the dietary starch is supplied by cereal grains. Starch content of cereal grains ranges from 45% for oats to 72% for corn (DM basis). Forages vary in starch content from <15% of DM for alfalfa and perennial grass forages to as much as 35% for corn silage. Ruminal fermentation of starch is extremely variable from <50 to >90% and is a function of the rate of fermentation and retention time of feed particles in the rumen.

To increase energy intake by lactating dairy cattle, feeds high in starch are commonly substituted for fibrous forages and other feeds. Additionally, when diets higher in starchy grains, and consequently lower in NDF, are fed to lactating cows, the DM intake (**DMI**) usually increases (Allen, 2000).

The apparent digestibility of starch is approximately twice that of NDF when fed to dairy cows and should increase the energy content of the diet (Firkins et al., 2001). But, the actual increase in energy content of the diet may be less than predicted when starchy concentrates replace forages (Weiss and Shockey, 1991). Why is this response observed? When starch replaces dietary forage fiber, total tract digestion of NDF is often reduced (summarized well by Beckman and Weiss, 2005). A similar response has been observed when corn silage was rolled to increase ruminal starch digestibility and simultaneously ruminal NDF digestion was reduced (Fanning et al., 2002). In many feeding situations, increasing amount of dietary starch will reduce NDF content and thereby increase the probability of negative associative effects of starch on NDF digestion (Firkins et al., 2001).

Nonfiber Carbohydrate or Starch and Sugars?

Routine analysis of the NFC fractions is new for commercial testing laboratories. But, it is important to develop routine analyses for these fractions as they become more routinely used in ration formulation. Interestingly, a recent survey of nutritionists and consultants in the U.S. revealed that approximately 54% of them thought that an NFC or nonstructural carbohydrate (**NSC**) value was as good as individual starch or sugar analyses for ration formulation (L. Chase, Cornell University, 2005, personal communication). This response among consultants is likely to change as we learn more about starch and other NFC fraction utilization by cattle and more complex models are routinely used to formulate diets and predict animal response.

Even though the carbohydrate recommendations presented in Table 1 are based on a combination of research and field experience, use of these recommendations will allow us to better control the fermentation in the rumen of cattle at high levels of feed intake that is really one of our major goals as dairy nutritionists. Properly balancing the carbohydrate fractions in Table 1 should minimize the incidence of ruminal acidosis, maximize microbial yield, and minimize the need for relatively expensive supplemental sources of ruminally undegradable protein. We need to consider starch content and degradability, sugar content and whether there are differences among sugars in ruminal rate of fermentation, soluble fiber (pectin and β-glucans) content, rate of NDF digestion, NDF availability, and physically effective NDF (**peNDF**).

Starch is the only component of the NFC fraction that escapes from the rumen in substantial amounts. The amount that will escape ruminal fermentation depends on starch type, processing, feed intake level, the peNDF content of the diet, and pattern of daily meal consumption (highly influenced by feeding environment and management

routines). The impact of meal feeding patterns on starch utilization requires much more research. Starch comprises approximately 50 to 100% of the nonstructural carbohydrates in most feedstuffs. In addition to total starch concentration, the rate and extent of ruminal starch digestion also influences the amount of any particular starch source that may be fed safely in a diet (NRC, 2001). Rate of fermentation of starch varies considerably by type of grain and grain processing. Total tract starch digestion typically ranges from 85 to 99% (Firkins et al., 2001). Major factors that affect the measured starch digestion in dairy cattle include genetics of the grain, grain processing, the analytical method used to assay for starch, variable DMI, and the NDF content of the diet (Firkins et al., 2001).

Starch is variable in small intestinal and hindgut digestibility (Knowlton et al., 1999). For example, Knowlton et al. (1999) measured that as little as 55 and as much as 85% of corn starch appearing in the small intestine was digested; the lowest digestion was observed for dried corn, either ground or rolled, with high-moisture corn being highest. A probable explanation was the degree of gelatinization and the disruption of the protein matrix surrounding the starch. Steam flaked corn has greater fermentability in the rumen and greater digestion in the small intestine than steam rolled corn (Knowlton et al., 1999). Degree of processing is a major factor determining extent of digestion in both the rumen and hindgut.

Optimal Dietary NFC Content

Optimal concentration of NFC or NSC in diets for lactating dairy cows is not well defined as summarized in the most recent NRC publication (NRC, 2001). To avoid ruminal acidosis and other metabolic problems, the maximum concentration of NFC should be approximately 33 to 43% of ration DM (Nocek, 1997). Optimal NFC concentration in diets for high producing cows is a function of: 1) the effects of rapidly degradable starch on ruminal NDF digestion, 2) amount of NFC that replaces NDF in the diet, 3) site of starch digestion, 4) DMI and physiological state of the animal, and 5) processing and storage methods that may alter rate and extent of NFC digestion (NRC, 2001). Obviously the same could be stated for starch since it is typically the largest fraction of the NFC pool.

Some research has attempted to define optimal ranges for dietary NFC. Most of these studies have found that diets containing <25 to 30% or >45% NFC resulted in reduced milk yield (Nocek and Russell, 1988; Hoover and Stokes, 1991; Batajoo and Shaver, 1994). The diets in these studies were based on combinations of alfalfa and corn silages and mostly traditional concentrate feeds. Recent research (for example Boddugari et al., 2001 and Ipharraguerre and Clark, 2003) with nonforage sources of fiber clearly demonstrates that dietary starch may be reduced to <25%, and NFC to <30%, with no negative impact on lactational performance. There was little difference in cow response for diets containing between 36 and 42% NFC (Batajoo and Shaver, 1994). Varga and Kononoff (1999) evaluated 16 studies and concluded that a 1 lb increase in NFC intake resulted in a 2.4 lb increase in milk yield.

Dietary NFC, Starch, and peNDF Contents

Haddad and Grant (2000) evaluated the effect of 30, 35, 40, or 45% NFC (obtained by adding corn starch to the diet) on the in vitro digestion kinetics of NDF from alfalfa or corn silages. Digestion was measured at low pH (5.8) or a higher pH (6.8) to mimic fermentation conditions representative of cows consuming a diet either deficient or adequate in peNDF. The optimal NFC to NDF ratio for maximal extent of ruminal NDF digestion differed between the two forages. For alfalfa fermented at pH 6.8, extent of NDF digestion was greatest between 30 and 40% NFC, but at pH 5.8, NDF digestion was greatest at 35% NFC. For corn silage fermented at either low or high pH,

NDF digestion was greatest at 30% NFC. A NFC to NDF ratio of 0.70-1.20 maximized NDF digestion for alfalfa only when pH was maintained at 6.8. This study demonstrated that the optimal dietary NFC content for maximum ruminal NDF digestion for a given forage is a function of fermentation pH that reflects the peNDF content of the diet.

Dietary Starch to Fiber Ratio

Recently, Beckman and Weiss (2005) published a paper that evaluated whether increasing dietary NDF:starch ratio influenced NDF digestibility when diets were formulated to have similar NDF digestibility. All diets contained 41.5% corn silage (DM basis), but the content of corn varied between 23.3 and 34.8% with NDF:starch ratios of 0.74, 0.95, and 1.27. A soybean hull:cottonseed hull mixture (54% soyhulls and 46% cottonseed hulls) which had the same NDF digestibility as the forage NDF was substituted for the corn grain in varying proportions to obtain the desired NDF:starch ratios. Starch content of these diets varied from 25.4 to 33.3%, and NDF varied between 24.7 and 32.2%.

Intake tended to increase as NDF:starch ratio increased and total tract DM and energy digestibilities decreased. However, NDF digestibility was not influenced by NDF:starch ratio. Greater DMI appeared to compensate for reduced digestible energy content such that energy intake was similar among the diets. This study demonstrated that NDF digestibility may be less sensitive to increases in the NDF:starch ratio under carefully controlled experimental conditions. Practically, there is almost always complete confounding of NDF and starch content, and the animal response is a composite response to all the carbohydrate fractions. Dietary formulation approaches that allow greater use of highly digestible NDF from byproduct feeds (replacing either forage or concentrate) represent a strategy for feeding either high or low starch diets and obtaining desirable lactational performance.

Nonforage Sources of Fiber and Dietary Starch Content

Recent research demonstrates that dietary NFC and starch contents may be reduced to low concentrations when high amounts of nonforage fiber sources are fed. Ipharraguerre et al. (2002) fed diets in which soybean hulls replaced ground corn from 0 to 40% of dietary DM. Corn was reduced from 40.3 to 1% of dietary DM. The dietary NSC (starch and sugars) ranged from 35.9 to only 15.6% of DM, while the NDF ranged between 26.6 and 45.4%. There were no differences among the diets, from high to low NSC, in either fat-corrected milk production or DMI.

Boddugari et al. (2001) evaluated diets in which a wet corn gluten feed product comprised up to 70% of the ration DM (replacing all of the corn grain and 50% of the forage). The NFC content ranged from 43.2 to 27.0% of DM across two studies. The efficiency of fat-corrected milk production (**FCM/DMI**) was similar for all diets, even when the content of NFC was much lower than commonly recommended. These studies were short-term (4-wk periods), and a subsequent trial evaluated response to a 40% wet corn gluten feed-based diet for the first 63 days in milk (Boddugari et al., 2001). The two diets contained either 43.6 or 35.1% NFC (0 versus 40% wet corn gluten feed product) and the efficiency of fat-corrected milk production was actually improved from 1.47 to 1.79 for cows fed the low NFC, low starch diet.

Biologically, significant differences exist among the commonly used byproduct feeds in their carbohydrate fractions. For example, Mills and Grant (2002) observed different lactational responses when either soybean hulls or wet corn gluten feed replaced corn grain at the same dietary NDF level. We need to keep this in mind as we incorporate various byproducts into rations. We will lower starch content, but depending on the byproduct, we will also have variable (and potentially

important) effects on other dietary carbohydrate fractions, such as sugars, soluble fiber, and organic acids. But, the two papers cited here clearly demonstrate the effectiveness of low starch, low NFC diets with two byproducts (soybean hulls and corn gluten feed) that vary dramatically in carbohydrate composition.

Interaction of Forage and Nonforage Fiber Sources

Fibrous particles have a high probability for escape from the rumen due to their small particle size and high specific gravity. They are rapidly fermented and so are less buoyant. Because most nonforage sources of fiber do not stimulate rumination as effectively as coarse forages, dietary forage must have adequate particle length for normal rumination when significant amounts of forage fiber are replaced with nonforage fiber. Additionally, forage of longer particle length forms a digesta mat that more effectively filters and entangles smaller particles (such as byproducts and fine forage particles), allowing greater time for fermentation in the rumen.

Nebraska researchers evaluated the effect of ruminal mat consistency on passage and digestion of wet corn gluten feed in lactating dairy cows (Allen and Grant, 2000). Diets were formulated to contain approximately 40% alfalfa, 24% wet corn gluten feed, plus a corn and soybean meal-based concentrate. One diet contained alfalfa silage and the other contained a 1:1 blend of alfalfa silage and coarsely chopped alfalfa hay of similar quality to increase particle size. Cows fed the diet with added hay and wet corn gluten feed had greater rumination activity and ruminal mat consistency, a 35% reduction in passage rate of corn gluten feed, 40% greater ruminal NDF digestion, and 6% more milk production. Earlier research has demonstrated the same positive effect with soybean hulls (Weidner and Grant, 1994). The bottom line is that adequate forage particle length and a well-formed ruminal digesta mat will not only promote cow health but will slow passage of byproducts and allow more complete ruminal NDF digestion and greater productivity.

Summary

Prevailing recommendations for dietary starch range between 25 and 30% of DM. Many factors influence the optimal amount of starch, including intrinsic properties of the starch source, processing, animal factors (notably DMI level), other dietary fractions, and cow management. Altering the dietary content of starch necessitates changes in other carbohydrate fractions as well, and so we should focus on the ratio of starch to NDF (or starch to peNDF). When replacing forage NDF and(or) starchy concentrates with nonforage sources of fiber, we typically increase digestible NDF and reduce starch. Research has shown that byproduct-based diets can support excellent efficiency of milk production with much lower than commonly recommended amounts of starch and NFC.

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Table 1. Carbohydrate recommendations for lactating dairy cows.[1]

Fraction	Amount
Total NDF, % of DM	28-32
PeNDF[2], % of NDF	20-24
Forage NDF, % of DM	18-23
Fermentable NDF, % of NDF	>35.0
NFC[3], % of DM	30-43
Soluble fiber, % of DM	4-10
Starch, % of DM	23-30
Fermentable starch, % of starch	83-86
Sugars, % of DM	4-8
Sugar:soluble protein ratio	1.5:1
Fermentable total carbohydrates, % of DM	42-44
Total VFA[4], % of DM	0-5

[1]Adapted from Sniffen (2004).
[2]Physically effective neutral detergent fiber.
[3]Nonfiber carbohydrate.
[4]Volatile fatty acids.

In Vitro Digestibility of Forages

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Introduction

Forages are a necessary component of diets for lactating dairy cows because they provide coarse fiber needed to optimize rumen function. However, forages alone provide insufficient nutrients to achieve high milk yield, and they must be supplemented with other feed ingredients. Because forage quality is highly variable, their quality must be assessed before diets are formulated. Forages have been traditionally analyzed for crude protein and fiber concentrations because of their direct effect on diet formulation. More recently, in vitro neutral detergent fiber digestibility (**IVFD**) has been identified as an important quality parameter that is highly variable among forages and has consistent effects on productivity of dairy cows. However, it is important to understand the unique characteristics and limitations of in vitro measurements of forage NDF digestibility to maximize the benefit of enhanced IVFD. This paper will answer some frequently asked questions regarding the interpretation and utilization of IVFD data of forages.

Why is In Vitro Fiber Digestibility Important?

In vitro NDF digestibility of forages is extremely variable; 30-hour IVFD ranged from 35.6 to 69.9 % and from 23.2 to 59.2 %, respectively, for corn silage and legume hay analyzed at Dairy One Forage Lab (Ithaca, NY) from 2000 to 2004 (95% confidence interval adapted from www.dairyone.com; Table 1). In addition, wet chemistry forage analyses performed at the Cumberland Valley Analytical Services (Maugansville, MD; www.foragelab.com) during the last two years indicated that IVFD is poorly related to the concentration of NDF, ADF, or CP for corn silage and legumes (Table 2), indicating that IVFD is an additional and independent measure of forage quality. In vitro digestibility has become widely used; in 2004, 13.1, 24.2, and 36.8% of forage samples analyzed for NDF content (for mixed forage hay, mixed forage haylage, and corn silage, respectively) were also evaluated for IVFD at the Dairyland Laboratories, Inc. (Arcadia, WI; www.dairylandlabs.com). This indicates that nutritionists and dairy producers believe that IVFD as an important quality parameter of forages.

While many parameters of forage quality affect diet formulation and possibly diet cost, few actually affect feed intake and milk yield when diets are properly formulated. The IVFD of forages has consistent effects on productivity of dairy cows, making this analytical value a very important quality parameter of forages. Several years ago, we reported that a one-unit increase in in-vitro or in-situ digestibility of NDF was associated with 0.37 and 0.55 lb/day increase in dry matter (**DM**) intake and 4% fat-corrected milk yield, respectively (Oba and Allen, 1999b). This relationship was developed by statistical analysis of treatment means from experiments reported in Journal of Dairy Science. To validate this finding, 12 forage comparisons

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reported in 9 recent articles of the Journal of Dairy Science were reviewed (Table 3). These recent publications compared different corn or sorghum hybrids except for one article (Neylon and Kung, 2003), in which effects of cutting height of corn silage were evaluated. Nine comparisons out of twelve reported that milk yield significantly increased when diets containing corn silage with enhanced IVFD was fed, and the remaining three comparisons reported that milk yield numerically increased without statistical significance. All experiments except for one (Ballad et al., 2001) reported significant differences in IVFD (30-hour) for the forages compared and were used for further statistical evaluation. The average difference in IVFD for those forages was 7 units, and this was associated with the difference of 1.8 lb/day of DMI and 3.3 lb/day of 4% FCM yield; one unit increase in IVFD was associated with 0.26 lb/day of DMI and 0.47 lb/day of 4% FCM yield. These values are reasonably close to the benchmark that we established previously (Oba and Allen, 1999b). It is important to note that effects of enhanced IVFD were not confounded by different dietary NDF contents for the 12 comparisons in Table 3; mean dietary NDF contents were 33.2 and 33.4%, respectively, for diets containing forages with greater IVFD and those with lower IVFD. This is important because feed intake is negatively related to dietary concentration of forage NDF (Allen, 2000). Thus, this more recent literature also strongly supports the idea that the quality of NDF, determined by IVFD measurements, is positively related to animal performance.

What is In Vitro Digestibility?

The IVFD of forages is determined by incubating dried ground forages in flasks with rumen microbes for a given period of time. Forages are dried and ground (usually to pass through a 1-mm screen) so that a representative sample can be taken. The ground forage samples are placed in individual flasks and incubated with rumen fluid containing rumen microbes collected from cows with rumen cannula. The flask also contains buffers, macro-minerals, trace-minerals, nitrogen sources, and reducing agents to maintain pH and provide nutrients required for growth of rumen bacteria. Because oxygen is toxic to rumen bacteria, flasks are gassed with carbon dioxide to maintain anaerobic conditions, and temperature is held at 104°F (body temperature) during the incubation. A variation of this method is when forage samples are sealed in porous dacron bags which are incubated in groups in jars containing rumen fluid and media.

Every effort is made to provide the optimum environment for survival and growth of fiber-digesting bacteria in the incubation media. This is extremely important because digestion is a function of both enzyme activity and structural characteristics of substrates. If enzyme activity is limiting because of inadequate buffering or lack of essential nutrients, IVFD will be reduced, and more importantly, differences in IVFD among forages will be compressed and not reflective of the true differences among forages. Forages are rarely fed as a sole ingredient to dairy cows but are supplemented with other ingredients to enhance ruminal fermentation and nutrient supply to the animal. Therefore, it is important to use an in vitro system that measures the maximum IVFD of forages, not one that limits IVFD because of lack of buffering or essential nutrients.

It is important to recognize that IVFD is a biological evaluation rather than chemical evaluation of forage quality; microbial activity in rumen fluid of cows can vary with diet and over time relative to feeding which affects the results. Thus, measurements of in vitro digestibility are associated with greater intrinsic variation compared with chemical measurements, such as CP and NDF. This variation can be reduced by feeding the donor cows a high forage diet, sampling rumen fluid at the same time relative to feeding, and blending rumen fluid from several cows for each incubation.

In vitro digestibility is not necessarily the same as in vivo digestibility because the environment in the rumen is often less than optimum for fiber-digesting bacteria. For example, rumen pH is often lower than optimum for the fibrolytic bacteria because highly fermentable diets are typically fed to high producing cows. In addition, forage fiber particles in the rumen are longer than those of ground forages used for in vitro measurements of digestibility. Longer particle size limits the surface area for microbial degradation per unit of fiber mass. Therefore, in general, in vitro digestibility of forages should be greater than in vivo digestibility as long as an optimum fermentation environment, such as pH, temperature, and anaerobic conditions, is carefully maintained in the incubation media. In addition, the range in NDF digestibility of forages measured in vitro is greater than the range measured in vivo (Oba and Allen, 1999b) because the same retention time is used across samples, although actual retention time of forages likely varies with rate of digestion (Allen, 2000).

What is In Situ Digestibility?

Some researchers evaluate in-situ NDF digestibility of forages rather than IVFD. What are the differences between in-vitro and in-situ measurements? Is one superior than the other as a tool for evaluation of forage quality? Our opinion is that for ranking forages for NDF digestibility as a proxy for intake potential, IVFD is best. For the in-situ digestibility measurement, ground forage samples are placed in small porous dacron bags and inserted into the rumen through rumen cannula. Although in-situ measurements evaluate forage samples directly in the rumen of live animals, enzyme activity might be limited by low pH, decreasing differences among forages. In addition, although dacron is available with different pore sizes, a pore size must be selected (usually ~50 μm) that allows entry of microbes but retains feed particles, a challenge at best.

Can IVFD be Used to Predict Energy Concentration of Forages?

The recent Nutrient Requirements of Dairy Cattle (NRC, 2001) suggests that 48-hour in vitro digestibility can be used as a measure of digestible NDF at maintenance. The NRC (2001) discounts the energy content of forages based on actual intake level of animals which a forage is fed to and total digestible nutrients (**TDN**) concentration of diets (i.e., diets with greater TDN content discount energy content of feeds at a greater rate as intake increases). Thus, the dairy NRC (2001) appears to do a better job conceptually in estimating energy density of forages compared with previous editions. Indeed, the energy content of forages is lower if fed to cows with greater feed intake. In addition, forages fed in high grain diets likely have lower digestibility compared with those fed in low-grain diets because of sub-optimal enzymatic capacity for fiber digestion in the rumen. However, these changes made in the current NRC (2001) did not solve the intrinsic problem that limits the use of in-vitro digestibility for estimation of energy content of forages: inconsistent measurements.

Because of the biological nature of in vitro digestibility measurements, it is challenging to get a same "absolute" value among several analytical laboratories. Consistency of measurements within a laboratory may be improved by adopting the best procedures and careful training of technicians. But, rumen fluid required for determination of IVFD is collected from different animals fed different diets at each analytical laboratory and variation in enzyme activity potentially affects the results to a great extent; IVFD might be 50% for a sample analyzed in one lab and 40% in another. It is not likely to get one consistent value for IVFD across several laboratories. This is one limitation for use of IVFD data for energy value. If you want to use IVFD to estimate energy content of forages, you need to have a consistent standard for enzymatic capacity used for the in-vitro measurements across all laboratories.

In addition, an incubation time of 48 hours is too long to estimate actual NDF digestibility even at maintenance level (as discussed below), and compensatory digestion of NDF in the large intestine make predicting energy concentration from IVFD a challenge. Therefore, in-vitro digestibility does not provide an "absolute" value that can be used for diet formulations. Chemical measurements, such as lignin content (% of NDF), eliminate intrinsic variation associated with biological assays. Use of commercial enzymes with a known activity may be another choice in the future. These alternative options raise other types of questions, but this further discussion is beyond the scope of this paper.

So How can IVFD be Used?

Even though we cannot get an absolute energy value from in-vitro digestibility measurements, IVFD still provides very useful data for nutritional management of dairy herds. For instance, IVFD is a powerful tool to rank forages by their quality. As discussed earlier, diets containing forages with different IVFD consistently affect animal performance. Positive effects of enhanced IVFD are greater for cows yielding more milk. This is likely because their maximum feed intake is limited by physical fill in the rumen to a greater extent compared with lower-yielding cows. Milk production responses to brown midrib corn silage, which has enhanced IVFD, were positively correlated with milk yield (Oba and Allen, 1999a). Lower producing cows had little response in DMI and milk yield to the corn silage with greater IVFD, while higher yielding cows responded by increasing feed intake and milk yield. Lower production responses for low producing cows is likely because their feed intake is not limited by physical fill of the diets. Thus, forages with greater IVFD should be allocated to higher yielding cows that will benefit the most. If a farm can feed different lots of forage to 2 or more groups of lactating cows, there is an opportunity to increase the benefit of enhanced IVFD by feeding the forage with greater IVFD only to cows that will benefit the most. Because forages with enhanced IVFD might cost more to buy or produce (greater seed cost, lower yield), animals must respond enough to justify the investment for enhanced IVFD.

The IVFD data may also affect how you formulate the diets. When grain is less expensive than forages, dairy diets are normally formulated to include the maximum amount of grain without causing any digestive disorders, such as rumen acidosis or laminitis. On the other hand, when grain price increases, feed costs can be reduced by increasing the forage concentration in the diet. Because forage NDF is filling and often limits feed intake, forages with greater IVFD will allow more forage to be fed without compromising milk production. In a previous experiment (Oba and Allen, 2000), cows fed a corn silage with enhanced IVFD (55.9%) in a high forage diet without supplemental corn grain, produced as much milk as cows fed a corn silage with lower IVFD (46.5%) in a diet which contained dry ground corn at 29.2 % of dietary DM (33.7 versus 33.5 kg/day). Similarly, Weiss and Wyatt (2002) compared high-fiber corn silage with a dual-purpose corn silage. Although diets containing high-fiber corn silage had greater forage NDF content, they supported similar milk production as those containing corn silage with high starch concentration probably because of the greater IVFD. Identification of forages with greater IVFD will allow greater forage to be fed and decrease feeding costs when grain is costly without reductions in milk yield. This creates significant flexibility in diet formulation, especially because grain costs relative to forages are highly variable.

Analysis of forage for IVFD is also an important troubleshooting tool when switching forages. For instance, milk yield sometimes decreases when switching from old corn silage to the new crop or from one lot of alfalfa to another. It is a good idea to sample the current forage before switching so that it can be sent to the lab for IVFD

analysis if production decreases. While a production decrease when switching to new crop corn silage might be from excessive kernel passage, if new corn silage is significantly lower in IVFD, physical fill might become a dominant factor limiting feed intake and decreasing milk yield as well. In addition, if new corn silage is significantly greater in IVFD than corn silage that you have been feeding, the new diet may depress milk fat content unless the diet is adjusted. If you open the silo a couple of weeks before you start feeding to high producing cows and feed it to the low group or heifers, you will have sufficient time to take a representative sample, analyze it for IVFD, and make necessary adjustments in diet formulation. Assessment of IVFD for new corn silage to compare with that from a previous year can help explain a production drop or prevent a potential problem before it occurs.

Although IVFD analysis provides useful data in nutritional management, it is important to know that you cannot compare IVFD between grasses and legumes. Although IVFD is in general greater for grasses compared with legumes, filling effects of legumes in the rumen are usually less than those of grasses, probably because of different physical characteristics such as fragility of fiber or buoyancy in the rumen (Allen, 2000). Many experiments evaluating legumes versus grasses reported that cows fed legumes had greater feed intake and milk production at similar IVFD (Oba and Allen, 1999a), suggesting that the comparison of IVFD across different forage families is not appropriate. But, if we have mixed forage samples with unknown ratio of legumes and grasses, how should we interpret the data? At first, you may want to check the ADF to NDF ratio of the forages because this value is greater for legume, averaging 80%, whereas it is about 50 to 60% for grasses. If you find a wide variation in the ADF to NDF ratio among forages of which you wish to compare the IVFD values, you should not use IVFD data to make any decisions in nutritional management because it implies a significant mixture of grasses and legumes. In general, feeding grasses and legume-grass mixes to high producing cows should be avoided because the fiber is more filling and will limit feed intake to a greater extent.

What Should I Analyze?

When you receive in vitro digestibility data from a laboratory, you will see two types of digestibility: IVFD and in vitro true dry matter digestibility (**IVTDMD**). The IVTDMD is a calculated value from IVFD, assuming that everything except for fiber is hydrolyzed by the end of the incubation time. Although this is a reasonable assumption, you may not get additional information about the quality of forages from IVTDMD data. Wet chemistry forage analyses performed at the Cumberland Valley Analytical Services (Maugansville, MD) during the last two years indicated that IVTDMD are negatively related to NDF content and positively related to CP content for all forage types (Table 4). You may sometimes find that IVTDMD is greater for one sample and that IVFD is greater for the other when you send multiple samples for analysis. This occurs if one sample has lower concentration of NDF that is less digestible, and another sample has higher concentration of NDF that is more digestible. How should we interpret those data? The objective of in vitro digestibility measurements is to gain additional information which you cannot obtain from conventional chemical measurements. The IVFD data reflect the quality of forage fiber, which is difficult to determine by other analytical methods, while IVTDMD does not.

Similarly, you will not gain a lot of additional information from analyses of total mixed ration (**TMR**) digestibility. As discussed earlier, the in vitro procedure is not an appropriate method to estimate in vivo digestibility and will not give you additional and valuable information to make decisions in nutritional management. If you need to obtain a rough estimate for TMR digestibility, more

economical other measurements such as NDF or starch content can be used. In addition, it is extremely challenging to obtain a representative TMR sample because of the wide variations in particle size and DM concentration. So, the value obtained from TMR analysis needs to be interpreted with extreme caution.

What is the Optimum Incubation Time: 24, 30, or 48h?

The Dairy NRC (2001) stated "Digestible NDF can be obtained using a 48-hour rumen in vitro assay . . . to calculate digestible NDF at maintenance". We think that 48 hours is too long to use for an incubation time for two reasons: 1) the retention time of indigestible NDF in cows at maintenance is likely less than 48 hours, and 2) grinding forages greatly increases their rate of digestion so the incubation time must be lowered to compensate.

The primary use of IVFD data is to rank forages by their potential to stimulate intake and milk production because IVFD of forages is an indicator of the filling effects of forage fiber in the rumen for a given forage type. Thus, we need to select the optimum incubation time, which allows us to detect the differences in filling effect of forage fiber in the rumen. To accomplish this goal, we need to know the length of time that fiber stays in the rumen. While total fiber leaves the rumen either by digestion or passage, indigestible fiber leaves the rumen by passage only. Therefore, the retention time of indigestible fiber reflects the maximum time that fiber stays in the rumen. The retention time of indigestible NDF, which is the reciprocal of its turnover rate in the rumen, ranged from 26.8 to 32.0 hours for cows producing 73.9 lb/day of milk (Oba and Allen, 2000) and from 27.0 to 30.3 hours for cows producing 79.6 lb/day (Oba and Allen, 2003). This retention time is expected to be shorter for cows producing more than 88 lb/day. If you are interested in the filling effects of forage when fed to high producing dairy cows, they need to be estimated assuming a shorter retention time of digesta in the rumen. Therefore, the incubation time for IVFD should not be any longer than 30 hours, if you are interested in forage quality for high producing dairy cows.

You may think that a 24-hour IVFD is highly correlated with 30- or 48-hour IVFD, thus selection of a specific incubation time does not really matter. This argument may sound logical, but you may miss an essential part of data if you select an inappropriate incubation time. Let's think about an example. You are comparing two samples of alfalfa silage. If you see 3 units of difference in 48-hour IVFD, you may think this difference is not significant. However, if the IVFD data obtained from the same samples but using 30-hour incubation shows a 10-unit difference, you expect that the forages you compared will cause significant difference in animal performance. You may see the opposite case: 10-unit difference for 48-hour incubation and 3-unit difference for 30-hour incubation. Although relative ranking between forages stays same, you may draw a wrong conclusion unless you select the right incubation time. So, why do you want to analyze 48-hour in vitro digestibility when you are interested in forage quality for high producing cows? If you are feeding these forages to high producing cows and wish to rank them by their filling effects in the rumen, a 24 or 30 hour of incubation is the right choice because it does not make sense to compare the filling effects of these forages assuming the retention time of 48 hours. However, if you are interested in forage quality for heifers or dry cows to rank them by its potential digestibility, you should choose a longer incubation time because it is closer to the retention time of digesta in the rumen of heifers or dry cows. Selection of the appropriate incubation time is important to make the right decision based on in vitro digestibility data.

How to Evaluate Analytical Laboratories?

Because the objective of forage analysis for IVFD is to rank forages, you should not compare samples analyzed across different laboratories. Procedures used at different labs vary widely as do the diets fed to cows used as rumen fluid donors and these factors can affect IVFD. It is best to send all samples that you wish to compare to a trusted lab and have them analyzed for IVFD in the same run to increase analytical precision. Precision and accuracy are two important criteria when you evaluate forage analytical laboratories.

Precision is a more important criterion than accuracy if the primary objective of your IVFD analysis is to rank forages. Precision can be defined as the ability of a measurement to be consistently reproduced, while accuracy can be defined as the ability of a measurement to match the actual value of the quantity being measured. However, the accuracy of measurement is also essential in IVFD analysis because the in vitro incubation environment needs to be optimal so that enzymatic capacity does not limit fiber digestion. So, the inaccurate but precise measurements indicate that a lab consistently fails to optimize the fermentation environment, which also is not desirable.

It might be difficult to check the accuracy of analysis, but you can check the precision of analysis by inter-assay coefficient of variation (**CV**) and intra-assay CV. The CV is the expression of standard deviation as a percentage of a mean. For an example, if a standard sample is placed in three flasks within an incubation bath, the three measurements of IVFD are ideally identical but are slightly different in reality. This variation is referred to as an intra-assay CV. Thus, the lower CV is the better. When you try to compare two forages that differ in IVFD by 2 units (50 vs. 48%), you may wonder if the difference of 2 IVFD units or 4 % [(50 - 48) / 50 x 100] is meaningful. If the intra-assay CV is 1%, you may be able to say that the difference is meaningful. But, if the intra-assay CV is 4%, the difference likely happens by chance, and you do not want to make any management decisions based on this analysis. Inter-assay CV is the variation observed among several different incubation runs. If this variation is too large, you may not want to compare a sample analyzed this year with the one analyzed in a previous year because the difference between two measurements likely happens by chance. Good laboratories should be able to provide you with their inter-assay and intra-assay CV if you ask. In any case, it is best to analyze any samples you want to rank or compare with each other in the same incubation bath to minimize potential confounding variations.

Several commercial labs provide service for IVFD analysis by near-infrared reflectance spectroscopy (**NIRS**). The NIRS is a technology that estimates chemical composition and bonds of forage samples by measuring reflectance of light with near infrared wavelengths and using that to predict IVFD. However, NIRS measurements still need to be calibrated with the data obtained from wet-chemistry, and different equations need to be used for each forage species and often for each growing environment of forages. Therefore, the accuracy of a measurement depends on the accuracy of analysis in wet-chemistry. One problem with NIRS that is common to all prediction methods is that the range of data is compressed. This means that a 5 unit difference in IVFD between two samples measured using traditional techniques is likely to be less using NIRS.

Summary

Fiber digestibility of forages is positively related to animal performance and varies greatly. The IVFD should not be used to adjust energy density of forages but is very useful to to rank forages for their filling effects of NDF in the rumen. The IVFD analysis allows us to identify forages with greater potential to increase intake and milk

production so that we can allocate them to high producing cows which will benefit the most. Analysis of IVFD provides essential information to make good decisions in nutritional management and improve the profitability of dairy operations.

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Table 1. Mean and the 95% confidence interval for corn silage and legume hay in CP, NDF, and IVFD analyzed during 2000-2004 at Dairy One (Ithaca, NY; www.dairyone.com).[1]

	n	Mean	Minimum	Maximum
Corn silage				
CP	77,401	8.3	6.2	10.4
NDF	80,894	44.8	32.2	57.4
30-hour IVFD	5,791	52.8	35.6	69.9
Legume hay				
CP	51,389	21.1	15.6	26.7
NDF	51,055	38.6	27.5	49.6
30-hour IVFD	770	41.2	23.2	59.2

[1]CP = crude protein, NDF = neutral detergent fiber, and IVFD = in vitro fiber digestibility.

Table 2. Correlation coefficient of 30-hour IVFD (% of NDF) with NDF (% of DM), ADF (% of DM), CP (% of DM), and lignin (% of NDF). All samples were analyzed for 30-h IVFD, NDF, ADF, CP, and lignin by wet chemistry during the last two years (Courtesy of Cumberland Valley Analytical Services, Maugansville, MD).[1]

	n	NDF	ADF	CP	Lignin/NDF
Legume	1864	-0.09	-0.20	0.11	-0.47
Mixed mainly legume	466	-0.49	-0.55	0.28	-0.64
Mixed	632	-0.43	-0.48	0.49	-0.58
Mixed mainly grass	501	-0.64	-0.63	0.62	-0.56
Grass	93	-0.43	-0.54	0.50	-0.63
Corn silage	5338	-0.06	-0.10	-0.16	-0.45

[1]IVFD = In vitro fiber digestibility, DM = dry matter, NDF = neutral detergent fiber, ADF = acid detergent fiber, and CP = crude protein.

Table 3. Effects of enhanced 30-hour forage IVFD on DMI, milk yield, and 4% FCM yield in recent publications.[1]

	30-hour forage IVFD (% of NDF)	Dietary NDF (% of DM)	DMI (lb/day)	Milk Yield (lb/day)	4% FCM Yield (lb/day)
Aydin et al., 1999 (JDS 82:2127-2135)					
Normal sorghum	40.1	32.3	47.3	47.3*	45.5*
BMR sorghum	49.2	31.6	49.9	53.5*	52.1*
Ballard et al., 2001 (JDS 84:442-452) [a]					
Mycogen (TMF™ corn silage)	28.2	35.3	...	68.4*	71.3*
Cargill (BMR corn silage)	45.7	34.7	...	73.5*	75.0*
Ebling and Kung, 2004 (JDS 87:2519-2527)					
Conventional corn silage	39.9	33.9	51.5*	91.1*	79.6
BMR corn silage	54.0	33.5	56.9*	97.5*	82.1
Ivan et al., 2005 (JDS 88:244-254)					
Corn silage with lower cell-wall content	50.7	30.8	53.2*	73.7*	69.7*
Corn silage with high cell-wall content	54.8	33.2	55.9*	78.5*	75.5*
Corn silage with lower cell-wall content	50.7	30.8	58.3	76.1	73.5*
Corn silage with high cell-wall content	54.8	30.8	59.6	78.1	76.8*
Neylon and Kung, 2003 (JDS 86:2163-2169)					
Corn silage with lower cut height	48.4	34.2	55.9	99.4*	88.4
Corn silage with higher cut height	50.7	33.5	56.3	102.7*	87.8
Oba and Allen, 1999a (JDS 82:135-142)					
Control corn silage	39.4	31.6	51.7*	85.6*	78.5*
bm3 corn silage	49.1	30.8	56.3*	91.7*	84.0*
Oba and Allen, 2000 (JDS 83:1333-1341)					
Control corn silage	46.5	29.1	50.2*	73.7*	69.9*
bm3 corn silage	55.9	28.7	51.9*	81.9*	72.4*
Control corn silage	46.5	38.4	45.1*	66.9*	65.8*
bm3 corn silage	55.9	37.5	48.4*	74.1*	72.6*
Thomas et al., 2001 (JDS 84:2217-2226)					
Dual-purpose corn hybrid	49.2	37.1	62.9	99.2*	97.7
Leafy corn silage hybrid	53.9	36.1	60.9	102.5*	100.8
Weiss and Wyatt, 2002 (JDS 85:3462-3469)					
Dual-purpose corn silage	35.4	28.9	52.6	73.3	73.3
High fiber corn silage	40.1	31.9	52.1	74.8	73.3
Dual-purpose corn silage	35.4	31.6 (18.1 [b])	51.5	74.4	73.9
High fiber corn silage	40.1	27.6 (20.4 [b])	52.1	78.1	73.7

[1]IVFD = In vitro fiber digestibility, DMI = dry matter intake, FCM = fat-corrected milk, JDS = *Journal of Dairy Science*, and BMR = brown midrib.
* Significant effects of treatment ($P < 0.05$)
[a] Data were not used for the statistical analysis as *P*-value for IVFD was not reported.
[b] Forage NDF (% of dietary DM)

Table 4. Correlation coefficient of 30-hour IVTDMD % of DM with NDF (% of DM), ADF (% of DM), CP (%DM), and 30-hour IVFD (% of NDF). All samples were analyzed for 30-hour IVFD, NDF, ADF, CP, and lignin by wet chemistry during the last two years (Courtesy of Cumberland Valley Analytical Services, Maugansville, MD).

	n	NDF	ADF	CP	30-hour IVFD
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Mixed	632	-0.74	-0.76	0.55	0.92
Mixed mainly grass	501	-0.82	-0.80	0.69	0.96
Grass	93	-0.65	-0.69	0.61	0.96
Corn silage	5338	-0.60	-0.60	0.31	0.82

[1]NTDMD = In vitro true dry matter digestibility, DM = dry matter, NDF = neutral detergent fiber, ADF = acid detergent fiber, CP = crude protien, and IVFD = in vitro fiber digestibility.

Formulation of Rations with Optimal Cations and Anions for Lactation

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Summary and Conclusions

Based on published reports evaluating the effects of dietary cation-anion difference [**DCAD**: meq (K + Na – Cl – S)/100 g of dietary DM] on lactational performance of dairy cows, a value in the range of +25 to +30 meq is effective and sufficient to achieve maximum feed intake and milk yield. Considering all of the results currently available, the magnitude and difference in lactational responses is quite small over the range +20 to +40 meq/100g DM. Less than +20 meq was quite detrimental to lactational performance and greater the +40 meq was not significantly beneficial and was even detrimental at higher DCAD concentrations. Thus, as long as the DCAD is within the +20 to +40 meq range, little (or no) benefit is expected by supplementing additional cation (e.g., Na or K). In large part, published results are from experimentation with dairy cows in mid- to late lactation. There are few reports of experiments with very high yielding and (or) cows in the first trimester of lactation; such studies under these circumstances would be useful.

When reviewing and interpreting published research reports, summaries, or especially advertisements about DCAD and supplementing cations, it is very importance to consider the following: 1) Is the DCAD correctly calculated in the report? This is not always the case? 2) Is the DCAD reported or cited that for the four-element equation **(DCAD4)** which includes Na, K, Cl and S or the three-element equation (DCAD3 such as with Na, K and Cl)? This can make considerable difference (between 13 and 19 meq/100 g of dietary DM for diets with 0.2 to 0.3% S in the four-element compared the three-element equation) in interpretation and setting of the target DCAD in formulation. **3)** What is the actual or predicted feed intake associated with the particular DCAD and concentrations of Na, K, Cl, and S being studied or targeted? Quoted concentrations of DCAD, Na, K, Cl and S as "requirements" are risky in practical application in dairy nutrition without accurate information about feed intake.

To evaluate and implement formulation strategies to achieve a target DCAD several points are important. If the objective is to increase DCAD4, this might be done by reducing Cl and (or) S contributed by specific basal ingredients or supplements. After that consideration, the cations Na and K are equally efficacious to increase DCAD, and similar lactational performance is expected if increased DCAD is targeted and considered beneficial. Assuming that the actual nutritional requirements (grams per day) for Na and K are met already, the fundamental formulation objective to increase DCAD should be to use the cation source that is least cost on a milliequivalent basis. Consideration also should be given to reducing the amount of supplemental cation (K or Na); this is excreted in greater amounts by the cow and must be effectively recycled via crops or other means. Excessive K, Na, Cl, and S in our dairy farming systems are currently potential problems.

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Introduction

The DCAD has been a topic of considerable research in dairy nutrition for the last 2 decades (NRC, 2001). Much of the early work addressed effects of DCAD on periparturient Ca metabolism and metabolic health of transition dairy cows (Block, 1994; NRC, 2001). Over roughly the same period of time, some but less research focused on the effects of DCAD on lactational performance of dairy cows. Physiological influences of DCAD on acid-base homeostasis and mineral utilization are reviewed and discussed elsewhere (Block, 1994).

Definitions

In the earlier research reports with lactating cows, DCAD was often expressed as the three-element equation: milliequivalents (meq): (K + Na – Cl)/100 g of dietary DM. In this paper, this calculation will be referred to as DCAD3, whereas DCAD4 will denote the four-element equation of meq: (K + Na - Cl - S)/100 g of dietary DM. Whenever possible, the DCAD4 is used as cited in the report, or where the DCAD3 was reported, the DCAD4 was calculated by me using the S concentration reported, or in a few cases assuming that S was supplemented to meet the cows' requirements (e.g., 0.2% S in dietary DM which is equal to about 13 meq of S/100 g of dietary DM). To covert dietary mineral element concentrations to meq/100 g of dietary DM the following are used: [(%K divided by 0.039) + (%Na divided by 0.023)] – [(%Cl divided by 0.0355) + (%S divided by 0.016)], dry basis.

The Objectives of this paper are to review the published reports on the effects of DCAD on lactational performance of dairy cows, to consider if there is an optimal DCAD based on published information, and to consider several questions and factors related to DCAD in ration formulation to achieve optimal lactational performance.

Background and Literature Review on DCAD in Lactation

The factorial method, summing the grams of mineral element needed for maintenance, lactation, growth, and pregnancy divided by the absorption coefficient for that particular element was used to estimate the total dietary requirement (grams per day) of K, Na, and Cl (NRC, 2001). The dietary recommendation for S was set at 0.2% of ration DM because insufficient information was available to use the factorial approach. As a point of reference for the remainder of the discussion in this paper and based on current total dietary requirements (grams per day) for K, Na, and Cl for lactating cows with milk yield (**MY**) ranging from 55 to 120 lb/day, the calculated DCAD3 is about +29 meq/100 g of dietary DM; the DCAD4 (including the dietary recommendation for total S) is about +16 meq/100 g. These values are 3 to 4 meq/100 g DM greater than those calculated using NRC (1989) recommendations. There is no dietary requirement of the cow for DCAD *per se* as it is a "concentration expression", just as there are no requirements for percentages of K, Na, and Cl in rations for lactating dairy cows.

DCAD in lactation rations: Research from 1995 and earlier

The NRC (2001) provided a summary of much of the research done prior to 1995, directly addressing aspects of macromineral electrolytes on lactational performance of dairy cows and indirectly the effects of DCAD. The study of Tucker et al. (1988) was the first study (cool season) in which DCAD intentionally was varied to measure lactational and physiological responses. They varied DCAD3 by altering the amounts of either cation (K or Na) and the anion Cl. The DCAD3 treatment values were -10, 0, +10, and +20 meq/100 g of dietary DM. Treatment rations were fed to mid-lactation Holstein cows. Dry matter intake (**DMI**) and MY increased with increasing (more positive)

DCAD3. Dry matter intake and MY of cows fed the ration with +20 meq DCAD3 were greater than that of cows fed -10 meq. The experimental design and diet formulation were such that researchers were able to differentiate among influences that each element (Na, K, or Cl) to vary the DCAD3 might have had on DMI and MY. No differences due to specific elements *per se* were detected. Authors stated that improvement in lactational performance of cows fed rations of greater DCAD3 was independent of the effects of the individual elements used to alter the DCAD3.

In another study (cool season) from the University of Kentucky, Ghorbani et al. (1995) varied the DCAD4 (-11, +18, +55, and +76 meq/100 g of dietary DM; DCAD values are calculated by me from mineral element concentration values in Table 2 of the report; calculated treatment DCAD are different from those in the report). The DCAD treatments were fed in a basal ration (40% corn silage: 60% concentrate, dry basis) to 12 mid-lactation Holstein cows in a replicated 4 X 4 Latin square design. Dry matter intake was lower for cows fed -11 or +18 vs. +55 or +76 meq, 38.1 or 42.5 vs. 44.7 or 44.9 lb/day, respectively. Actual MY (unadjusted for solids content) was lower (51.9 lb/day) for cows fed -11 meq but similar (overall average = 54 lb/day) among cows fed positive DCAD over the range used in the experiment. Yield of 3.5% fat-corrected milk (**FCM**) was lower for the -11 meq treatment compared with treatments with +18, +55, or +76 meq (51.9 vs. 55.4, 57.2, and 59.0 lb/day); FCM yields of cows fed +18 and +55 meq were similar, as were those of cows fed +55 and +76 meq; however, yield was greater for cows fed the ration with +76 compared with those fed +18 meq. Fat content of milk increased as DCAD increased when sodium bicarbonate was added and calcium chloride was removed from the ration formulations. Milk protein content was reduced for cows fed the highest (+76 meq) DCAD compared with that of cows fed the other treatments. Caution should be used in evaluating responses in this experiment because the concentration of Na (0.02%, dry basis) in the -11 meq diet was too low to meet the cows' Na requirement, and the Cl contents (0.06, 0.05, and 0.15%, dry basis) of diets with the three higher DCAD values, respectively, likely did not meet the cows' Cl requirements (NRC, 2001) at the reported feed intake rates.

In another cool season experiment, Delaquis and Block (1995) measured lactational performance and physiological responses of 12 Holstein cows in three stages of lactation. Within early [25 to 50 days in milk (**DIM**)], mid (107 to 137 DIM), and late (162 to 234 DIM) stages of lactation, two DCAD4 treatments (n = 6 cows/treatment/stage) were: +6 vs. +26; +14 vs. +37; and, +20 vs. +38 meq/100 g of dietary DM, respectively. Only DMI, MY, and milk composition responses are addressed here. Daily DMI of cows increased with high vs. low DCAD4 treatments within early-lactation [(35.6 vs. 33.4 lb/day); 3.27 vs. 3.19% of body weight (**BW**); and, mid-lactation (37.4 vs. 34.3 lb/day); 3.25 vs. 3.03% of BW]; values as a percentage of BW were calculated by me from results in the report. In late-lactation, DMI for low and high DCAD4 were not different (37.0 vs. 39.2 lb/day; 2.82 vs. 2.95 % of BW). Milk yield responses were similar to DMI responses with cows on low and high DCAD4 treatments yielding 40.3 vs. 42.9 lb/day in early-lactation, 40.0 vs. 41.6 lb/day in mid-lactation; and no difference was detected in late-lactation (32.8 vs. 33.7 lb/day). Significant, but generally small differences, were noted in milk protein and lactose percentages and yields due to increasing DCAD4 in early and mid-lactation. The DMI and MY responses in early- and mid-lactation to increasing DCAD4 are not surprising. The lowest DCAD in both stages was quite low (+5.5 [early] or +14.0 [mid] meq/100 g) for lactation diets and would be expected to decrease performance based on reports of Tucker et al. (1988) and Sanchez et al. (1994a,b). Although lactational responses to increasing DCAD4 were noted in early- and mid-lactation in this experiment,

overall DMI and MY of cows were atypical of modern Holstein cows. Thus, the stage of lactation data and differences noted in this experiment do not provide much insight as to whether early-lactation cows (most generally presumed to have higher MY and metabolic and nutrient demands) may benefit from higher DCAD4.

Based on a series of lactation performance experiments conducted during the 1980s in Florida with mid-lactation Holstein cows, Sanchez et al. (1994a) conducted regression analysis to evaluate DMI and MY responses to varying DCAD. The database (1022 cow-period treatment means from 326 mid-lactation cows) included results of individual cow-period DMI and MY and milk composition from 10 experiments in which factorial arrangements of treatments included two or more dietary concentrations of mainly K, Na, Cl, Mg, Ca, and P; S was formulated and supplemented (as sulfate-salt) as needed to achieve 0.2% S among all treatments and experiments. Dietary concentrations of the macromineral elements ranged from below to above NRC (1989) recommendations. The DCAD3 over all 10 experiments ranged from +6 to +61 meq/100 g of dietary DM; this computes to a DCAD4 of -7 to +48 meq/100 g.

Figure 1 displays the overall MY (unadjusted for solids-content), 4% FCM yield, and DMI responses of cows over the experimental range of DCAD4. Responses were clearly curvilinear, indicating that some optimal DCAD existed. For both DMI and MY, maximum daily rates were at DCAD4 = +25 meq/100 g of dietary DM. However, magnitude of the differences from lowest to highest responses between +7 and +44 meq of DCAD4 was quite small; about 0.55 lb/day for DMI and MY. Many (if not most) lactation rations for mid-lactation dairy cows fall within this DCAD4 range. However, when DCAD4 ranged from +25 up to +48 meq/100 g of dietary DM, DMI declined about 1.1 lb/cow/day and MY declined over 2 lb/cow/day. When the empirical regression equations describing optimal DCAD for maximal DMI and MY were evaluated against independent data from the literature (Tucker et al., 1988; West et al., 1991; 1992), reasonable agreement was found (Sanchez et al., 1994a). Greatest average MY of cows in this regression analysis was less than 51 lb/cow/day and maximum DMI was just over 48 lb/cow/day. Therefore, it is not known if these results are applicable to higher yielding and(or) earlier lactation cows. Additionally, because of the desired dietary treatment concentrations of K, Na, and Cl in the original experiments, the distribution of much of the data is well above the former NRC (1989) or current NRC (2001) recommended concentrations of these macromineral elements to meet requirements. Thus, relatively high DCAD values are associated with much of the data. How these regression responses would compare with a dataset in which the preponderance of data more closely bracketed DCAD concentrations approximating recommended NRC (2001) concentrations for K, Na, Cl, and S is not known.

Similar evaluations with sufficient data to model optimal DCAD on lactational performance of early-lactation and high yielding dairy cows has not been reported. Also, the question of whether or not it makes any difference whether K or Na is used to increase DCAD has not been answered adequately for cows at any stage of lactation. The studies of Tucker et al. (1988) and West et al. (1991) indicate that increasing either K or Na concentration (typically by adding a bicarbonate or carbonate salt of Na or K), either of which changes DCAD, resulted in similar lactational responses.

During heat stress conditions

Esbanosa et al. (1984) found that increasing the DCAD3 from -14 to +35 meq during Texas heat stress increased feed intake and MY. Of course, it is now known that feeding negative DCAD compared with positive DCAD is deleterious for

lactating cows, regardless of the climatic conditions. Subsequently, West et al. (1991) reported similar improvements in DMI and MY, when different amounts of either K or Na were used to achieve the same DCAD3 (West et al., 1992).

Sanchez et al. (1994b) conducted additional regression analysis using the large dataset described previously. Specifically, the optimal DCAD was evaluated at which maximal DMI and 4% FCM yield were achieved during warm and cool seasons. Results of these regression analyses are in Figure 2. For both DMI and 4% FCM yield, optimal DCAD4 was about +22 meq for the warm season and about +30 meq/100 g of dietary DM for the cool season. Over the range of DCAD values in the dataset, DMI and 4% FCM yield were 10 to 17% less in warm weather than cool weather.

DCAD in Lactation Rations: Research after 1995

Roche and coworkers working in Australia and New Zealand studied the DCAD of rations for late pregnant nonlactating (Roche et al., 2003c; 2002) and lactating dairy cows (Roche et al., 2003a,b) in pasture-based systems. In their first lactation experiment, early-lactation cows were fed individually a ration typical for early-lactation in southeastern Australia of 11 lb of dry rolled barley plus ad libitum pasture forage (cut-and-carry for the experiment). The DCAD4 was varied by drenching individual cows twice daily after milking with appropriate amounts of magnesium sulfate, magnesium chloride, and(or) sodium bicarbonate (Roche et al., 2003b). The final DCAD concentrations of the experimental treatments were +21, +52, +102, and +127 meq/100 g of total dietary DM, with five cows receiving each treatment. As DCAD increased from +21 meq, DMI declined (tendency: $P < 0.1$), average daily body weight gain, and milk protein production declined; however, concentrations of milk fat, protein, and lactose were unaffected by varying DCAD. There was a non-significant trend (55.9, 54.1, 54.3, 51.0 lb/cow/day) for reduction in MY as DCAD4 increased from +21, +52, +102, and +127 meq, respectively. Milk protein yield declined nearly 20% as DCAD4 increased from +21 to +127 meq/100 g of dietary DM.

In their most recent experiment, Roche et al. (2003a) evaluated lactational performance of early-lactation cows in a pasture-based system. In New Zealand, the DCAD of the ration may range from 0 to +100 meq/100 g DM depending on the particular pasture and fertilization scheme. However, the effects of different DCAD concentrations on lactational performance and acid-base status were not adequately characterized. Holstein-Friesian cows (n = 36) were grazed together and forage intake was estimated for individual cows. Average basal concentrations of K, Na, Cl, S (% of DM), and DCAD4 were 3.74, 0.30, 1.10, 0.36, and +55 meq/100 g DM during the 5-week study. One of four experimental treatments was delivered twice daily by drenching individual cows randomly assigned to receive supplements containing varying amounts of sodium bicarbonate, and magnesium and calcium chlorides to alter DCAD4. The actual final DCAD4 treatments (from pasture intake plus drench) were +23, +45, +70, and +88 meq/100 g DM; these values, based on re-calculation, are different than those listed in the abstract (personal communication with J. R. Roche, 2003). Dry matter pasture intake (overall average = 37.4 lb/cow/day), yield of milk (overall average = 57.1 lb/cow/day), yield and concentrations of milk protein and lactose, BW gain, and body condition score (**BCS**) change were all not affected by increasing DCAD4. There were small significant linear increases in milk fat percentage (3.96 to 4.22%) and fat yield (10% increase overall) with increasing DCAD. Systemic acid-base status was affected as reflected by increases in blood pH, bicarbonate, base excess, and urine pH as DCAD increased. The authors concluded that overall lactational performance of early-lactation cows was not affected over this wide

range of DCAD4 in this pasture-based system. There certainly was no suggestion that increasing DCAD4 above +23 meq/100 g DM was beneficial to overall lactational performance, except for the slight rise in milk fat percentage and yield with increasing DCAD4.

Sanchez et al. (2002) reported in an abstract some results of five field trials (each in a separate herd) conducted by splitting the high herd cows into two groups (n/treatment group = 85 to 145) in four commercial dairy farms and one university herd. Trials were conducted in non-heat stress conditions. In each dairy, two different DCAD4 were fed to each group with one DCAD treatment as Control and the other some higher DCAD (Treatment) resulting from removal of Cl (in one trial), addition of K (in three trials), or addition of K and Na (in one trial). The magnitude of increase in DCAD between Control and Treatment for the five trials was +6, +8, +5, +10, and +6 meq/100 g of dietary DM. Because these were field trials, cows were group-fed so information is not available about DMI for statistical analysis. The actual MY or FCM yields were not reported (e.g., the high group average pre-trial or treatment averages after application of Control and Treatment); however, the magnitude of difference between DCAD treatments within each farm was listed in the abstract. In two of the five trials, there was an increase in actual MY (unadjusted for solids content) with increasing DCAD; in these two trials, the Control DCAD was 18 or 19 meq and it was increased to 25 or 26 meq/100 g DM, respectively. In three trials, no response in MY to increasing DCAD was detected; in these cases, the Control DCAD was 38, 25 and 33 meq/100 g DM before being raised to a higher value with K and(or) Na supplementation. In one of the five trials, fat yield was increased (0.4 lb/cow/day) by increasing DCAD from 25 to 35 meq/100g DM (milk fat% was not reported in the abstract). Fat-corrected MY also was increased by 5.6 lb/cow/day in this trial in which DCAD was increased by supplementing some combination of K and Na salts; unadjusted MY actually was 2 lb/cow/day less with the higher DCAD Treatment in this trial. In the two other trials, FCM yield was increased by 3.0 (by reducing dietary Cl) or 3.3 (by adding K) lb/cow/day by increasing DCAD. In the other two of the five trials, unadjusted MY, fat, and FCM yields were not affected by increasing the DCAD from 38 to 43 meq or 33 to 39 meq/100 g dietary DM; K (5 of DM) was increased from 1.52 to 1.80% in one trial and from 1.50 to 1.70% in the other trial.

In summary, the five trials reported by Sanchez et al. (2003) suggest that: 1) increasing DCAD by removing Cl, or adding Na or(and) K, was efficacious especially in situations when the Control DCAD was in the range of 18 to 25 meq/100 g DM (low end of the range of these five trials); and 2) lactational responses were not detected with supplementing additional cations when the Control DCAD was greater than 25 meq/100 g of dietary DM.

Recently, Hu and Murphy (2004) presented a meta-analysis of 12 studies from published research reports involving 17 trials in which DCAD was varied in rations for lactating dairy cows. Depending on the variable evaluated, data from between 35 and 54 dietary treatments were evaluated by regression analysis using mixed model statistical procedures. Average MY for the entire data set was 51 lb/cow/day and ranged from 33 to 79 lb/cow/day. The majority of data were from mid-lactation dairy cows. The overall average DCAD3 (as reported) was +26 and ranged from -19 to +64 meq/100 g of dietary DM. The average dietary S concentration among all diets was 0.33% and ranged from 0.11 to 0.91%, dry basis; but, it is not possible from the report to relate specific S concentrations with specific DCAD reported by the authors. Therefore, to provide a DCAD4 for comparison, a S concentration of 0.2% or the NRC (2001) recommendation was assumed when referencing a DCAD4.

For the entire dataset, DMI was maximal when DCAD4 was +28 meq/100 g of dietary DM. Highest MY (unadjusted for solids content) by regression analysis was found when DCAD4 equaled +22 meq, whereas 4% FCM yield was greatest at +37 meq. The magnitude of the difference in 4% FCM yield determined by regression analysis between DCAD4 of +25 and +60 meq was quite small, about 1.5 lb/cow/day over the entire range. Interestingly, because DCAD is considered a major factor affecting systemic acid-base status, Hu and Murphy (2004) evaluated the relationship between DCAD and blood pH. Normal physiologic blood pH is tightly controlled in the range of 7.38 to 7.42. Based on their regression analysis, cows fed DCAD4 from +7 to +27 meq/100 g of dietary DM had blood pH within that normal range.

The results of the work of Hu and Murphy (2004) using a different database (all different experiments) compared with that of Sanchez et al. (1994a) and provide similar conclusions about the DCAD4 for overall optimum lactational performance of mid-lactation dairy cows. The one exception being at somewhat higher DCAD for maximal FCM yield in the Hu and Murphy (2004) analysis compared with the analysis of Sanchez et al. (1994a).

During heat stress conditions

Researchers in Georgia continued to evaluate the possible effects of DCAD on lactational performance during warm weather (Wildman et al., 2002, 2003, 2004; West, 2003). In one study, mid-lactation (188 DIM) cows were fed rations for 80 days with DCAD4 of 30 vs. 45 meq/100 g dietary DM, factored with varying dietary ratios of K-to-Na of 2-to-1, 3.5-to-1, or 5-to-1. No main effects or interactions among DCAD or K-to-Na ratios on DMI, energy-corrected MY, or milk fat or protein percentages were detected. Based on blood and urine measurements taken during the study, authors suggested that sufficient blood buffering capacity existed, even with the lower DCAD4 (+30 meq) dietary treatment because additional cation and bicarbonate were excreted in urine.

In another Georgia study, late-lactation cows (225 DIM) were used in a 6-week study during hot weather with a 2 x 2 factorial arrangement of DCAD3 (+25 vs. +50 meq/100 g dietary DM) and dietary crude protein (**CP**) concentrations (15 vs. 17%, dry basis). There was a tendency for a DCAD3 X CP interaction for MY, with +50 meq DCAD resulting in lower MY (61.2 lb/cow/day) than +25 meq (69.8 lb/cow/day) with 17% CP ($P < 0.09$), but this difference was not detected with 15% CP. No differences between treatments were observed for DMI or milk protein percentage; milk fat percentage increased with greater DCAD3 and by higher CP percentage.

Following on previous work, Wildman et al. (2004) reported an additional study in which the DCAD3 was +25 or +50 meq/100 g of dietary DM. Eight mid-lactation Holstein cows (180 DIM) were used in a replicated 4 x 4 Latin square in late summer and fall. The DCAD treatment was factored with treatments of 33 vs. 42% rumen undegradable protein (**RUP**; as a percentage of CP). There was no main effect of DCAD3 on DMI or FCM yield. However, there was an interaction of DCAD3 with RUP content in that cows had greater DMI and FCM yield at higher compared with lower RUP when fed higher DCAD3 (+50 meq). However, there were no benefits to increasing RUP within treatments for +25 meq DCAD3.

K, Na, Cl, and S Concentrations and DCAD of Selected Feeds

A fairly common comment from the field nowadays is that the K percentage of many forages is quite high and also that the Cl percentage is oftentimes higher than previously assumed based on "book" values. It also has been suggested that

the concentrations of Cl have increased appreciably compared with previous values. Certainly, it has become more common to analyze Cl content of feeds since increased attention is paid to DCAD in ration formulation. Table 15-3 of the NRC (2001) provides mineral element composition from recent laboratory analyses with estimates of variability within feed.

Fertilization using KCl (potash) on grass (including corn for silage) and legume fields for mechanically harvested hay and haylage and for pasture is common to stimulate plant growth and to increase stand longevity in cold climates. There also is the idea that perhaps the concentrations of K and Cl in forages are correlated.

To examine and hopefully better understand the profiles of the macromineral elements of the DCAD equation, we requested and were provided feed analysis data from four commercial feed testing laboratories in the U.S. The total original database (called New database henceforth) included 95,490 individual feed samples with complete or partial analyses. For this report, partial chemical analyses of 12 forages and 5 concentrate feeds commonly used in dairy rations are presented for comparison and evaluation (Table 1). Presented are comparable macromineral, fiber component, and CP analyses [mean, N = number of analyses in mean, and standard deviation (±SD)] as determined from the New database and reported in NRC (2001), where available comparable data from NRC (1989; 1978) also are listed.

Several general observations can be made from the information in Table 1. Even with large numbers of forage sample analyses (e.g., from about 1,000 to over 30,000) for each feed, there still are appreciable differences in mean concentrations of some elements among the New database amd NRC (1978; 1989; 2001). This fact accentuates the need for nutrient analyses of the specific individual forages being used in each dairy farm. Without chemical analyses of the forages unique to the farm, there would not seem to be much reason or benefit to trying to achieve a specific targeted "optimal" DCAD in formulation. One easily could be off by 10 to 20 meq/100 g, or more, for the total diet if using book values versus actual analyses. In general, as one would expect, the DCAD is appreciably more positive for the forages listed than the concentrate feeds (Table 1).

In comparison to values for NRC (2001), overall many of the Na values for forages in the New database are higher. The reason for this is not known. The K, Na, Cl, S, and DCAD concentrations for corn silage were quite similar among sources of analyses. However, the concentrations of Cl in the NRC (2001) for legume (alfalfa) hay and grass hay are quite a lot higher than found in the New database. Other major differences in mineral element concentrations exist among the different sources of analytical information. This again, emphasizes the need for actual laboratory analyses if DCAD is an important consideration in ration formulation. To obtain accurate information about mineral element concentrations, analyses must be done by wet-chemistry analysis and not by near infrared reflectance spectroscopy (**NIRS**) (Shenk and Westerhaus, 1994).

Another evaluation of interest with respect to the DCAD of feeds is to better understand what macromineral elements/values in the DCAD equation have the most influence on the calculated DCAD for specific feeds in the New database. Table 2 presents the proportion of the total variation in calculated DCAD value that is associated with each macromineral element in the equation for each feed. For example, based on the evaluation of data in the New database for oatlage, K is responsible for 49% of the variation of the calculated DCAD value, whereas Na and Cl have smaller (27 and 22%, respectively) influences; the influence of S is quite small. In contrast for oat hay, K has relatively minor

influence (17%), whereas Na and Cl have appreciable and greater influences on the calculated DCAD. Overall, S does not account for much of the variation in calculated DCAD except for wet brewers grains. This information may be useful in crop fertilization and ration formulation to assist in targeting certain feeds for certain management groups and classes of cows if consideration of or targeting for a particular DCAD is an objective. The values listed in Table 2 ARE NOT coefficients to be placed in front of each element in the DCAD equation.

Ration Formulation and DCAD: Questions and Considerations

Is there an optimal DCAD for rations of lactating dairy cows?

As a point of reference, the DCAD4 resulting from formulating rations to meet NRC (2001) requirements for K, Na, Cl and S is about +16 meq/100 g dietary DM. Based on available published research reports from 1984 through 2004 and meta-analyses (Sanchez et al., 1994a,b; Hu and Murphy, 2004) evaluating a number of lactational performance and physiological variables, the optimal DCAD for lactation rations is in the range of +25 to +30 meq/100 g of dietary DM. The one exception is that FCM yield was maximum at +37meq/100 g in the meta-analysis of Hu and Murphy (2004). Though, showing relatively small differences, DMI and MY responded in a curvilinear fashion with the gradual decline beginning when DCAD4 exceeded about +30 meq/100 g of dietary DM (Figures 1 and 2). This may be a palatability issue (versus metabolic issue) associated with the supplemental salts in these totally mixed rations. A similar depression in DMI was not noted when salts were drenched to elevate DCAD beyond +23 meq/100 g DM (Roche et al., 2003).

This entire body of information on the effects of DCAD on lactational performance and a clear definition of an optimal DCAD(s) suffers from lack of adequate research with high yielding cows. Nearly all of the experiments were done with mid- to late-lactation cows. Few research results are reported comparing different DCAD with truly high producing and/(or) early-lactation dairy cows. Doubtless, this is the physiological state where one could most justify the hypothesis that higher DCAD might be efficacious to support homeostasis in the face of higher metabolic acid production associated with elevated lactation.

Can DCAD be too high or too low?

A number of experiments cited in this paper in which a relatively wide range in DCAD was studied demonstrated that DCAD can be too high or too low. Based on the entire body of information, it seems certain that DCAD4 of greater than +40 meq or less than +20 meq/100 g of dietary DM should be of concern. The DCAD4 of rations based on NRC (2001) nutrient requirements (about +16 meq/100 g DM) could benefit from small additions of cation sources, such as feed-grade sodium bicarbonate or potassium carbonate. As DCAD4 approached zero or negative values among reported studies, lactational performance was affected deleteriously.

To increase DCAD, is Na or K the better choice?

The practical choices to increase DCAD are sodium bicarbonate or potassium carbonate. Sodium carbonate and potassium bicarbonate also have been evaluated sparingly in experiments, and in general, did not appear sufficiently efficacious or are considered too expensive for feeding to dairy cows. There is no clear-cut evidence in the published reports to support that sodium bicarbonate is superior to potassium carbonate to increase DCAD and lactational performance of dairy cows, or visa versa. Most typically in dairy rations in the U.S., Na is more likely to be marginally deficient

compared with K, which may indicate its consideration as first selection in formulation to increase DCAD. Doubtless, to increase DCAD, the fundamental formulation question boils down to which cation source is the *best buy (best value) on a milliequivalent basis, not on a weight basis,* and secondly, which element (Na or K) is most likely to be (marginally) deficient for lactating cows and result in less excretion which can not be captured and recycled effectively via crops or other means.

Is optimal DCAD different in cool vs. hot weather?

Based on the available published reports from Florida and Georgia (Sanchez et al., 1994b; Wildman et al. 2002, 2003, 2004), there is no convincing evidence that DCAD should be increased during heat-stress conditions compared with non-heat stress. Overall, optimal lactational performance during hot weather occurred within the range of +25 to +30 meq/100 g of dietary DM.

Does rate (level) of MY affect the optimal DCAD for lactation?

The highest average MY of any treatment in the reports reviewed was 69 lb/cow/day. Therefore, this question has not been adequately addressed by controlled research. Additional information would be useful. In a study by Mooney and Allen (2002), 40 higher yielding Holstein cows (average MY during the experiment = 85 lb/cow/day) were fed dietary treatments supplemented with sodium bicarbonate, sodium chloride, potassium bicarbonate, or potassium chloride. There were no differences in feed intake or MY among cows fed any of the dietary treatments.

Keys to Practical Ration Formulation

1. Analyze the K, Na, Cl, and S contents of all feed ingredients used in ration formulation by wet-chemistry analysis to insure accuracy. The contents of these elements are variable within feed type, especially for forages within and among farms, and are heavily influenced by fertilization practices and other agronomic and weather-related factors.

2. In ration formulation, the first step should be to meet the requirements for K, Na, Cl (grams per day) and S (percentage) (NRC, 2001).

3. Next, check the DCAD4 of the resulting formulation. If it falls between +25 and +30 meq/100 g dietary DM, the DCAD is within the optimal range based on published reports. Additionally, if the DCAD4 is within +16 to +40 meq, quite small (negligible) differences in DMI or MY would be expected.

4. If the DCAD4 is considered too low and needs to be increased, the primary driver of how much cation must be added to achieve a particular "DCAD target" is largely influenced by basal diet Cl concentration, and to a lesser extent S concentration. Many common feeds may have relatively high Cl concentrations (Table 1). It is important to note that 0.1 percentage units of S in the diet has about twice the impact to affect the DCAD value as does 0.1 percentage units of Cl. However, common basal feed ingredients typically contain considerably more Cl than S.

5. If the basal DCAD4 is low, the first formulation strategy to increase DCAD might be to remove some Cl or S (i.e., high Cl-containing or high S-containing supplements or feeds).

6. Once anion removal is accomplished as much as practically possible, the DCAD4 of the basal ration can be increased by supplementation with feed grade sodium bicarbonate or potassium carbonate. There is no published research conclusively

indicating that one cation is superior to the other to increase DCAD for lactating dairy cows. That is, a milliequivalent of K or Na is essentially equal to adjust DCAD, assuming that the nutrient requirement (grams per cow per day) of each element has been met. Therefore, the one selected to increase DCAD should be the source that provides a milliequivalent of cation at the least cost.

7. Finally, there are no "requirements" for concentrations of Na, K, Cl, or DCAD. It is important to remember that high producing cows typically consume more feed than lower producing or later lactation cows. Therefore, even fed the same DCAD, higher producing cows consume more equivalents of cations (Na and K) to help maintain homeostasis.

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Table 1. Macromineral element concentrations, dietary cation-anion difference (DCAD), fiber components and crude protein concentrations of selected feeds: comparison of composition from New feed database, NRC (2001), NRC (1989), and NRC (1978), dry basis.[a]

Feedstuff	%K N ±SD	%Na N ±SD	%Cl N ±SD	%S N ±SD	DCAD[b] N ±SD	%Ca N ±SD	%P N ±SD	%Mg N ±SD	%ADF N SD	%NDF N ±SD	%CP N ±SD
Forages											
Corn silage:											
New database	1.09	0.04	0.27	0.11	13.9	0.26	0.23	0.18	25.59	43.22	8.67
	30207	9701	8917	14958	3972	31214	31030	30812	30746	20151	30848
	0.24	0.06	0.12	0.02	6.16	0.07	0.03	0.04	3.35	5.00	8.67
NRC 2001	1.20	0.01	0.29	0.14	14.21	0.28	0.26	0.17	28.1	45.0	8.8
	1033	6991	468	27		1033	1033	1033	1033	1033	1033
	0.30	0.01	0.10	0.02		0.10	0.04	0.04	3.3	5.3	1.2
NRC 1989	0.96	0.01	-	0.15		0.23	0.22	0.19	28.0	51.0	8.1
NRC 1978	1.05	0.01	-	0.08		0.27	0.20	0.28	31.0		8.0
Legume (alfalfa) hay:											
New database	2.40	0.14	0.59	0.28	28.5	1.47	0.28	0.30	30.55	39.24	21.15
	11243	6407	4625	6236	3047	11857	12137	11985	11813	8246	11772
	0.58	0.47	0.30	0.06	14.71	0.29	0.05	0.07	3.77	5.52	2.46
NRC 2001	2.53	0.01	0.74	0.25	28.7	1.52	0.26	0.30	31.2	39.6	20.2
	11212	4242	565	4250		11212	11272	11212	12195	12178	12218
	0.49	0.12	0.39	0.05		0.27	0.05	0.06	4.6	6.3	2.6
NRC 1989	2.52	0.14	0.38	0.28	42.4	1.41	0.22	0.33	31.0	42.0	18.0
NRC 1978	2.08	0.15	0.38	0.30	30.3	1.25	0.23	0.30	38.0		17.2
Legume (alfalfa) haylage:											
New database	2.71	0.19	0.64	0.26	33.4	1.33	0.33	0.29	34.59	42.67	21.09
	12230	5785	3243	4424	2075	12618	12796	12802	12546	6936	12539
	0.58	0.45	0.28	0.05	13.86	0.27	0.05	0.06	4.08	5.15	2.41
NRC 2001	2.87	0.06	0.62	0.24	43.6	1.34	0.32	0.27	37.0	45.7	20.0
	8479	2729	374	3255		8479	8479	8479	8562	8567	8576
	0.59	00.09	0.33	0.04		0.26	0.06	0.05	4.8	6.5	3.0

Table 1. (Con't.)

Feedstuff	%K N ±SD	%Na N ±SD	%Cl N ±SD	%S N ±SD	DCAD[b] N ±SD	%Ca N ±SD	%P N ±SD	%Mg N ±SD	%ADF N SD	%NDF N ±SD	%CP N ±SD
Forages											
Grass hay:											
New database	1.87	0.17	0.54	0.18	21.8	0.51	0.24	0.21	38.76	61.51	11.16
	3516	2026	1091	1976	694	3735	3777	3787	3725	2631	3727
	0.58	0.40	0.26	0.06	13.38	0.19	0.07	0.07	3.98	6.36	3.20
NRC 2001	2.83	0.03	0.74	0.28	35.3	1.01	0.31	0.26	31.5	49.6	18.4
	21					21	21	21	21	21	21
	0.65					0.32	0.06	0.08	2.0	1.8	3.1
Grass haylage:											
New database	2.45	0.21	0.66	0.24	34.8	0.55	0.32	0.23	35.64	51.87	14.73
	784	591	552	547	440	837	853	851	830	587	825
	0.69	0.46	0.32	0.07	16.78	0.20	0.07	0.06	4.75	7.47	3.33
NRC 2001	2.64	0.01	0.45	0.25	39.66	0.89	0.36	0.26	35.7	54.4	17.6
	95		2	3		95	95	95	95	95	95
	0.73			0.02		0.26	0.06	0.07	1.9	1.6	3.0
Barlage:											
New database	1.33	0.66	0.82	0.20	23.5	0.42	0.30	0.18	32.77	47.03	13.22
	1785	1464	1248	1300	1162	1802	1784	1777	1770	1406	1786
	0.94	0.72	0.31	0.04	16.48	0.12	0.06	0.04	4.49	5.95	2.41
NRC 2001	2.43	0.13	0.72	0.17	36.9	0.48	0.30	0.18	34.5	56.3	12.0
	420	214	11	97		525	525	420	528	387	528
	0.78	0.23	0.54	0.04		0.19	0.06	0.05	4.9	7.0	2.6
Oat hay:											
New database	1.91	0.56	0.89	0.19	31.8	0.37	0.25	0.18	35.72	55.07	10.78
	313	244	225	210	170	314	320	315	275	166	280
	0.89	0.62	0.55	0.05	20.36	0.14	0.06	0.05	3.57	4.91	2.67
NRC 2001	2.01	0.33	1.08	0.14	26.6	0.37	0.22	0.17	36.4	58.0	9.1
	403	403	51	180		403	403	403	419	419	422
	0.71	0.28	0.51	0.06		0.22	0.07	0.06	4.5	6.3	2.9

Table 1. (Con'td.)

Feedstuff	%K N ±SD	%Na N ±SD	%Cl N ±SD	%S N ±SD	DCAD[b] N ±SD	%Ca N ±SD	%P N ±SD	%Mg N ±SD	%ADF N SD	%NDF N ±SD	%CP N ±SD
Oatlage:											
New database	2.58	0.66	0.81	0.21	36.8	0.49	0.32	0.21	38.21	56.03	13.50
	506	355	256	338	221	506	522	511	502	388	533
	1.01	0.94	0.40	0.05	21.44	0.16	0.07	0.05	4.14	5.89	3.00
NRC 2001	2.89	0.24	1.34	0.19	34.7	0.52	0.31	0.20	38.9	60.6	12.9
	615	207	28	194		615	615	615	631	632	634
	0.77	0.30	0.91	0.05		0.21	0.07	0.05	4.2	5.7	1.6
Triticale silage:											
New database	3.05	0.12	0.94	0.21	36.6	0.49	0.35	0.18	36.45	55.71	14.48
	203	116	76	93	52	210	207	211	213	147	211
	0.91	0.22	0.56	0.05	20.53	0.21	0.07	0.05	4.85	6.77	3.61
NRC 2001	3.01	0.05		0.21		0.57	0.33	0.19	39.6	59.7	13.8
	107	40		25		107	107	107	107	107	107
	0.88	0.08		0.06		0.30	0.07	0.06	5.7	8.3	4.0
Wheatlage:											
New database	2.33	0.13	0.68	0.19	29.9	0.39	0.30	0.16	36.91	55.74	13.07
	937	475	189	257	141	926	939	947	935	501	948
	0.72	0.23	0.36	0.04	16.85	0.14	0.07	0.04	4.10	5.86	2.88
NRC 2001	2.28	0.07	0.83	0.17	27.34	0.38	0.29	0.16	37.6	59.9	12.0
	459	249	36	179		223	459	459	470	471	471
	0.69	0.13	0.49	0.05		0.16	0.08	0.05	4.9	7.4	3.0
NRC 1989	1.39	0.07	0.07	0.24	21.7	0.27	0.27	0.62	--	--	11.9
NRC 1978	1.39	0.07	0.07	0.24	21.7	0.27	0.27	0.62	--	--	11.9

Table 1. (Con'td.)

Feedstuff	%K N ±SD	%Na N ±SD	%Cl N ±SD	%S N ±SD	DCAD[b] N ±SD	%Ca N ±SD	%P N ±SD	%Mg N ±SD	%ADF N SD	%NDF N ±SD	%CP N ±SD
Sorghum silage:											
New database	1.57	0.08	0.58	0.13	22.2	0.44	0.21	0.26	35.55	54.86	8.07
	771	263	136	240	97	796	779	777	817	622	718
	0.54	0.13	0.30	0.04	12.10	0.17	0.05	0.07	5.92	8.42	1.55
NRC 2001	2.57	0.03	0.56	0.15	41.9	0.64	0.24	0.31	40.7	63.3	10.8
	131	63	5	53		131	131	131	139	139	140
	0.97	0.05	0.22	0.05		0.41	0.07	0.08	5.1	7.2	3.2
NRC 1989	2.25	0.02	--	0.06		0.46	0.21	0.44	42.0	68.0	10.8
NRC 1978	2.56	0.02	--	0.06		0.48	0.19	0.49			11.1
Ryelage:											
New database	3.15	0.04	0.87	0.25	42.0	0.45	0.43	0.18	34.48	54.50	17.06
	1265	629	172	185	113	1270	1275	1294	1258	498	1264
	0.65	0.04	0.38	0.06	17.46	0.13	0.09	0.04	4.39	5.08	3.23
NRC 2001	3.34	0.05	0.90	0.20	49.7	0.43	0.42	0.16	34.9	57.8	16.1
	1155	563	24	240		1155	1155	1155	1173	1174	1175
	0.66	0.08	0.51	0.05		0.16	0.08	0.10	4.9	6.3	3.1
Concentrates											
Barley:											
New database	0.46	0.14	0.16	0.14	5.4	0.08	0.40	0.15	6.79	17.91	13.35
	131	115	76	110	72	130	130	130	176	179	179
	0.23	0.21	0.05	0.02	4.61	0.03	0.06	0.02	1.62	3.04	1.60
NRC 2001	0.56	0.02	0.13	0.12	4.0	0.06	0.39	0.14	7.20	20.8	12.4
	287	229	31	139		319	321	287	727	331	795
	0.12	0.02	0.07	0.01		0.02	0.06	0.02	2.8	8.6	2.1
NRC 1989	0.47	0.03	0.18	0.17	-2.4	0.05	0.38	0.15	7.0	19.0	13.5
NRC 1978	0.45	0.03	0.20	0.18	-4.1	0.05	0.37	0.15	7.0		13.9

Table 1. (Con'td.)

Feedstuff	%K N ±SD	%Na N ±SD	%Cl N ±SD	%S N ±SD	DCAD[b] N ±SD	%Ca N ±SD	%P N ±SD	%Mg N ±SD	%ADF N SD	%NDF N ±SD	%CP N ±SD
High moisture ear corn:											
New database	0.47	0.01	0.13	0.10	2.5	0.05	0.28	0.12	9.32	19.61	8.73
	931	166	29	245	20	976	1187	1176	1150	543	1157
	0.07	0.01	0.04	0.01	2.26	0.03	0.04	0.02	2.52	4.48	0.82
NRC 2001	0.48	0.01	0.07	0.09	5.1	0.05	0.28	0.12	9.4	21.0	8.4
	2608	470	54	907		2608	2608	2608	2673	2675	2684
	0.07	0.03	0.03	0.01		0.03	0.03	0.01	3.7	6.9	1.0
NRC 1989	0.53	0.02	0.05	0.16	3.0	0.07	0.27	0.14	7	28	9.0
NRC 1978	0.56	0.05		0.22		0.05	0.26	0.17			9.3
High moisture shelled corn:											
New database	0.41	0.02	0.09	0.10	2.6	0.03	0.32	0.12	3.89	10.10	9.50
	3366	533	183	1726	88	3430	4461	4493	3409	2447	4494
	0.05	0.04	0.06	0.01	2.29	0.03	0.04	0.01	1.22	1.60	0.86
NRC 2001	0.43	0.01	0.05	0.10	3.8	0.03	0.30	0.12	3.6	10.3	9.2
	4633	439	107	1317		4633	4633	4633	4728	4729	4761
	0.06	0.01	0.01	0.01		0.03	0.03	0.03	1.6	2.7	0.9
NRC 1989	0.35	0.01	0.05	0.14	-0.8	0.02	0.32	0.14	3.0	9.0	10.0
NRC 1978	0.35	0.01	0.05	1.14	-0.8	0.03	0.31	0.13	3.0		10.0
Soybean meal:											
New database	2.21	0.02	0.08	0.41	31.7	0.38	0.75	0.32	7.94	12.07	51.96
	211	286	58	298	423	417	411	411	346	317	932
	0.19	0.02	0.07	0.03	5.38	0.08	0.06	0.02	2.33	3.38	2.84
NRC 2001	2.41	0.03	0.13	0.39	35.0	0.35	0.70	0.29	6.2	9.8	53.8
	246	237	96	142		256	256	243	248	248	549
	0.25	0.25	0.65	0.05		0.10	0.08	0.03	10.0		49.9
NRC 1989	1.98	0.03	0.08	0.37	26.6	0.30	0.68	0.30	10.0		49.9
NRC 1978	2.21	0.31	0.03	0.49	38.6	0.36	0.75	0.30	10.0		49.6

Table 1. (Con'td.)

Feedstuff	%K N ±SD	%Na N ±SD	%Cl N ±SD	%S N ±SD	DCAD[b] N ±SD	%Ca N ±SD	%P N ±SD	%Mg N ±SD	%ADF N SD	%NDF N ±SD	%CP N ±SD
Wet brewers grains:											
New database	0.13	0.03	0.07	0.35	-21.8	0.99	0.64	0.22	22.76	47.25	30.97
	381	259	90	185	76	5	380	397	416	290	471
	0.10	0.05	0.07	0.07	4.37	0.26	0.10	0.05	2.55	5.30	4.68
NRC 2001	0.47	0.01	0.12	0.33	-11.5	0.35	0.59	0.21	23.1	47.1	28.4
	427	13	1	190		427	427	427	686	685	1127
	0.26	0.01		0.06		0.22	0.10	0.26	3.8	6.8	4.0
NRC 1989	0.09	0.23	0.17	0.32	-12.5	0.33	0.55	0.16	23.0	42.0	25.4
NRC 1978	0.09	0.28	0.13	0.34	-10.4	0.29	0.54	0.15	23.0		26.0

[a]If data were not available from NRC (1989; 1978) rows were not included for that feed in the table. ADF = acid detergent fiber, NDF = neutral detergent fiber, CP = crude protein, N = number of samples, and SD = standard deviation.

[b]DCAD = meq: (K + Na - Cl - S)/100 g of DM.

Table 2. Proportion (%) of total variation (R^2) of calculated dietary cation-anion difference **(DCAD)** associated with each variable (cation or anion) in the DCAD equation for various feeds in the database[a].

Feedstuff	K	Na	Cl	S
	- - - - - - - - - - R^2 - - - - - - - - - -			
Forages				
Corn silage	59	20	18	2
Legume (alfalfa) hay	56	10	25	8
Legume (alfalfa) haylage	61	4	31	4
Grass hay	52	19	22	7
Grass haylage	67	4	25	4
Barlage	22	54	22	2
Oat hay	17	38	44	1
Oatlage	49	27	22	2
Triticale silage	53	5	41	1
Wheatlage	68	12	19	1
Sorghum silage	58	4	36	2
Ryelage	61	2	34	3
Concentrates				
Barley	14	71	8	6
High moisture ear corn	68	3	17	12
High moisture shelled corn	59	11	16	14
Soybean meal	70	2	16	12
Wet brewers grains	22	4	11	63

[a]DCAD = meq(K + Na – Cl –S)/100 g of dietary DM. The values listed in Table 2 ARE NOT coefficients to be placed in front of each element in the DCAD equation.

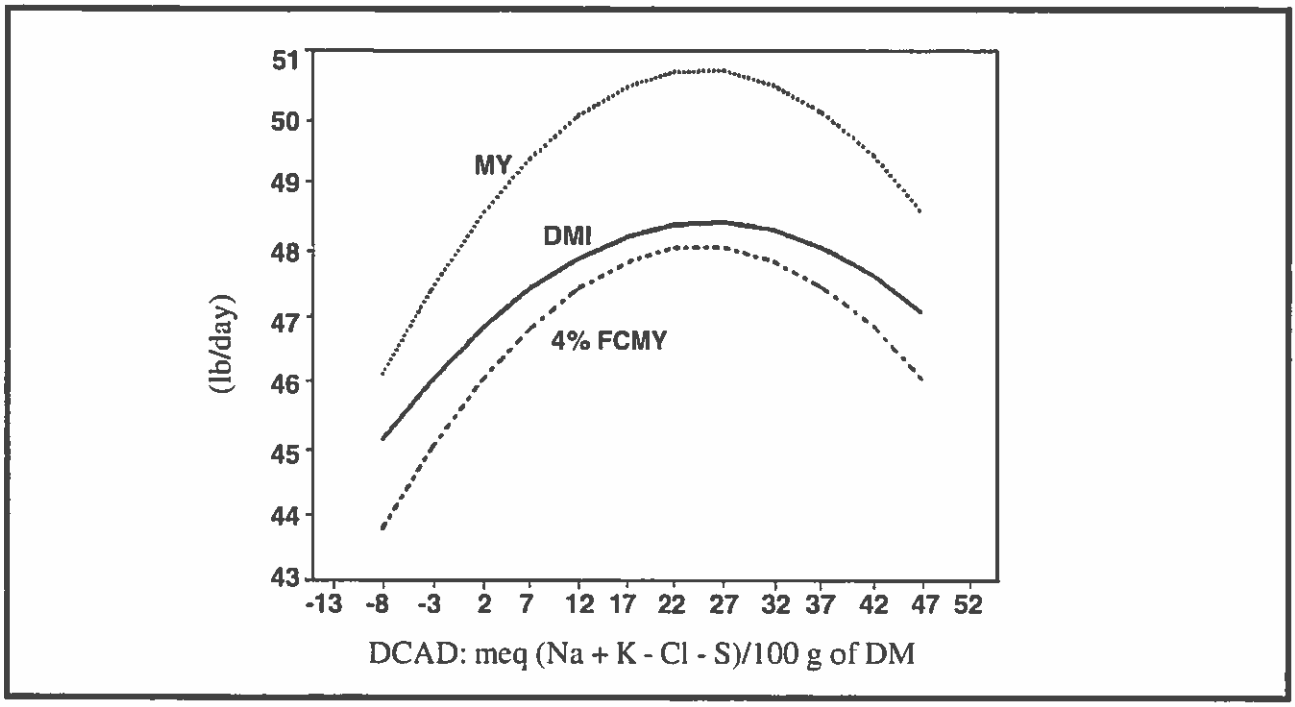

Figure 1. Milk yield (MY), 4% fat-corrected MY (4% FCMY), and DMI responses to mid-lactation Holstein cows to varying DCAD4 (DCAD = dietary cation-anion difference)

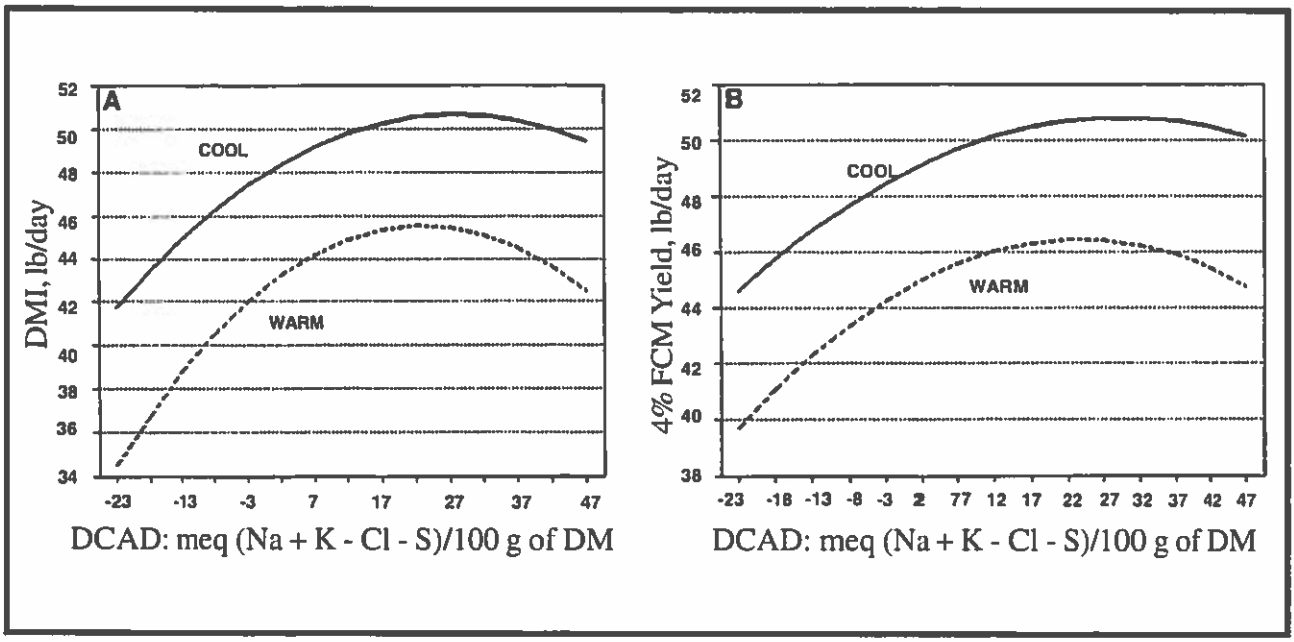

Figure 2. Dry matter intake (**DMI**; A) and 4% fat-corrected milk yield (4% FCMY; B) of mid-lactation Holstein cows fed varying DCAD4 (DCAD = dietary cation-anion difference) during cool and warm seasons in Florida (Sanchez et al., 1994b).

Feeding Practices of High-Producing Herds in Michigan

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Abstract

The feeding, nutrition, and herd management practices used on 18 Michigan dairy herds with Michigan DHI (**MI-DHI**) rolling herd average (**RHA**) of greater than 28,989 lb of milk were used for an on-farm survey during May to July 2004, in an attempt to explain how those herds accomplished their high DHI milk production. Herd DHI milk production averaged 29,989 and ranged from 28,551 to 33,419 lb of milk. Total lactating cow DHI herd size averaged 587 cows and ranged from 83 to 2217 cows. When compared to all Michigan herds enrolled on MI-DHI for the July 2004 test date, the most notable difference was DHI reported milk production items. The DHI herd management reported items were similar or slightly different. Neither nutrient composition of diets for lactating, dry, and close-up dry cows, nor the use of supplements or additives was unusual. All herds emphasized daily attention to feeding, nutrition, and herd management as the factors they thought contributed to their herd's high milk production.

Introduction

Feeding, nutrition, and herd management practices have a great impact on milk production, herd health, and farm profitability. Characterizing these management practices has been the subject of several studies (Jordan and Fourdraine, 1993; Kellogg et al., 2001; Jordan, 2002; Shaver and Kaiser, 2004).

For April 2004, Michigan DHI (MI-DHI) reported 35 herds with a RHA greater than 29,000 lb of milk. We conducted an on-farm survey with 18 of the 35 herds from late May to early July 2004 to identify feeding, nutrition, and herd management practices used on those herds in an attempt to help explain how those herds accomplished their high DHI milk production. This paper reports the results of that on-farm survey.

Survey Methods

Eighteen Michigan Holstein dairy herds with a RHA greater than 29,000 lb of milk for the April 2004 test date were randomly selected as survey participants of their feed, nutrition, and herd management practices based on yearly RHA for milk production and herd size. The selected herds were assigned to four subgroups based on herd size; <250 cows (5 herds), 250 to 500 cows (5 herds), 500 to 1000 cows (5 herds), and >1000 cows (3 herds).

The survey form used was developed similar to that used by Shaver and Keiser (2004). From late May to early July 2004, we visited all herds. The herd owner or herdsperson assisted in completing the survey form, and we validated the data obtained during the visit. In addition during the visit, we had the opportunity to observe specific or unique feeding and herd management practices employed on these herds and to record comments from the herd owners and herdspersons as to why

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they implemented certain herd management practices.

Permission was obtained from the herd owners to access and to use their MI-DHI herd records. The survey herds MI-DHI, RHA for their July 2004 test date averaged 29,989 lb of milk, with a range of 28,551 to 33,419 lb. The nutritionists for the herds provided diet printouts for lactating and dry cow groups. The printouts were used to determine feedstuffs used in diets and the nutrient composition of diets. All herds fed a mixed ration (**TMR**).

Results

MI-DHI Herd Information

The MI-DHI information for the 18 herds obtained for the July 2004 MI-DHI herd test day is presented in Tables 1a through 2. The last column of Tables 1a through 2 contains the mean values for all 648 Michigan herds enrolled in MI-DHI for the July 2004 test date. Tables 1a and 1b report the DHI data on a herd size basis. Fifteen herds milked three times daily, and three herds milked two times per day.

The RHA and peak milk, as expected, were the most notable differences for all 18-survey herds combined as compared to the MI-DHI means (Table 1c). The other DHI herd management items listed in Tables 1a through 1c, certainly contribute to the 18 herd's high production, but any single item alone does not reveal great differences when compared to all the MI-DHI herds. The DHI annual herd turnover for the 18-survey herds (Table 2) was also similar to the MI-DHI mean and suggest that the surveyed herds' high milk production was not the effect of high cow turnover.

General Herd Management Information

Tables 3 through 6 describe the general management of the herds and facilities management. The number of cow groups (Table 3) varied, with the larger herds having more groups as expected. The criteria for moving lactating cows to another group (Table 4) also varied, with reproductive status being the main criteria for moving cows to another group.

The mean number of lactating cows per free stall (Table 5) for all herds was slightly above 1 stall per cow. However, the maximum stocking density was 1.47 cows per free stall, and this occurred mainly in the larger herds with newer facilities. The stocking density "over-loading" by some of the herds was an interesting observation and greater than reported by Shaver and Kaiser (2004).

Feed bunk space for lactating cows (Table 6) ranged from 0.72 to 2.69 ft/cow for all groups on the day the herd was visited, and this is similar to the findings of Shaver and Kaiser (2004). Feed bunk headlocks for the lactating cows were used in 5 herds and not used in 13 herds. In the herds with greater than 500 cows, only one herd used feed bunk headlocks.

Feeding Management Information

The number of feedings per day to the lactating cow groups (Table 7) varied between 1 to 6 times per day which is similar to that reported by Shaver and Kaiser (2004). This was influenced by facility layout, feed bunk capacity, and herd size. The one herd feeding 6 times per day had elevated feed bunks with limited feed holding capacity. Herd size, group, mixer capacity, labor availability, and feeding logistics influenced the number of feedings per day on individual herds. Feed push-up per day (Table 8) ranged from 2 to 12 and was not affected by herd size.

Monitoring of feedstuff dry matter (**DM**) (Table 9) varied by feed type and herd size. Haylage DM was determined most often. Larger herds tended to determine DM of feedstuffs more often.

A written record of feedstuff DM was done on 56% of the herds, with the reported purpose that the data was used by the nutritionist and for on-farm diet adjustments.

Monitoring of daily feed intake of the lactating cow groups (Table 10) was done in various ways for the herds surveyed. Eleven herds, 65% of those reporting, kept a written record of daily feed intake. Those herds indicated that the data were used to determine TMR batch sizes for the next feeding and for monitoring feed intake history by their nutritionist.

Most herds reported that feed bunks were cleaned daily. Orts from the lactating cow groups (Table 11) were re-fed mainly to growing heifers or steers, or was disposed of. Some herds re-fed orts to low-producing groups and the close-up dry cows.

The proportion of time the main feeder did the feeding (Table 12) varied by herd size. For the <250 cow herd size, the main feeder did most of the feeding because of a smaller labor pool. The >1000 cow herd size had one or two people who were designated feeders. The herds from 250 to 1000 cows tended to have more people who did a proportion of the feedings.

Roughage Storage and Management

Most herds used bunkers for storing roughages (Table 13), with high moisture corn mainly stored in upright silos. Also, most but not all herds covered the bunkers with plastic. Our observation during the visit to the herds was that all herds were very particular to feed only the better appearing silages to the lactating cows. They did not feed silage from the top of the bunker or the spoiled appearing silage near the sidewalls. All herds made particular mention of that practice. We observed that the silages in bunkers were well packed. The herd owners emphasized the importance of bunker packing during harvest.

When asked what methods the herds used to decide when to harvest first-cutting alfalfa (Table 14), 6 herds used the alfalfa NDF prediction methods of growing degree days **(GDD)** or predictive equations for alfalfa quality **(PEAQ)**. Most herds used more traditional methods for deciding when to harvest first-cutting alfalfa. We asked this as part of the survey because we were interested in knowing if these high producing herds were implementing the predicting methods for alfalfa NDF to decide when to harvest first-cutting alfalfa. The results indicate that the use of the predicting methods GDD or PEAQ was not as high as we expected.

All herds indicated they had goals for DM percentage ranges during harvest (Table 15), but only a few reported that they had a standard protocol for monitoring DM during harvest. When herds purchased roughages from a custom grower, they indicated that DM was determined more frequently. Silage inoculants (Table 15) were used by a number of herds.

We also were interested in the criteria the herds used to select corn silage hybrids (Table 16). Sixty six percent of the herds indicated that they utilize NDF digestibility as part of their criteria when selecting corn silage hybrids. All herds indicated that they use a number of criteria to make their final selection.

Diets and Feedstuff Information

To obtain information on the nutrient composition of the diets for the lactating, dry, and close-up dry cows, we used the diet printouts that were provided to us from each herd's nutritionist. All herds utilized a nutritionist for diet formulation and consulting. Sixteen of the herds used nutritionists that were associated with a feed company and 2 herds used a nutritionist that did not provide any of the ingredients used in the diets.

The nutrient composition of the diets are presented in Tables 17a through 17e. The nutrient composition for all the diets appeared to be within expected nutrient values. In our survey we utilized the diet printouts from the nutritionists and this presented some difficulties when we tried to determine the diet nutrient composition because some printouts did not contain certain values for certain nutrients, thus we were not able to present that data. Shaver and Kaiser (2004) collected samples of feed ingredients and the high group TMR for laboratory analysis. This would have been desirable to do for our study, but it was a larger task than we were capable of doing.

We were also interested in the various feedstuffs used in the diets of the herds, and this is presented in Table 18. For our study, we asked the herd owners or herdspersons to list the ingredients, and in particular, the feed additives they used in the lactating, dry, and close-up cow diets. They were able to provide a partial listing, but all referred us to their nutritionist for a complete listing. From the nutritionist's diet ingredient printouts, we were able to ascertain a partial listing of particular nutritional supplements and additives that were included in the diets. However, most herds used a "custom blended grain mix" and "custom mineral/ vitamin mix" and for those mixes, many of the nutritional supplements and additives were not reported or were part of a company's or nutritionist's proprietary product or formulation.

Summary

The most interesting observation we made during our visits with the herd owners and herdspersons was their attention to feeding and herd management details. All herds emphasized that they placed a high priority on all aspects of herd management. They were particularly focused on feeding management practices.

Acknowledgments

We would like to express our appreciation to the following people who assisted with this survey: the 18 herd owners; their nutritionists for diet printouts; MI-DHI for providing the DHI records; Dr. Kathy Lee, MSU-Dairy Extension, for sorting and assimilating the DHI records; and the MSU Dairy Extension program for financial support.

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Table 1a. General information from DHI records (July 2004, MI-DHI test date).[1]

Item	Herd size <250 (n=5) Mean	<250 (n=5) Min	<250 (n=5) Max	250-500 (n=5) Mean	250-500 (n=5) Min	250-500 (n=5) Max	MI DHI (n=648)
Total cows in herd	149	83	222	286	241	334	153
Cows in milk, %	91	88	96	87	85	91	88
RHA milk, lb	31,053	29,943	33,419	30,099	29,028	30,945	23,763
RHA with fat, lb	1085	1016	1172	1181	1048	1406	881
Milk fat, %	3.5	3.4	3.7	3.9	3.5	4.5	3.7
RHA milk protein, lb	926	885	975	903	852	938	691
Milk true protein, %	3.0	2.9	3.1	3.0	2.9	3.0	2.9
Milk SCC, x1000	146.2	93	205	215.6	149	267	281
Days in Milk	196.6	170	224	203.0	188	218	195
Times milked, /day	3	3	3	2.4	2	3	-[2]
1st lactation peak, lb	102.8	95	108	96.4	91	101	77
2nd lactation peak, lb	127.8	113	133	127.0	125	130	97
3rd+ peak, lb	137.8	122	147	133.6	130	137	103
All cows peak, lb	121.0	109	127	118.8	115	122	92
Summit, 1st lact, lb	93.0	89	95	86.8	81	91	-[2]
Summit, 2nd lact, lb	119.2	110	129	118.6	117	120	-[2]
Summit, 3rd+ lact, lb	127.4	121	136	123.8	121	126	-[2]
Summit, all cows, lb	111.0	105	117	108.8	106	110	-[2]
Days to 1st service, all cows	87.2	70	117	84.6	70	121	95
Days open, all cows	150.8	127	186	155.2	131	168	171
Calving interval, months	14.2	13.4	15.3	14.3	13.5	14.7	14.8
Services/pregnant all cows	2.8	2.1	3.9	2.9	2.0	4.4	2.8
Days dry, all cows	58.4	56	61	63.2	53	73	61
Age, 1st lactation, months	24.6	24	25	23.6	22	25	25
Age, all cows, months	38.4	36	40	42.2	39	46	43
DHI annual turnover, %	39.6	27	50	31.8	26	40	34

[1]MI-DHI = Michigan Dairy Herd Improvement, RHA = rolling herd average, and SCC = somatic cell count.

[2]Not reported in summary for all MI-DHI herds.

Table 1b. General information from DHI record (July 2004, MI-DHI test date).[1]

Item	Herd size						MI DHI (n=648)
	500-1000 (n=5)			>1000 (n=3)			
	Mean	Min	Max	Mean	Min	Max	
Total cows in herd	608	505	718	1783	1462	2217	153
Cows in milk, %	88	81	90	89	85	92	88
RHA milk, lb	29,497	29,078	29,931	28,850	28,551	29,311	23,763
RHA with fat, lb	1079	927	1187	1041	955	1210	881
Milk fat, %	3.7	3.2	4.0	3.6	3.3	4.1	3.7
RHA milk protein, lb	868	857	883	858	833	873	691
Milk true protein, %	2.9	2.9	3.0	3.0	2.9	3.1	2.9
Milk SCC, x1000	214.0	126	299	336.0	309	386	281
Days in Milk	193.0	166	218	205.0	185	216	195
Times milked, /day	3	3	3	3	3	3	-[2]
1st lactation peak, lb	97.0	91	105	101.0	97	108	77
2nd lactation peak, lb	123.2	112	131	131.7	128	137	97
3rd+ peak, lb	133.0	125	140	137.3	135	141	103
All cows peak, lb	114.2	106	121	122.3	120	127	92
Summit, 1st lact, lb	86.0	81	91	87.3	82	91	-[2]
Summit, 2nd lact, lb	114.8	104	119	120.7	118	123	-[2]
Summit, 3rd+ lact, lb	121.4	109	128	123.0	122	125	-[2]
Summit, all cows, lb	104.0	97	107	108.7	105	112	-[2]
Days to 1st service, all cows	75.4	60	108	67.3	55	74	95
Days open, all cows	147.2	128	184	152.3	134	166	171
Calving interval, months	14.1	13.4	15.3	14.2	13.6	14.7	14.8
Services/preg, all cows	2.5	1.7	2.9	2.7	2.6	2.9	2.8
Days dry, all cows	58.4	42	72	52.7	46	64	61
Age, 1st lactation, months	24.0	23	25	24.3	23	26	25
Age, all cows, month	38.8	33	43	41.0	38	44	43
DHI annual turnover, %	34.4	26	41	34.0	27	43	34

[1]MI-DHI = Michigan Dairy Herd Improvement, RHA = rolling herd average, and SCC = somatic cell count.

[2]Not reported in summary for all MI-DHI herds.

Table 1c. General information from DHI records (July 2004, MI-DHI test date).[1]

Item	All 18 herds			MI-DHI
	Mean	Min	Max	(n=648)
Total cows in herd	587	83	2217	153
Cows in milk, %	89	81	96	88
RHA milk, lb	29,989	28,551	33,419	23,763
RHA with fat, lb	1103	927	1406	881
Milk fat, %	3.7	3.2	4.5	3.7
RHA milk protein, lb	892	833	975	691
Milk true protein, %	3.0	2.9	3.1	2.9
Milk SCC, x1000	216.1	93	386	281
Days in Milk	198.8	166	224	195
Times milked, /day	2.8	2	3	-[2]
1st lactation peak, lb	99.1	91	108	77
2nd lactation peak, lb	126.9	112	137	97
3rd+ peak, lb	135.2	122	147	103
All cows peak, lb	118.7	106	127	92
Summit, 1st lact, lb	88.4	81	95	-[2]
Summit, 2nd lact, lb	118.1	104	129	-[2]
Summit, 3rd+ lact, lb	124.0	109	136	-[2]
Summit, all cows, lb	108.1	97	117	-[2]
Days to 1st service, all cows	79.9	55	121	95
Days open, all cows	151.3	127	186	171
Calving interval, months	14.2	13.4	15.3	14.8
Services/pregnant, all cows	2.7	1.7	4.4	2.8
Days dry, all cows	58.8	42	73	61
Age, 1st lactation, months	24.1	22	26	25
Age, all cows, months	40.0	33	46	43
DHI annual turnover, %	35.1	26	50	34

[1]MI-DHI = Michigan Dairy Herd Improvement, RHA = rolling herd average, and SCC = somatic cell count.

[2]Not reported in summary for all MI-DHI herds.

Table 2. Reasons for cows leaving survey herds from DHI records (July 2004, MI-DHI test date).

Reason	Herd size <250 Mean, %	250-500 Mean, %	500-1000 Mean, %	>1000 Mean, %	All 18 herds Mean, %	MI-DHI Mean %
Dairy purposes	23.2	0.2	12.3	0.1	9.9	5.1
Low production	4.7	22.1	20.0	29.5	17.9	16.9
Reproduction	30.1	25.4	16.8	14.9	22.6	20.3
Mastitis	7.9	14.0	9.5	6.5	9.8	10.2[1]
Udder	4.2	2.6	1.7	0.5	2.4	-[1]
Feet/leg problems	6.8	4.5	5.6	4.7	5.5	8.5
Disease	2.6	2.4	6.8	10.1	5.0	18.6
Died	12.9	20.1	17.8	23.2	18.0	20.3
Injury/other	7.4	8.4	9.2	10.1	8.6	-[2]
No reason	0.4	0.2	0.4	0.4	0.4	-[2]

[1]Michigan Dairy Herd Improvement (MI-DHI) combines culling reason for Mastitis and Udder in summary for all MI-DHI herds.
[2]Not reported in summary for all MI-DHI herds.

Table 3. Number of groups (lactating & dry).

Herd size	Mean	Minimum	Maximum
<250 cows	3.8	3	5
250-500 cows	5.0	4	6
500-1000 cows	7.2	6	9
>1000 cows	12.0	10	14

Table 4. Criteria or reasons for moving lactating cows to another group.

Criteria	Number herds using criteria
Days in milk	4
Reproductive status	10
Milk yield	6
Need to dry off	1
Health	1
Move cows to balance group sizes	2

Table 5. Number of lactating cows per free stall.

Group	Mean	Minimum	Maximum
Post-fresh	1.02	0.67	1.25
High-producing	1.14	0.94	1.47
Mid-lactation	1.18	1.08	1.47
Low-producing	1.10	0.73	1.36
1st lactation	1.16	1.05	1.44

Table 6. Feed bunk space for lactating cows (ft/cow).

Group	Mean	Minimum	Maximum
Post-fresh	2.12	1	2.66
High-producing	1.67	1	2.69
Mid-producing	1.79	1.36	2.08
Low-producing	1.55	0.72	2.18
1st lactation	1.47	1	1.81

Table 7. Number of feedings per lactating cow group (times/day).

Group	Mean	Minimum	Maximum
Post-fresh	1.5	1	3
High-producing	2.0	1	6
Mid-producing	1.8	1	3
Low-producing	1.6	1	3
1st lactation	1.7	1	3

Table 8. Number of feed push-ups per day.

Herd size	Mean	Minimum	Maximum
<250 cows	6.4	3	10
250-500 cows	3.6	2	4
500-1000 cows	5.2	3	9
>1000 cows	8.0	4	12

Table 9. Dry matter (DM) determination of feedstuff (times/month).[1]

Feed	Herd size <250	250-500	500-1000	>1000	Mean	Minimum	Maximum
Haylage	1.37	2.80	2.25	3.33	2.34	0	8
Corn silage	0.83	2.00	2.25	3.33	1.95	0	4
HMC	0.31	0.68	1.23	1.29	0.90	0	4

[1]56% (9/16 herds) kept written record of feedstuff DM history; HMC = high moisture corn.

Table 10. Monitoring of daily feed intake of lactating cow groups.[1]

Item	Number herds who do/number herds reporting	
Monitor daily	17/18	
Visual observation, not recorded	6/17	
Written record	11/17	
Weigh and record orts	2/17	
Use TMR recording software	3/17	(n = 1 for 500-1000 cows; n = 2 for >1000 cows)
Plan to buy TMR recording software	3/17	(500-1000 cows)

[1]TMR = total mixed ration.

Table 11. Destination of orts from lactating cow groups.

Group orts fed to	N (%)	Group Orts are from, number Fresh	High-Group	Mid-Group	Low-Group	1st lactation
Heifers	21 (34)	3	8	2	7	1
Low-producing	8 (13)	2	3	2	-	1
Close-up dry cows	3 (5)	0	1	1	1	0
Steers	9 (15)	2	2	1	2	2
Dispose of	20 (33)	4	4	3	6	3

Table 12. Proportion of time main feeder did the feeding.

%, of Time	Herd size <250	250-500	500-1000	>1000	Total herds
0-40	0	1	2	0	3
41-60	1	1	1	0	3
61-80	2	0	1	1	4
81-100	2	3	1	2	8

Table 13. Storage facilities for fermented feeds.

Feed	Storage type			
	Bunker[1]	Upright Silo	Bagged	Other
Haylage	15 (14)	1	2	0
Corn silage	15 (12)	1	2	0
High moisture corn (HMC)	5 (5)	10	1	2[2]

[1]Number of herds that cover bunkers in parentheses.
[2]Use HMC temporarily, one farm did not use HMC.

Table 14. Methods used by herds to decide when to harvest 1st cutting alfalfa.

Method	Number
Growing degree days	5
PEAQ[1]-stick	1
Plant height	3
Bud stage	8
Calendar date	6
Other (based on grass maturity, advised by nutritionist, when neighbors start)	3

[1]PEAQ = Predictive equations for alfalfa quality.

Table 15. Goals used for percentage of DM during harvest and use of silage inoculants by herds.

Feed	Goal for DM during harvest, %			Use of silage inoculant	
	Mean	Minimum	Maximum	N	%
Haylage	37	30	50	12 (13)[1]	66 (72%)[1]
Corn silage	33	30	45	12	66
High moisture corn	70	65	78	6	46 (6/13)[1]

[1]Use inoculant depending on circumstances.

Table 16. Criteria used for corn silage hybrid variety selection.

Criteria	Herds using criteria, %
NDF-digestibility	66
Yield	40
Other[1]	40

[1]Seed price, test weight, variety yield plot data, weather condition tolerance, or advice of seed dealer.

Table 17a. Diet nutrient composition from nutritionist diet printouts for High-producing group or single TMR for all lactating cow groups (18/18 herds data).[1]

Item	Mean	Minimum	Maximum
Formulated for, lb milk/cow/day	103	90	120
TMR, % DM	48.2	39.2	55.5
DM Intake/cow, lb/cow/day	56.3	50.4	66.0
Nutrient composition, DM basis			
CP, %	18.5	17.2	19.6
RUP, % of CP	35.7	28.5	42.5
NE_L, Mcal/lb DM	0.79	0.72	0.83
ADF, %	18.6	15.3	21.8
NDF, %	29.1	25.5	32.3
NFC, %	39.3	37.0	42.8
Fat, %	5.2	3.5	6.2
Ca, %	0.97	0.83	1.11
P, %	0.41	0.31	0.47
Mg, %	0.33	0.29	0.42
K, %	1.37	1.01	1.68
Vitamin A, IU/lb DM	3611	619	7200
Vitamin D, IU/lb DM	927	576	1620
Vitamin E, IU/lb DM	20.5	10.0	31.0

[1]TMR = total mixed ration, DM = dry matter, CP = crude protein, RUP = rumen undegradable protein, NE_L = net energy for lactation; ADF = acid detergent fiber, NDF = neutral detergent fiber, and NFC = nonfiber carbohydrates.

Table 17b. Diet nutrient composition from nutritionist diet printouts for low-producing lactating cow diets (6/18 herds had specific low-producing group diets).[1]

Item	Mean	Minimum	Maximum
Formulated for, lb milk/cow/day	76	65	92
TMR, % DM	47.4	43.2	53.5
DM Intake, lb/cow/day	50.8	38.7	61.0
Nutrient composition, DM basis			
CP, %	17.6	16.3	18.3
RUP, % of CP	34.1	31.3	35.4
NE_L, Mcal/lb DM	0.78	0.76	0.79
ADF, %	19.2	18.3	21.5
NDF, %	29.8	27.6	31.7
NFC, %	39.9	38.5	41.5
Fat, %	4.8	3.9	5.8
Ca, %	0.92	0.77	1.05
P, %	0.43	0.40	0.44
Mg, %	0.33	0.30	0.35
K, %	1.41	1.25	1.59
Vitamin A, IU/lb DM	2877	1967	3450
Vitamin D, IU/lb DM	673	553	770
Vitamin E, IU/lb DM	24.5	15.8	37.7

[1]TMR = total mixed ration, DM = dry matter, CP = crude protein, RUP = rumen undegradable protein, NE_L = net energy for lactation; ADF = acid detergent fiber, NDF = neutral detergent fiber, and NFC = nonfiber carbohydrates.

Table 17c. Diet nutrient composition from nutritionist diet printouts for Fresh lactating cow diets (4/18 herds had specific fresh group diets).[1]

Item	Mean	Minimum	Maximum
Formulated for, lb milk/cow/day	83	80	94
TMR, % DM	48.4	44.7	50.4
DM Intake, lb/cow/day	41.9	35.3	52.3
Days cows are in group, days	32	8	45
Nutrient composition, DM basis			
CP, %	18.2	17.8	18.8
RUP, % of CP	36.2	30.9	38.9
NE_L, Mcal/lb DM	0.79	0.78	0.80
ADF, %	19.0	17.7	21.0
NDF, %	29.7	26.8	32.5
NFC, %	38.4	37.0	40.3
Fat, %	5.0	4.3	5.9
Ca, %	0.98	0.84	1.10
P, %	0.44	0.37	0.52
Mg, %	0.35	0.32	0.42
K, %	1.41	1.24	1.81
Vitamin A, IU/lb DM	4064	618	8816
Vitamin D, IU/lb DM	953	559	1529
Vitamin E, IU/lb DM	41.2	19.7	70.0

[1]TMR = total mixed ration, DM = dry matter, CP = crude protein, RUP = rumen undegradable protein, NE_L = net energy for lactation; ADF = acid detergent fiber, NDF = neutral detergent fiber, and NFC = nonfiber carbohydrates.

Table 17d. Diet nutrient composition from nutritionist diet printouts for Close-dry cow diets (9/18 herds had specific close-up group diets).[1]

Item	Mean	Minimum	Maximum
TMR, % DM	49.8	44.9	56.3
DM intake, lb/cow/day	29.2	23.4	32.1
Nutrient composition, DM basis			
CP, %	15.4	12.8	17.1
RUP, % of CP	36.7	28.4	40.6
NE_L, Mcal/lb DM	0.71	0.62	0.74
ADF, %	21.7	15.1	27.1
NDF, %	37.2	27.4	44.0
NFC, %	32.3	31.4	33.6
Fat, %	3.6	3.0	5.4
Ca, %	1.10	0.58	1.40
P, %	0.36	0.30	0.48
Mg, %	0.37	0.27	0.44
K, %	1.20	0.82	1.65
Vitamin A, IU/lb DM	6157	950	8302
Vitamin D, IU/lb DM	1056	465	1540
Vitamin E, IU/lb DM	60.0	43.0	82.5
Anions used in diet	4/9 herds used anions		

[1]TMR = total mixed ration, DM = dry matter, CP = crude protein, RUP = rumen undegradable protein, NE_L = net energy for lactation; ADF = acid detergent fiber, NDF = neutral detergent fiber, and NFC = nonfiber carbohydrates.

Table 17e. Diet nutrient composition from nutritionist diet printouts for Dry cow diets, (8/18 herds had specific dry group diet printouts).[1]

Item	Mean	Minimum	Maximum
TMR, % DM	44.6	37.5	48.3
DM Intake lb/cow/day	30.5	26.6	33.5
Nutrient composition, DM basis			
CP, %	15.0	12.8	18.3
NE_L, Mcal/lb DM	0.65	0.62	0.72
ADF, %	28.8	21.4	34.9
NDF, %	42.2	33.0	47.1
Fat, %	2.9	2.6	3.1
Ca, %	0.86	0.32	1.26
P, %	0.39	0.31	0.59
Mg, %	0.34	0.27	0.44
K, %	2.00	1.58	2.50
Vitamin A, IU/lb DM	4577	1722	6539
Vitamin D, IU/lb DM	1212	650	2160
Vitamin E, IU/lb DM	52.8	16.5	83.0

[1]TMR = total mixed ration, DM = dry matter, CP = crude protein, RUP = rumen undegradable protein, NE_L = net energy for lactation; ADF = acid detergent fiber, NDF = neutral detergent fiber, and NFC = nonfiber carbohydrates.

Table 18. Feedstuffs used in lactating cow TMR diets; data were obtained from nutritionist diet printouts (total herds = 18).

Feedstuff	Number herds/total, using feedstuff as a separate ingredient
Alfalfa silage	18/18
Dry hay	5/18
Straw	1/18
Corn silage	18/18
Dry corn grain	8/18
High moisture corn grain	16/18
Soybean meal	9/18
"By-Pass" soybean meal product	1/18
Roasted soybeans	3/18
Canola meal	1/18
Urea	1/18
Corn distillers grain	5/18
Blood meal	1/18
"Protected" amino acid product	4/18
Whole cottonseed	6/18
Liquid fat product	1/18
"By-Pass" fat product	6/18
Beet or citrus pulp	6/18
Soy hulls	1/18
Brewers hrain	1/18
Sugar	1/18
Bakery by-product	1/18
Molasses-liquid product	3/18
Custom blended grain mix[1]	14/18
Custom mineral/vitamin mix[2]	4/18

[1]Custom blended grain mixes contained an assortment of feedstuffs and additives.
[2]Custom mineral/vitamin mixes contained an assortment of minerals, vitamins, and additives.

New Version of SESAME

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Abstract

We released a new version of the software SESAME in November 2004. SESAME calculates break-even prices of feedstuffs based on their nutritional composition and market prices using a maximum likelihood method. Four major changes were implemented in this third major release. First, the net energy for lactation (NE_L) content of feedstuffs is dynamically calculated. In prior versions, NE_L had to be calculated and manually entered by the user. In Version 3, NE_L is calculated using the system implemented by the National Research Council (**NRC**) in its 2001 publication. Second, the quality adjustment factors for forage first proposed by Weiss (2002) have been fully incorporated. There are quality attributes in forages that are not entirely captured by their nutritional densities. The economic value of these quality attributes are captured by the adjustment factors. Third, we added graphical options to make the visual output more useful. Lastly, the software distribution has been entirely moved to an on-line system with direct payment by credit card. The database platform used is robust, allowing users to analyze purchasing decisions as well as estimating break-even prices of new feed ingredients.

Introduction

There is a constant need to estimate what feed ingredients are worth compared with what they are priced at. Producers need this information to make informed decisions regarding their feed procurement. Feed manufacturers need this information to decide what commodities should be inventoried in their limited number of storage bins. Feed processors need this information to estimate the returns to new equipment and processes that generate new feed ingredients with altered nutritional characteristics. Although mathematical programming (i.e., least-cost programs) can be used to generate such information, the method has severe limitations that restrict its inference range. We have proposed a market-based method that estimates break-even prices of feedstuffs from the value of the nutrients contained in feeds and the trading prices of all commodities in a given market (St-Pierre and Glamocic, 2000). A stand-alone software, SESAME™, was written to allow nutritionists and their clients a relatively easy access to the method. Details regarding SESAME and its application have been presented at this Conference (St-Pierre, 2000).

In November 2004, we released a new version of SESAME that incorporates recent work done in the area of feed evaluation, as well as new features to enhance the program usability. The objective of this paper is to describe the changes that have been incorporated in this new release.

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Changes to the Program

Dynamic calculation of dietary energy

In prior versions, the energy content of feedstuffs had to be calculated by the user before being manually entered in the program. This resulted in much confusion. For example, some users modified the nutritional profile of distillers dried grains without realizing that these changes did not modify the estimated energy content, and hence, had little impact on the calculated break-even prices. Version 3 incorporates the calculation scheme used by NRC (2001) in a dynamic fashion. A new NRC-Group attribute was added to each feedstuff (e.g., concentrate, forage, fat, animal, etc.) so that the proper NRC equation could be used in each instance. As in Table 15-1 of NRC (2001), NE_L is calculated at 3X maintenance, assuming that the diet has 74% total digestible nutrients (**TDN**).

Adjustment factors for forages

In a review of literature data, Weiss (2002) showed that the economic value of forages is not completely accounted for by nutrient density. At least for alfalfa, forages are not entirely substitutable. Cows respond to forage quality more than what nutritional content would indicate. Literature data adjusted for the trial effect indicate a reduction of 0.34 lb/day in fat-corrected milk (**FCM**) yield from a 1% increase in alfalfa NDF content (Figure 1). Additional work by Weiss on grass forage and St-Pierre on corn silage generalized the initial work of Weiss (2002). These adjustments are now fully implemented in SESAME V3.

Forage quality adjustments are based on expected change in FCM production. For alfalfa, a value of 44% NDF is set as the base. Thus, if a given lot of alfalfa contains 44% NDF, no adjustment is made. If NDF content is less than 44%, the economic value increases; if NDF content is greater than 44%, the value decreases. Adjustments are calculated based on a change in FCM yield of 0.34 lb per unit change in alfalfa NDF. Thus, adjustments are a function of milk price. Other minor assumptions are also accounted for as described by Weiss (2002).

Table 1 illustrates the effect of the quality adjustments on three lots of alfalfa hay differing in NDF content. At a milk price of $14.00/cwt of FCM, the adjustment amounts to approximately $4.00 per ton of hay for each one percentage unit change in NDF content. The adjusted break-even prices are more in line with historical market price differences for quality of alfalfa hay.

The adjustment factors for grasses are based on much more limited data than those used for alfalfa. For grasses, a value of 53% NDF was used as a base. Adjustments to break-even prices are calculated using the same method as the ones used for alfalfa. Because of the limited data on which the adjustment factors are calculated for grasses, we have less confidence in these f actors than those used for alfalfa. Adjustments for mixtures of grasses and legumes are based on the weighed adjustments using the proportion of grass and legume in the forage.

Adjustment factors for corn silage are entirely based on the DM content. A review of published literature (St-Pierre, unpublished) showed a curvilinear response in DM digestibility and intake to DM content of corn silage. The intake depression associated with DM content greater than 36% is based predominantly on older data with non-mechanically processed silage. It is possible that mechanical processing considerably reduces considerably the intake and digestibility depressions of dryer silages, but published data are still too sketchy to allow a correct quantification of this effect. Table 2 reports the adjustments used for corn silage break-even price calculations in SESAME Version 3.0.

New graphic options

Many users favor graphical presentation of results over tabular ones. In prior versions of SESAME, the graphical output worked properly as long as the problem did not include feedstuffs with prices considerably greater than the average price of all feeds used in a problem. In instances where high priced ingredients were included, as when protected amino acid products were included, the graphical display of the results was nearly worthless due to the great distortion of the x-scale (Figure 2a). Version 3 includes an option to exclude feeds whose estimated price exceeds the average price of all feeds by a certain percentage (the default is 50%). The user can thus produce clear graphics in nearly all situations (Figure 2b).

New on-line distribution

Prior versions of SESAME were distributed on a CD-ROM. Literature (users manual, tutorials, etc.) was shipped in a traditional three-ring binder. Payments were accepted only in the form of checks in U.S. dollars. This system was labor intensive, untimely, and extremely unfriendly, particularly, to our international users. In Version 3, the product is delivered on-line, and payment is made using a credit card. SESAME V3.0 is available in English and Spanish and can be downloaded from www.sesamesoft.com. The software can be downloaded and used for free on a 7-day trial basis, after which a license purchase is required. The cost for the initial license is $99/copy. Prior license holders who wish to upgrade can do it for $29/copy. All documents are now available from this site in pdf format.

Conclusions

Version 3 of SESAME incorporates major changes to the energy calculation of feedstuffs, to the adjustments made in estimating forage prices, to the graphical display of results, and in the system used for its distribution.

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Table 1. Quality adjustments for alfalfa hay of three different NDF content.[1]

	Hay #1	Hay #2	Hay #3
DM (%)	86	86	86
CP (% of DM)	20	20	20
Protein Degradability (% of CP)	81.1	81.1	81.1
NDF (% of DM)	40	44	48
NDF Effectiveness (% of NDF)	100	100	100
NE_L (Mcal/lb DM)	0.59	0.57	0.55
Break-even price ($/ton)[2]			
Unadjusted	104.74	105.19	104.32
Adjustment factor	+14.44	0	-14.44
Adjusted	119.18	105.19	89.88

[1]NDF = neutral detergent fiber, DM = dry matter, CP = crude protein, NE_L = net energy for lactation; RDP = rumen degradable protein, RUP = rumen undegradable protein, and FCM = fat corrected milk.
[2]Based on the following prices: NE_L, $0.08/Mcal; RDP, - $0.045/lb; Digestible RUP, $0.20/lb; non-effective NDF, -$0.05/lb; effective NDF, $0.05/lb; and FCM, $0.14/lb.

Table 2. Multiplicative adjustment factors for corn silage used in SESAME V3.0.

DM (%)	Multiplicative Adjustments
24	0.78
26	0.85
28	0.93
30-39	1.00
40	0.91
42	0.85

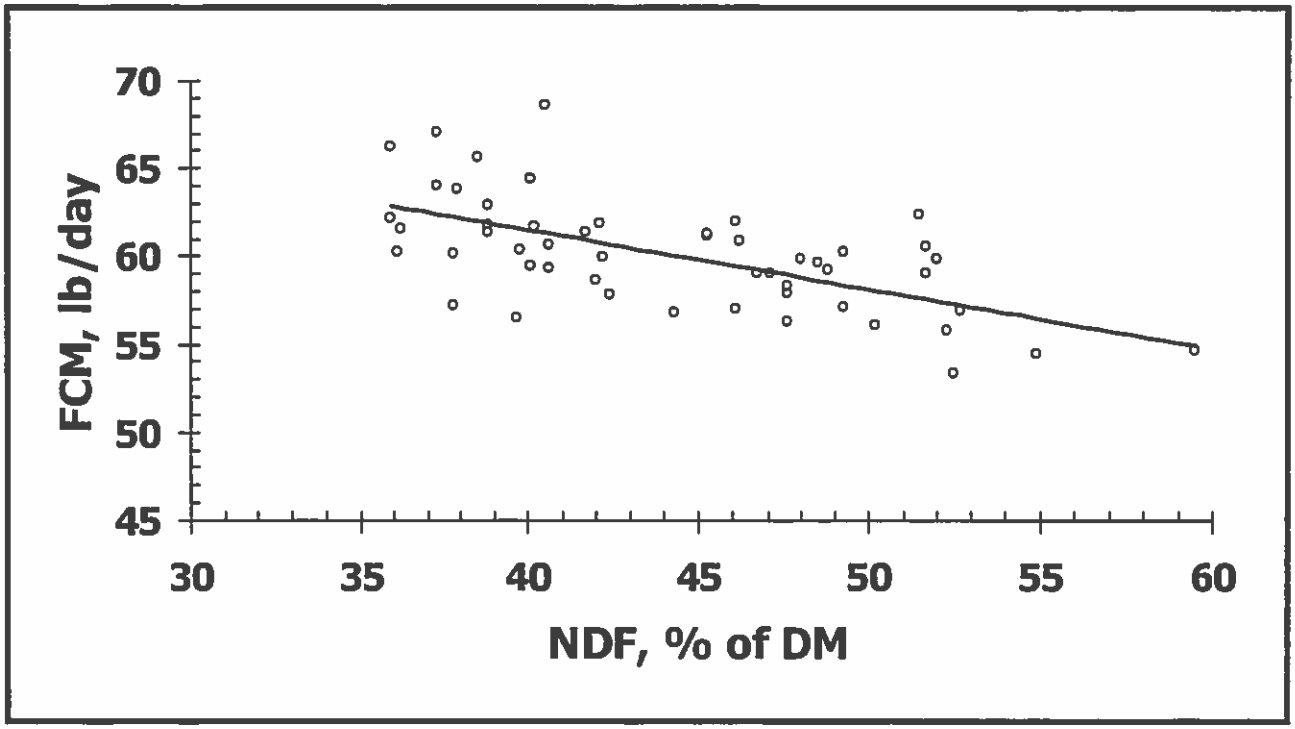

Figure 1. Effect of neutral detergent fiber (**NDF**) content of alfalfa on yield of 4% fat-corrected milk (FCM) when the alfalfa was fed in mixed diets to lactating dairy cows. Data were adjusted for trial effects. From Weiss (2002).

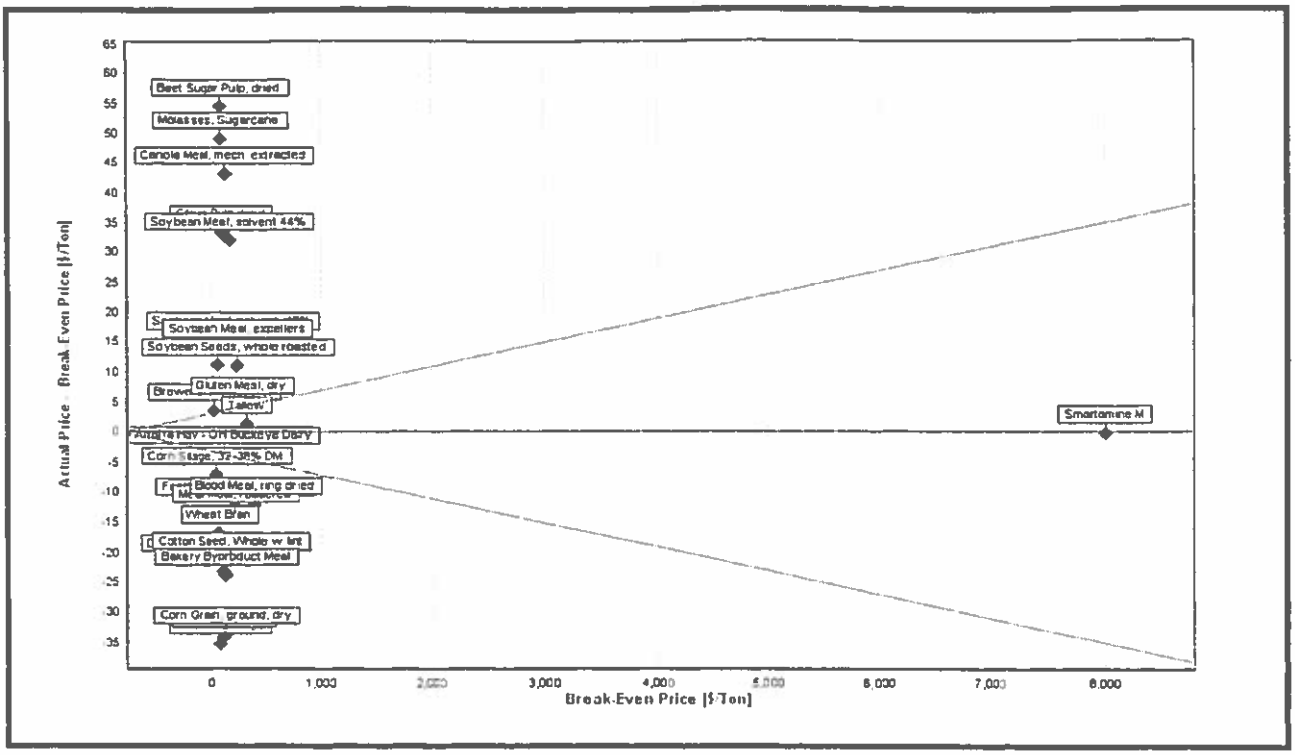

Figure 2a. Graphical display of results in SESAME V2.0. Distortion in the X-scale from a highly priced feedstuff reduced the clarity of the graphic.

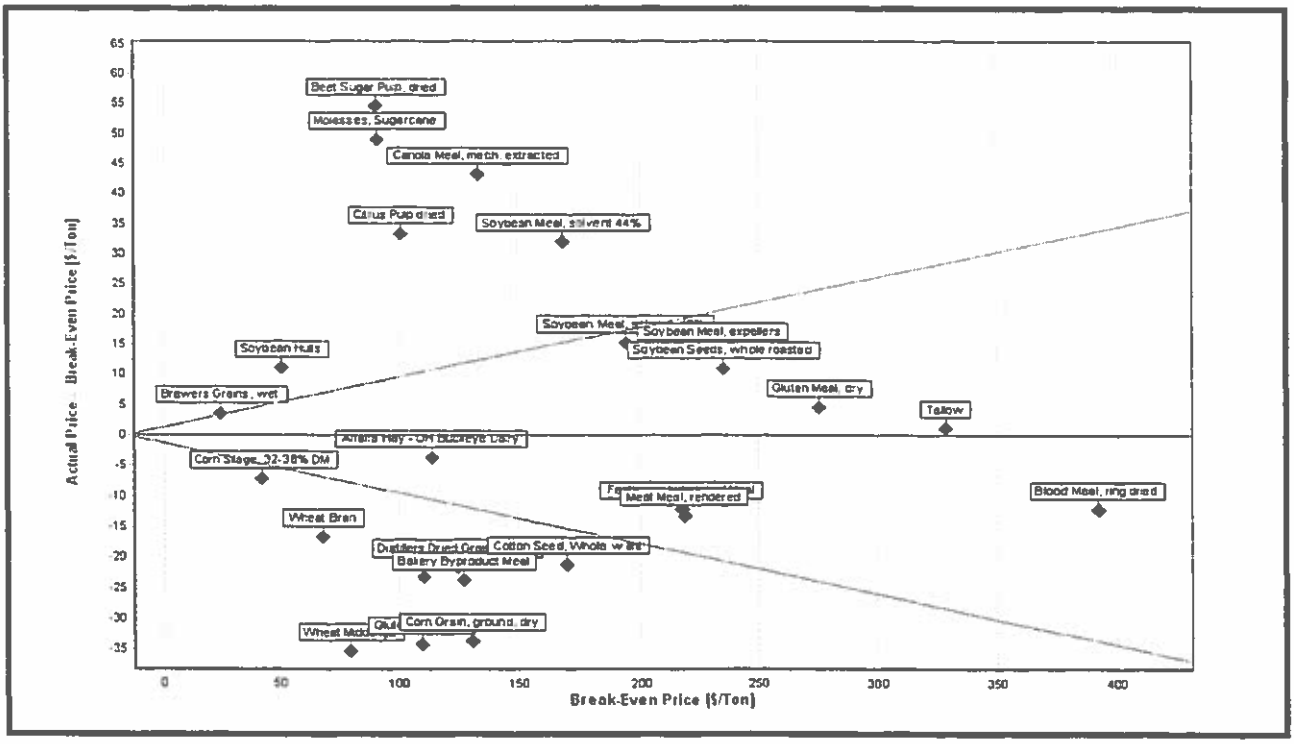

Figure 2b. Graphical display of results in SESAME V3.0. Highly priced feedstuffs can be removed from the graphic. This eliminates the distortion in the x-scale and restores clarity of the graphic.

Feeding Dairy Cows to Minimize Nitrogen Excretion[1]

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Abstract

Dairy cows utilize feed crude protein (**CP**; N x 6.25) with much greater efficiently than other ruminant livestock but still excrete about 2 to 3 times more N in manure than in milk. This contributes to increased costs of milk production and to environmental N pollution. The function of dietary CP is to supply the cow with metabolizable protein (**MP**) as absorbed amino acids (**AA**), but any extra dietary CP that does not contribute to absorbed AA that are used in production will be largely lost in the urine. Urinary N is the most polluting form of excretory N because much of it is lost as atmospheric ammonia or into surface and ground water. We conducted a number of trials testing various levels of CP in diets formulated from typical Midwest feeds. Generally, there were no increases in yields of milk, fat-corrected milk, or protein with more than 16.5% dietary CP. In one trial, reducing CP to 15.6%, but adding rumen undegraded protein (**RUP**) as heated soybean meal (**SBM**), did not support production equal to 16.6% CP. However, fish meal, especially low soluble fish meal, and canola meal were found to be more effective sources of RUP than SBM or cottonseed meal. Supplementing rumen-protected methionine has also been shown to be effective for allowing some reduction in dietary CP without losing milk yield. Frequent sampling and analysis of feed ingredients is very important for tracking the CP contents of the actual diet fed. Monitoring milk urea can also be used to assess both dietary CP and urinary N excretion in lactating cows. The NRC (2001) protein feeding model is useful for predicting production responses to alterations in dietary protein and should be used regularly. Hay-crop silages are the most degradable source of dietary CP. Where possible, replacing alfalfa silage with alfalfa hay will improve CP efficiency and reduce N excretion. Reducing grain particle size increases ruminal starch digestion and increases microbial protein formation, so long as ruminal pH is not depressed. The NRC (2001) model can also be used to match rumen-degraded protein with carbohydrate fermentation. Future research developments will allow even lower dietary CP levels to be fed, thus reducing N excretion, without loss of animal productivity.

Introduction

Ruminants make efficient use of diets that are poor in protein content or quality because ruminal microbes synthesize high quality protein plus capture recycled urea N that would otherwise be excreted in the urine. Numerous studies show that dairy cows utilize feed CP (N x 6.25) much more efficiently than other ruminant livestock; however, dairy cows still excrete about 2 to3 times more N in manure than in milk. Inefficient N utilization necessitates feeding large amounts of supplemental protein, increasing milk production costs, and contributing to environmental N pollution. An average cow producing about 18,000 lb of milk per lactation and

[1] Mention of any trademark or proprietary product in this paper does not constitute a guarantee or warranty of the product by the USDA or the Agricultural Research Service and does not imply its approval to the exclusion of other products that also may be suitable.

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also excretes about 23 tons of wet manure with about 240 lb of N distributed in those solids (Van Horn et al., 1996). The 15 million dairy cows and replacement heifers in the U.S. produce over 1 million tons of manure N every year (Kellogg et al., 2000). Of this amount, only 30% is actually recovered and applied to cropland (Kellogg et al., 2000). Dairy farms are thought to be significant contributors of nutrients to the hypoxia zone in the Gulf of Mexico, ground water in the Central Valley of California, and the Chesapeake Bay (Burkart and James, 1999; Harter et al., 2002; Ritter et al., 2003). Farm animals contribute about 50% (1.5 million tons of N annually) of the U.S. emission of ammonia and 25% (0.1 million tons N per year) of the total emissions of nitrogen oxides (NRC, 2003). It is estimated that about 25% of dairy manure N is lost as ammonia under current U.S. practices (Pinder et al., 2003), contributing to annual ammonia redeposition of manure N of 20 to 36 lb/acre in the Upper Midwest (Burkart and James, 1999). This unaccounted-for N input may add to nitrate-N losses in tile drainage water and eutrophication of surface waters via runoff. Moreover, dairy farmers are increasing herd size, importing more feed, and feeding more protein, further contributing to nutrient accumulation on land in dairy regions and greater nutrient impacts on the environment (Bundy and Sturgul, 2001). In the future, promulgation and enforcement of Concentrated Animal Feeding Operation rules likely will result in dairy farmers being held more accountable for environmental impacts coming from their animals' excreta.

How Much Are We Overfeeding CP?

The actual function of dietary CP is of course to supply the dairy cow with MP -- in the form of absorbed amino acids (AA)-- to meet her requirements for maintenance and production. Because extra dietary CP that is not utilized by the cow ends up in mainly the urine, we wanted to test the effects of increasing CP intake on N excretion as well as production using diets formulated from typical Mid-western ingredients. In the first of these trials, energy density was increased by reducing forage from 75, to 62, and 50% of dietary DM, giving diets with 36, 32, and 28% NDF; dietary CP was fed at about 15.1, 16.7, and 18.4% of DM at each NDF level (Broderick, 2003). There was no interaction between energy density and CP—that means that the cows responded to CP the same way at all 3 energy levels. Milk and protein yield both increased with the first CP increment, but there was not difference between production at 16.7 and 18.4% CP (Figure 1). There was a linear increase in N excretion with increased CP in the diet and most of the extra manure N was found in the urine. Virtually the entire incremental urinary N was excreted as urea, the form that can be quickly broken down and lost as volatile ammonia. This experiment was followed up by a second study in which step-wise increases of 1.5 percentage units, from 13.5 to 19.4% CP, were added to a 50% forage ration (Olmos Colmenero and Broderick, 2003). As expected, milk urea N (MUN), urinary urea, and milk N:N-intake reflected the linear decline in N efficiency with increasing CP (Table 1). We also found that production was highest on the 16.5% CP diet and observed a quadratic response that indicated that milk and protein yields were greatest at 16.8 and 17.1% CP, respectively. Over-feeding protein actually appeared to suppress production. These results were surprising because of the common practice of feeding high producing cows diets with 18% (Shaver and Kaiser, 2004) or even more CP (Gunderson et al., 1998; G.R. Oetzel, University of Wisconsin-Madison, Personal Communication). This effect may be explained by the fact that CP was increased by adding solvent SBM at the expense of high moisture corn, which diluted dietary energy (Olmos Colmenero, and Broderick, 2003). Moreover, there is a cost of about 7 kcal of net energy per g of N converted to urea (NRC, 2001). Similar findings of no increase (Sannes et al., 2002; Groff and Wu, 2003), or even reduced, milk yield (Wattiaux and Karg, 2004) with more than about 16.5% dietary CP have been

reported from a number of trials. These experiments were reversal studies (diets were switched after 3 to 4 weeks) conducted largely with mid-lactation cows, and thus, represent only the first iteration for identifying "optimal" CP levels. However, Wu and Satter (2000) found that the dietary CP regime supporting optimum yield of fat-corrected milk (**FCM**) over the whole lactation involved feeding 17.4% CP for the first 16-weeks after calving, followed by 16.0% CP for the remaining 28 weeks (Table 2). Increasing dietary CP to as high as 19.3% during the first-phase, or to 17.9% CP in the second phase, did not improve FCM yield. The approach of testing various CP levels in standard diets is now being used in conjunction with substituting different sources of RUP; however, our objective should always be to minimize the CP fed to maintain production. Reducing dietary CP intake in lactating cows substantially reduced volatile N losses from the stored manure (Külling et al., 2001).

Tracking Diet Composition

Dairy farmers and the consultants advising them often have to deal with considerable variation and imprecision in feed composition data, especially protein contents. This uncertainty is perhaps the major reason for wide spread over-feeding of CP. It is difficult to hit diet composition targets even when using daily ingredient sampling and total mixed ration (**TMR**) adjustment during feeding experiments conducted under controlled conditions, including using defined forage sources (e.g., Broderick, 2003). Greater problems are to be expected on commercial dairy farms due to greater variation and constantly changing feedstuffs. This makes paramount the frequent collection and analysis of representative feed samples. Feed sampling is a logical process that requires care to prevent separation of component fractions of differing densities and particle sizes. Proper sampling methods have been described in detail for forages, the most heterogeneous feeds (D. Putnam, University of California, Davis; http://alfalfa.ucdavis.edu/sampling/hayprobe.html). Briefly, these techniques involve accounting for as much variation as possible (e.g., cutting number, storage shed, and forage lot for a given hay shipment), randomly collection of enough samples to be representative of the whole supply, using proper coring or other sampling techniques to prevent fractionation, and sending the complete sample (i.e., a blend of all subsamples) to a laboratory certified by the National Feed Testing Association. A current list of certified laboratories is available on-line (www.foragetesting.org/). Although there is less variation in composition of concentrate ingredients, a similar sampling and testing philosophy should be reasonably applied to determine composition of all feeds used in the ration.

Clearly, having only data on CP content of an unknown feedstuff tells little about its MP and AA contents. However, knowing the feed's identity and its CP content on a DM basis provides much of the information required to properly utilize that ingredient. Reliable analyses, and accurate tracking of, DM, CP, and NDF in ration ingredients, are the primary objective of most feed analyses (Mertens, 1997). Within a ration composed of a limited number of macro-ingredients, CP content is the major factor dictating N utilization and excretion. Monitoring MUN is also a very useful technique in this context. Urea is the primary form of excretory N in mammals and blood urea equilibrates rapidly throughout body fluids, including milk; MUN concentrations reflect blood urea (Rook and Thomas, 1985) and equilibration between blood and milk occurs within 1 to 2 hours (Gustafsson and Palmquist, 1993). Therefore, MUN serves as a useful index of inefficient N utilization in the lactating dairy cow (Baker et al., 1995; Kohn et al., 2002). We found that dietary CP concentration, expressed on either a DM ($R2 = 0.84$) or energy ($R2 = 0.83$) basis, had the strongest relationship to MUN (Broderick and Clayton, 1997). The equation for computing CP from MUN was: dietary CP (% of DM) = 0.269*MUN (mg/dl) + 13.7. Associations were

not as strong for two factors clearly related to CP utilization: excess N intake (R^2 = 0.77) and N efficiency (R^2= 0.63); ruminal ammonia was the most poorly associated (R^2 = 0.57) of the factors we studied in depth. Urea in body fluids, including milk, results not only from excess protein degradation in the rumen but also from N inefficiency caused by excess supply of protein to the tissues. Nousiainen et al. (2004) recently reported a robust linear regression relating MUN (measured by infrared methods) to dietary CP from Nordic feeding trials. This equation can be rearranged to compute CP from MUN: dietary CP (% of DM) = 0.59*MUN (mg/dl) + 8.4. Kauffman and St-Pierre (2001) and Wattiaux and Karg (2004) both developed predictions for urinary N excretion from MUN that differ only slightly. It is clear that reliable field estimates of MUN could be used to identify diets that were relatively low or high in CP concentration, and dietary CP content (% of DM) could be estimated from MUN. Accurate and timely determination is perhaps the key to successful application of MUN to monitor dietary CP. It may be speculated that MUN readings will some day be made at cow side in the milking parlor. Indeed, Jenkins et al. (2002) have attempted to analyze MUN in cows during milking. Their system, although not robust enough for practical application, showed considerable promise.

Using Nutritional Models in Ration Formulation

The value of applying nutritional models, such as the NRC (2001) or the Cornell system (e.g., O'Connor et al., 1993), to formulation of dairy cow rations does not need extensive elaboration. Hanigan (2005) recently compared these two models with three others and concluded that the NRC (2001) model was somewhat more accurate at predicting protein flow from the rumen. Both the NRC (2001) and Cornell protein models are sound and useful, but both require accurate characterization of feedstuffs, not only chemical composition but also ruminal and intestinal degradation and digestion. The tabulated estimates of feed RUP in the NRC (2001) illustrate this problem. Although based on a simple, single compartment in situ model, many RUP estimates have been derived from very few in situ measurements. Although data on solvent SBM came from 14 determinations, only three values contributed to the mean for corn gluten meal. Another difficulty relates the time-lag between data production and model development. The NRC (2001) highlights how the equation from the NRC (1989), when applied to data published from 1989 to 1999, was less reliable at higher intakes for predicting ruminal microbial protein than the revised equation. However, we found that microbial nonammonia N (**NAN**) predicted using the revised equation yielded a slope of only 38% when regressed on microbial NAN flows measured at the omasum in 6 recent experiments. Part of the discrepancy may have resulted from an effect of level. The mean microbial NAN flow of 440 g/day observed in these trials was near the extreme of 500 g/day of the data set used to develop the revised NRC (2001) equation for microbial protein from intake of discounted total digestible nutrients (**TDN**). However, the overall NRC (2001) model was much more reliable in predicting rumen degradable protein (**RDP**), RUP, and total protein flows measured in the same trials (data not shown). This indicates that, while underestimating microbial synthesis, the model probably over-predicted RUP, but yielded an overall estimate of protein flow that was more nearly correct. Similar results have been observed using the Cornell system (D.G. Fox, Cornell University, personal communication). What is also surprising is that the NRC (2001) protein model does a more effective job at predicting milk and protein production than it does for estimating ruminal outflow of microbial protein, RUP, and total protein.

Reducing Degradability of Forage Protein

Silage harvesting methods are better mechanized than those used for making hay, and putting up hay-crops as silage reduces weather damage and increases (apparent) preservation of nutrients. The proportion of alfalfa and other forages fed as hay to dairy cattle in the eastern third of the U.S. declines yearly. However, when forages are ensiled, plant cell rupture releases proteases that break down forage proteins to nonprotein N (NPN) (McDonald et al., 1991). This breakdown is extensive, and NPN typically accounts for more than 50% of the total CP in alfalfa (Luchini et al., 1997) and other hay-crop silages (McDonald et al., 1991). Charmley and Veira (1990) found that suppressing NPN formation in ensiled alfalfa from 65 to 40% of total N increased NAN flow to the abomasum in sheep from 22 to 27 g/day; about 60% of the increase was due to greater microbial NAN flow. Although energy availability from alfalfa silage actually exceeded alfalfa hay in 3 of our lactation trials, and cows fed silage were more responsive to RUP from fish meal, indicating that the CP in silage was used more poorly than that in hay (Table 3; Broderick, 1995; Vagnoni and Broderick, 1997). In vitro studies using forages from 2 of these 3 trials indicated that there was similar ruminal protein degradation for both hay and silage, but greater microbial protein yield on hay (Peltekova and Broderick, 1996). Silage NPN, which is largely peptides and free AA (Muck, 1987), may be used with lower efficiency because ruminal microbes degrade these compounds to ammonia more rapidly than they degrade intact forage protein. Degradation of intact forage proteins, although rapid, may be more synchronous with ruminal microbial growth and result in more efficient capture of N from degraded protein than when similar amounts of CP are fed as silage NPN. The higher milk yields in the Western U.S. may result at least partly from greater feeding of alfalfa forage as hay rather than silage.

Matching Fermentable Energy with RDP

Because microbial protein accounts for most of the dairy cow's MP, one of the major tenets of the NRC (2001) model is to first meet the requirement for RDP. Matching ruminal energy fermentation with RDP will be effective for improving N efficiency, regardless of dietary protein degradability. There are substantial differences among starch sources (Herrera-Saldana et al., 1990), and within grains due to processing, in the rates of energy release in the rumen. Effects of processing on extent of ruminal digestion of corn starch is much greater than the effects on total tract digestibility (Table 4; Owens et al., 1986; 1997). We identified a grind size (a hammer mill with 3/8"screen) for high moisture corn that optimized ammonia uptake in ruminal in vitro incubations (Ekinci and Broderick, 1997). Feeding this ground high moisture corn (1.7 mm mean particle size) to lactating cows increased milk yield more than 5 lb/day and protein yield more than 0.25 lb/day compared to control high moisture corn (4.3 mm mean particle size). Ruminal acidosis and associated metabolic problems limit the amount of readily fermented carbohydrate that may be fed to produce MP from microbial growth. There are likely "optimal" levels of dietary concentrate and forage that will support maximal ruminal protein synthesis and milk production. A high forage diet containing 80% alfalfa silage and 20% concentrate was diluted stepwise with increasing amounts of high moisture corn to (% alfalfa silage DM/% concentrate DM) 65/35, 50/50, and 35/65 in a Latin square (reversal) trial (Valadares et al., 2000). True protein and NPN, as a proportion of total CP, were held constant by adding solvent SBM and urea as alfalfa silage decreased. The observed quadratic response curves were solved and maximums found for DM intake and yield of 3.5% FCM were at 51% concentrate (38% nonfiber carbohydrate; NFC); maximum fat yield was found at 43% concentrate (34% NFC). However, responses of milk and protein yields were not quadratic but linear -- both

were still going up at 35% forage and 65% concentrate. Moreover, purine derivative excretion in the urine, an indirect measure of ruminal protein synthesis, also showed the same linear response, despite low ruminal pH and other signs of NFC over-feeding (Valadares et al., 1999). Clearly, the lactating cow's demand for energy is substantial and optimal dietary concentrate probably is dictated more by long-term rumen and animal health than by maximum milk production.

Corn silage is commonly used to provide a high energy "forage" with which to dilute hay-crop forages and their highly degradable protein. Dhiman and Satter (1997) replaced 1/3 or 2/3 of the dietary alfalfa silage with corn silage. Compared to 100% of the forage from alfalfa, milk yield was 6% higher over the whole lactation when 2/3 of the dietary forage was alfalfa silage and 1/3 was corn silage; there also were comparable improvements in apparent N efficiency. Brito and Broderick (2003) assessed the effects of step-wise replacement of alfalfa silage with corn silage. The greatest improvement in N efficiency, without loss of production of milk, fat, and protein, occurred at about 50% of the forage from alfalfa silage and 50% from corn silage (Table 5). Additionally, replacing some of the dietary starch with very rapidly fermenting sugars holds promise for enhancing ruminal capture of degraded N. Corn starch was replaced with sucrose (Broderick et al., 2000), or dried or liquid molasses (Broderick and Radloff, 2004), in 3 separate feeding studies. The basal diets were formulated from alfalfa and corn silages plus high moisture corn and solvent SBM and averaged 2.6% total sugars in dietary DM. An overall analysis of the data from the 3 trials indicated maximums for total sugars (DM basis) were 6.8% for DM intake and 4.8% for protein yield. However, the effects of sugar feeding in these trials were primarily driven by increased feed intake.

Feeding RUP and Protected AA

The primary advantage of the newer ration formulation systems is their value in identifying when lactating cows will respond to RUP supplements. In the Midwest setting where diets are often based on high CP, and high NPN alfalfa silage, there are usually substantial responses to higher "bypass" proteins produced by heat-treating soybean proteins (Broderick et al., 1990; Faldet and Satter, 1991) or using special manufacturing processes, such as reducing the soluble protein content of fish meal (Broderick, 1992). Table 6 summarizes relative ruminal degradabilities and protein yield responses observed in feeding studies with expeller-heated soybean meal (Broderick et al., 1990) and low and high-soluble fish meal (Broderick, 1992). Although there were similar ruminal degradabilities found for expeller soybean meal and high-soluble fish meal, lactation response was greater for the fish meal. Moreover, the protein response to low-soluble fish meal was out of proportion to its relative ruminal escape. This reflects the higher quality AA pattern of fish meal protein. Compared to a iso-nitrogenous diet containing urea, we also found an interesting pattern of response to 3 true protein sources that differed in RUP and AA content (Brito and Broderick, 2004). Flows of RUP and total protein (NAN x 6.25) from the rumen were greatest on cottonseed meal, intermediate on canola meal, and lowest on solvent SBM; however, milk and protein yields were highest on canola, intermediate on SBM, and lowest on cottonseed meal (Table 7). We also tested whether we could reduce dietary CP below 16.6% by feeding a protected SBM (Olmos Colmerero and Broderick, 2004). Although milk and protein yields were similar with the 2 diets with 16.6% CP (with or without added RUP) to that obtained by feeding 17.6% CP, 2.6 lb/day of milk was lost by reducing dietary CP to 15.6%, even though that diet was supplemented with a SBM high in RUP (Table 8). Methionine and lysine are the two AA most often cited as limiting for lactating dairy cows (e.g., Schwab, 1996). The enhanced

production with RUP may have resulted from the AA patterns of fish meal and canola meal being complementary with microbial protein as AA sources for milk protein formation (Broderick, 1994). These results also indicate that RUP from SBM may not be as effective. Responses to ruminally protected methionine (**RP-Met**) have been more consistent than to protected lysine (Armentano et al., 1997) and this has reduced commercial interest in supplying protected lysine products. The advantage of post-ruminal supplementation with a specific AA is clear—requirements for the limiting metabolizable AA may be met with relatively little N input to the animal. The potential value of exploiting this strategy was shown recently in Germany where supplementing RP-Met to a 14.7% CP diet resulted in milk protein secretion equal to that of a 17.5% CP diet, but at 31 versus 27% conversion of dietary N to milk N (Kröber et al., 2000). We will report comparable results at the annual meeting of the American Dairy Science Association this summer. Similar protein yield, and even greater milk and FCM yields, were observed when RP-Met was fed with 17.3 and 16.1% CP diets versus an 18.6% CP diet without RP-Met.

Future Developments—Supplementation with N-Free "Amino Acids"

Recently, there has been renewed interest in supplementing diets with the liquid form of the hydroxy-analog of methionine (**MHA**, also abbreviated **HMB**; Koenig et al., 1999) as a post-ruminal source of methionine. Research conducted about 30 years ago suggested some benefit to feeding the calcium salt of this compound (Chandler et al., 1976). Wool growth responses with feeding calcium MHA were small, indicating that very little of this material escaped ruminal degradation (Cottle, 1988). However, a liquid MHA drench gave rise to about 20% of the wool growth response of the abomasally infused compound (Stephenson et al., 1990). Koenig et al. (1999) reported that 50% of the liquid MHA supplied orally contributed post-ruminal methionine. It has been speculated that escape may be enhanced because this form of MHA flows with the liquid phase or may be absorbed at the omasum (McCollum et al., 2000). A 50% ruminal escape would make this an economical form of supplemental methionine containing no N. However, recent research based on plasma AA concentrations suggested that very little liquid MHA served as a post-ruminal methionine source (C.G. Schwab, University of New Hampshire, personal communication). A ruminally-protected form of MHA is not available commercially. Branched-chain volatile fatty acids (**VFA**) were another N-free supplement that received considerable attention about 20 years ago. These compounds can be used by certain ruminal bacteria to synthesize the branched chain essential AA that are incorporated into their protein; there was some evidence that supplements of branched-chain VFA stimulated production of dairy cows fed corn silage diets (Felix et al., 1980). Interest in branched-chain VFA may have waned because the responses observed in large scale collaborative feeding studies, although usually positive, were much smaller than was reported in early trials. There has been about 30 years of experience using a number of the a-keto acids of the essential AA to replace dietary protein in human patients with kidney disease (e.g., Chow and Walser, 1974; Walser et al., 1987). A possible future stratagem might be to use ruminal protection of several of these α-keto acids as N-free sources of AA with the object of reducing N excretion to the environment from lactating cows.

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Table 1. Effect of dietary CP on milk production, milk composition, digestibility, and urinary N excretion (Olmos Colmenero and Broderick, 2003).[1]

	Dietary CP, % of DM						*P*	
	13.5	15.0	16.5	17.9	19.4	SE	Linear	Quad
DMI, lb/day	47.6^{b}	48.1^{ab}	49.6^{a}	47.6^{b}	47.8^{ab}	0.9	0.91	0.12
BW gain, lb/day	0.49	0.46	0.7	0.57	0.64	0.16	0.21	0.72
Milk Production, lb/day	80.0^{b}	82.0^{ab}	84.4^{a}	80.7^{b}	81.6^{ab}	2.0	0.60	0.11
Milk/DMI	1.71	1.71	1.72	1.7	1.72	0.04	0.87	0.99
3.5 % FCM, lb/day	75.2^{b}	78.5^{ab}	80.9^{a}	78.7^{ab}	79.6^{ab}	2.4	0.09	0.17
Fat, %	3.17^{c}	3.26^{abc}	3.23^{bc}	3.49^{a}	3.45^{ab}	0.12	0.00	0.99
Fat, lb/day	2.51	2.65	2.73	2.71	2.73	0.13	0.06	0.30
Protein, %	3.09	3.15	3.09	3.18	3.16	0.04	0.15	0.92
Protein yield, lb/day	2.43^{b}	2.54^{ab}	2.60^{a}	2.49^{ab}	2.54^{ab}	0.09	0.21	0.10
SNF, %	8.92	8.96	8.93	9.01	9.00	0.05	0.09	0.89
SNF, lb/day	7.08^{b}	7.28^{ab}	7.58^{a}	7.14^{b}	7.30^{ab}	0.20	0.42	0.14
Milk N/N Intake	0.367^{a}	0.344^{b}	0.307^{c}	0.279^{d}	0.255^{e}	0.006	<0.01	0.58
DM digestibility, %	71.2^{c}	74.6^{a}	74.0^{a}	72.5^{b}	72.3^{bc}	0.6	0.79	<0.01
OM digestibility, %	72.1^{c}	75.5^{a}	75.0^{a}	73.6^{b}	73.5^{b}	0.6	0.47	<0.01
NDF digestibility, %	45.8^{c}	51.2^{a}	49.5^{ab}	48.0^{b}	48.7^{b}	1.0	0.18	<0.01
Urea-N excretion, g/day	63.2^{e}	91.0^{d}	128.4^{c}	174.0^{b}	208.1^{a}	6.6	<0.01	0.43
Microbial CP flow, g/day	993^{b}	1082^{ab}	1144^{a}	1127^{a}	1144^{a}	67	0.02	0.21

^{a,b,c,d}Means in rows without common superscripts are different ($P < 0.05$).

[1]CP = Crude protein, DM = dry matter, DMI = dry matter intake, BW = body weight, FCM = fat-corrected milk, SNF = solids not fat, OM = organic matter, NDF = neutral detergent fiber, SE = standard error of the differences of the least square means, and Quad = quadratic.

Table 2. Effect on yield of 3.5% fat-corrected milk (FCM) and excretion of manure N of feeding dairy cows four different CP regimes during the first 16 weeks and last 28 weeks of 44-week lactations. Data from Wu and Satter (2000).

	Week of lactation			
Protein regime	1-16	17-44	3.5 % FCM	Manure N
	(Ration CP, % of DM)		(lb/lactation)	
Low/Low	15.4	16.0	23,570^{b}	279^{c}
Mid/Low	17.4	16.0	25,640^{a}	309^{b}
Mid/Mid	17.4	17.9	26,020^{a}	358^{a}
High/Mid	19.3	17.9	25,480^{a}	355^{a}

^{a,b,c}Means in columns without common superscripts are different ($P < 0.05$).

Table 3. Effect of diet on DMI, BW gain, and yield of milk and milk components (Vagnoni and Broderick, 1997).[1]

Item	AH	AS	AH plus 3% FM	AS plus 3% FM	SE	$P > F$[2] Forage	FM	Forage x FM
DM intake, lb/day	57.8	54.5	56.9	55.1	0.7	<0.01	0.96	0.37
Milk, lb/day	89.7	86.9	90.2	90.6	0.9	0.11	<0.01	0.04
Fat, %	3.25	3.48	3.30	3.36	0.05	0.01	0.51	0.13
Protein, %	3.14	3.10	3.17	3.17	0.02	0.19	<0.01	0.38
Lactose, %	4.83	4.84	4.81	4.84	0.01	0.11	0.72	0.63
SNF, %	8.66	8.65	8.69	8.68	0.02	0.58	0.20	0.84
Yield, lb/day								
Fat	2.91	2.95	2.95	3.04	0.02	0.25	0.21	0.95
Protein	2.80	2.65	2.84	2.87	0.02	0.1	<0.01	0.03
Lactose	4.32	4.14	4.34	4.41	0.03	0.32	<0.01	0.04
SNF	7.74	7.39	7.85	7.89	0.04	0.15	<0.01	0.04
Efficiency, milk/DMI	1.58	1.60	1.59	1.67	0.02	0.01	0.03	0.20

[1]AH = Alfalfa hay, AS = alfalfa silage, FM = fish meal, DMI = dry matter intake, BW = body weight, SNF = solids not fat, and SE = standard error.
[2]Probability of a significant contrast effect.

Table 4. Effect of processing on digestibility of corn and barley starch (Owens et al., 1986).

Processing Method	Proportion of Starch Digestion, % Rumen	Small Intestine	Large Intestine	Total Tract
Cracked Corn	69	13	8	89
Ground Corn	78	14	4	94
Steam-Flaked Corn	83	16	1	98
High Moisture Corn	86	6	1	95
Ground Barley	94	. . .	. . .	. . .

Table 5. Effect of replacing alfalfa silage with corn silage (Brito and Broderick, 2003).

Item	Alfalfa Silage/Corn Silage			
	100/0	74/26	47/53	21/79
Composition (% of DM)				
Alfalfa silage	50.5	37.1	23.6	10.2
Corn silage	0	13.3	26.7	40.0
Crude protein	17.3	17.0	16.8	16.6
Production				
DM intake (lb/day)	58.4[a]	57.1[a]	55.1[b]	51.1[c]
Milk yield (lb/day)	91.5[a]	92.6[a]	91.5[a]	87.1[b]
Rumen ammonia (mg/dl)	21.0[a]	20.0[a]	17.5[b]	12.3[c]

[a,b,c]Means in rows without common superscripts are different ($P < 0.05$).

Table 6. Relative ruminal in vitro escape and utilization of supplemental protein (based on milk protien yield) from slowly degraded proteins in lactating cows fed alfalfa silage based diets.

Test Protein Source	Relative Response (Solvent soybean meal = 1)		
	Relative in vitro protein escape	Relative utilization (no. trials)	
Expeller soybean meal[1]	1.78	1.48	(3)
Fish meal[2]			
High solubles	1.70	1.56	(1)
Low solubles	1.98	2.07	(2)

[1]Broderick et al., 1990.
[2]Broderick, 1992.

Table 7. Effect of supplementing with urea or different sources of true protein on production and omasal protein flows in lactating dairy cows. Diets were composed principally of alfalfa and corn silages plus high moisture corn (Brito and Broderick, 2004).[1]

Item	Supplemental protein				SED	P > F
	Urea	SSBM	CSM	CM		
CP, % of DM	16.5	16.5	16.6	16.6		
Production (lb/day)						
DM intake	48.7[c]	53.4[b]	54.5[ab]	54.9[a]	0.9	<0.01
Milk	72.5[b]	88.2[a]	89.3[a]	90.6[a]	2.3	<0.01
Milk protein	2.03[c]	2.71[ab]	2.60[b]	2.80[a]	0.07	<0.01
Milk fat	2.23[c]	2.69[ab]	2.60[b]	2.84[a]	0.11	<0.01
Omasal protein flows (g/day)						
Microbial protein	2344[b]	2706[a]	2706[a]	2775[a]	120	0.04
RUP	538[c]	987[b]	1348[a]	1150[ab]	106	<0.01
Total protein	2882[c]	3693[b]	4054[a]	3925[ab]	220	<0.01

[1]CM = canola meal, CSM = cottonseed meal, SED = standard error of the least square means difference, SSBM = solvent soybean meal, CP = crude protein, DM = dry matter, and RUP = rumen undegraded protein.

[a,b,c]Means in rows without common superscripts are different ($P < 0.05$).

Table 8. Effect of supplementing RUP from heat-treated SBM or CP from solvent SBM on production and N metabolism in lactating dairy cows. Diets composed principally of alfalfa and corn silages plus high moisture corn (Olmos Colmenero and Broderick, 2004).[1]

Item	A	B	C	D	Contrasts (*P*)		
CP, % of DM	15.6+RUP	16.6-RUP	16.6+RUP	17.6-RUP	A vs. B	B vs. C	B vs. D
SBM, % of DM	4.5	0	5.9	0			
Production (lb/day)							
DM intake	55.6	56.4	56.2	58.2	0.39	0.81	0.09
Milk	85.5	88.2	88.8	88.4	0.08	0.68	0.91
3.5% FCM	90.6	93.0	94.6	94.1	0.21	0.44	0.59
Milk protein	2.67	2.78	2.73	2.80	0.44	0.54	0.76
Milk fat	3.31	3.40	3.46	3.44	0.37	0.43	0.54
Proportion of N-intake (%)							
Milk N	30.1	29.3	28.8	26.8	0.27	0.50	<0.01
Urinary N	33.3	33.2	35.7	37.6	0.97	0.12	<0.01
Fecal N	33.9	32.7	32.3	31.4	0.32	0.76	0.30

[1]RUP = Rumen undegradable protein, SBM = soybean meal, CP = crude protein, DM = dry matter, FCM = fat-corrected milk, and ESBM = expeller solvent soybean meal.

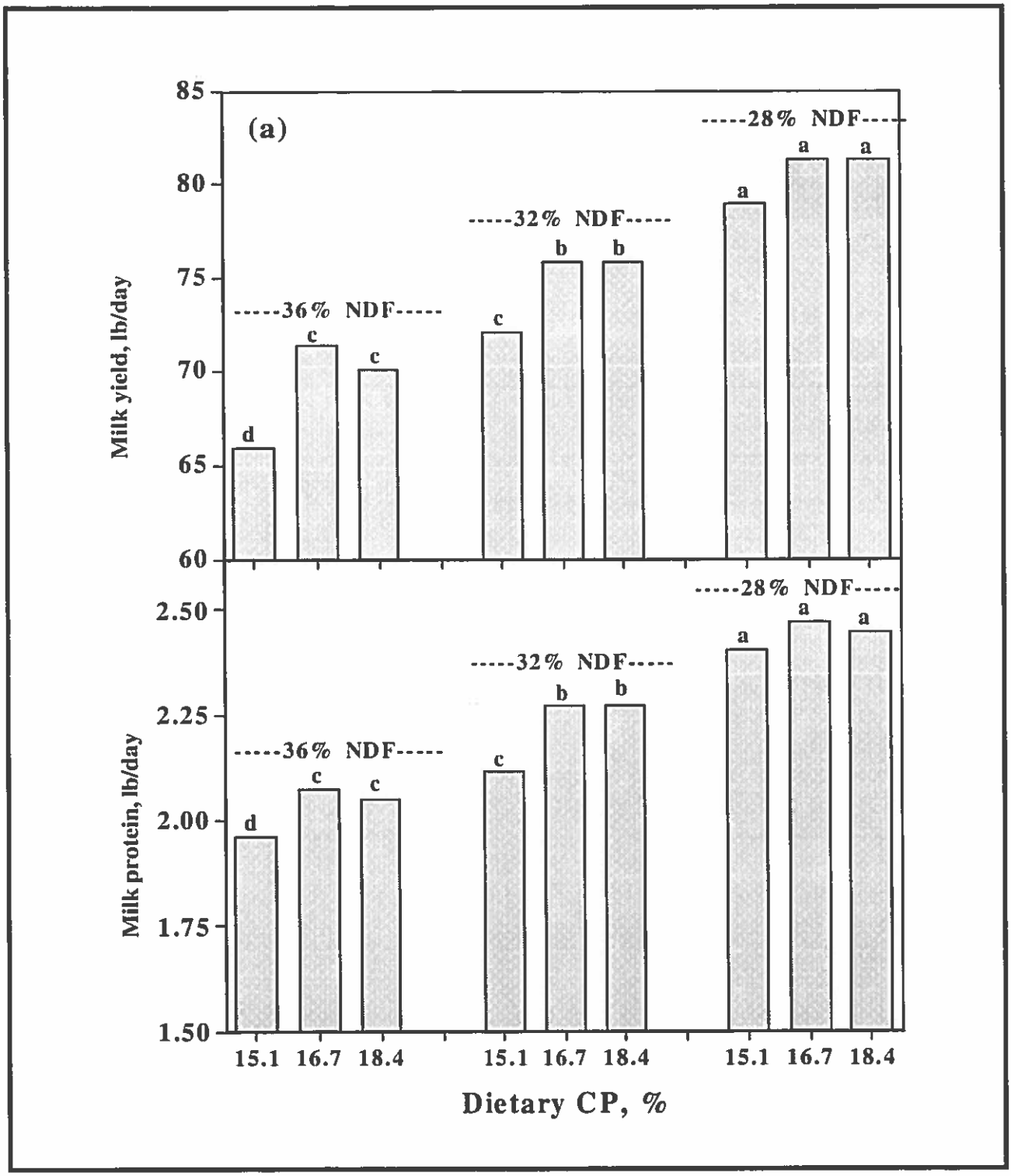

Figure 1. Effect on milk and protein yield of feeding lactating cows crude protein (CP; from solvent soybean meal) at 15.1, 16.7, and 18.4% of DM at each of 3 dietary energy densities (obtained by feeding 75, 62, and 50% of forage DM to give 36, 32, and 28% NDF; Broderick, 2003). Forage was 60% alfalfa silage and 40% corn silage in all diets. Bars with different superscripts are different ($P < 0.05$).