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Proceedings

Tri-State Dairy Nutrition Conference

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The Conference Planning Committe extends appreciation to Mrs. Amanda Hargett for her assistance in organizing the Conference and acknowledges Mrs. Michelle Milligan for assistance with preparation of the *Proceedings*.

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Also, abstracts from the papers presented at the 2001 Conference are available on the website.

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_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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Feeding Program Management

Physiological Effects of Heat Stress on Production and Reproduction

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Abstract

Heat stress has a significant impact on dairy cattle in the United States for a period of weeks to months each summer, depending on location. Several environmental factors contribute to heat stress, including elevated ambient temperature, radiant energy (direct and reflected sunlight), and high relative humidity, which compromise the ability of the cow to dissipate body heat. In addition, factors within the cow including level of production, feed intake, and activity contribute to heat production in the cow. When the cow is unable to dissipate sufficient heat to maintain thermal balance, her body temperature rises and heat stress occurs. The most noticeable response to heat stress is reduced milk yield, because this is measurable in both the milk tank and the milk check. Many other changes occur, including reduced feed intake, impaired reproductive performance, and often body weight loss. There are many housing, management, and nutritional modifications which one can implement to address the challenges associated with heat stress. Housing with cooling, minimizing exposure to the sun, and diet reformulation can be used to enhance milk yield and reduce intake losses. Cooling can also enhance reproductive performance of cows. An understanding of the effects of heat stress is necessary in developing an effective and economically viable system to manage cows during hot weather.

Introduction

Summer brings the need for management changes for dairy cows exposed to hot weather. Heat stress **(HS)** depresses feed intake, reduces milk yield, increases body weight loss, and impairs reproduction. Because feed intake declines sharply during hot weather, it is not unusual to lose 8 to 10 lb/day of milk per cow during summer. The effects of HS are costly to the dairy farmer, but there are opportunities to recover some of the losses to hot weather. There is no single magic bullet to prevent HS, but there are a number of management changes which can be used. This paper will address some tools to use during hot, humid weather.

How Does Hot Weather Affect the Cow?

The normal temperature of a dairy cow is 101.5°F. When temperatures exceed about 77°F or when the temperature-humidity index exceeds 72°F, cows show signs of HS. Indicators that cows are suffering the effects of hot weather include:

- Increased body temperature >102.6°F
- Panting >80 breaths/minute
- Reduced activity
- Reduced feed intake (>10 to 15%)
- Reduced milk yield (10 to 20%, or more!!)

The HS can occur chronically over an entire summer, such as in the deep south or west-

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ern states, or intense bursts of HS may occur for shorter periods in mid-western regions. These conditions are particularly harsh for lactating dairy cows because intense bursts of hot weather can be devastating if cows are not adapted to high temperatures. The cow has several mechanisms to help dissipate body heat. These include:

1) Conduction, where the cow conducts heat to a cooler surface.
2) Convection, where thermal currents leave the cow's body.
3) Radiation, where the cow radiates heat to a cooler environment, such as the cool night sky.
4) Evaporation, where moisture is evaporated from the surface of her body (sweating) and from her lungs (panting).

Conduction, convection, and radiation depend on a large difference between the cow's body temperature and environmental temperatures. These mechanisms can be exploited to cool the cow, mechanically or passively. Evaporation works best at low humidity. When the environmental temperature nears the cow's body temperature, coupled with high relative humidity, all the cow's cooling mechanisms are impaired. Consequently, the cow's body temperature rises and the cow exhibits physiologic responses to hot weather. The cow also reduces feed intake to produce less metabolic heat which is a protective mechanism.

There are several factors which influence how severe HS is for the cow. These include:

- ♦ Environmental conditions
- ♦ Level of production and feed consumed
- ♦ Stage of lactation
- ♦ Cooling management
- ♦ Exercise requirements
- ♦ Breed (?) and color

All these factors influence heat production, how effectively the cow dissipates heat, and the degree of stress to which the cow is subjected.

Heat Stress Effects on Reproduction

In addition to the effects on intake and milk yield, heat stress seriously impacts reproduction. In one Florida study, conception rate **(CR)** dropped from about 52% during cool months to 30% for the months of June through September (Badinga et al., 1985), and in practice, CR often declines to less than 10% during summer. Reduced CR was associated with increasing environmental temperature, but temperature had much less effect on CR in heifers than in cows. Cows are larger, have more difficulty dissipating heat, and when lactating, consume more feed and produce more heat at the time they are being bred. Mature cows are more susceptible to HS than heifers, resulting in poorer reproductive performance for cows. Heat stressed cows are less likely to exhibit standing heat and often show heat at night when they are less likely to be observed. In addition, duration of estrus is shorter for cows subjected to HS (Wolfe and Monty, 1974), shortening the time when cows may be observed in heat.

There are several reasons for impaired reproductive performance during hot weather. Higher intrauterine temperature likely reduces embryo survival, and there is a relatively narrow time around insemination when elevated uterine temperature has the greatest impact on conception. In Florida research, the uterine temperature on the day of insemination and the day following insemination had the greatest effect on fertility (Gwazdauskas et al., 1973; Thatcher, 1974). Embryos at day 1 of pregnancy are more susceptible to maternal heat stress than at days 3 to 7. Knowing this, one may cool the cow intensively for a short period around breeding and improve CR. Even if the embryo survives, its development may be inhibited by elevated uterine temperature. Early embryonic deaths were partly responsible for a decrease in CR from 44.4 to 25.3% as the environmental temperature increased from 83.1 to 98.1°F (Roman-Ponce et al., 1977). One reason for the greater uterine temperature is the higher body temperature and reduced uterine blood flow to remove heat because more blood is shifted to the skin to help dissipate body heat. In pregnant ewes, uterine blood flow was reduced 20 to 30% for each 1.8°F increase in core temperature (Dreiling et al., 1991).

Even with successful conception, HS has negative effects on the fetus, pregnancy, and subsequent lactation. Cows shaded during the dry period gave birth to larger calves and had greater 100- and 305-day milk yields than cows that were unshaded during the dry period (Collier et al., 1982). Reduced fetus size was correlated with reduced placenta size in sheep, and placenta weight was reduced 54% by heat exposure of ewes (Bell et al., 1989). They theorized that a smaller fetus resulted from placenta size, which may be due to hormonal changes brought on by HS. Thus, there are several ways in which heat stress impacts reproduction in the lactating dairy cow.

Modify the Cow's Environment

There is no doubt that shading is one of the most important and one of the cheapest ways to modify the cow's environment during hot weather. One can use trees, shade cloth, portable shades, permanent shade structures, or freestall barns. Florida research (Collier et al., 1982) showed over 10% gain in milk yield simply by shading cows. Cows shaded during the dry period had calves which weighed more at birth and milk yield increased almost 1800 lb (13.6%) in a 305-day lactation. Lactating cows must be provided shade to protect them from the heat of the sun. Smaller herds may use portable shades. Same consideration for shade use include:

Portable Shades:

- ♦ Portable shades minimize mudholes
- ♦ A minimum 80% shade cloth should be used
- ♦ Allow 16.5 m^2 (54.5 ft^2) per cow
- ♦ Minimum about 12 to 13 ft high
- ♦ Orient shade structures north to south (for drying effects of sun)

Permanent Shade Structures:

- ♦ Eave height at minimum of 13 ft, 15 to 17 ft preferred
- ♦ Adequate ridge vent: 30 inches for a 100 ft barn
- ♦ Slope: 4 inches on 12 inches preferred (4/12 pitch)
- ♦ Open ridge vent, others possible

Barns should be well ventilated. Barns with enclosed walls are very hot in summer. Side curtains can be opened in summer and coupled with an open ridge will greatly enhance passive ventilation.

Unfortunately, shade alone is usually not adequate. Additional cooling in the form of fans and sprinklers or evaporative cooling foggers are usually needed. Several different options are available. However, if you are going to put water on the cows, air movement by fans is a necessity. Sprinklers should soak the cow's back but not the udder. Fans should move enough air to evaporate the water. Water application should last from 0.5 to 3 minutes to apply 0.05 inches of water per cycle. Fans should run 12 to 14.5 minutes when using a 15 minute cycle, but can run continuously. Fans should be placed at a maximum of 10 fan diameters apart. Thus, 36 in. fans can be placed at a maximum 30 ft spacing, although some fan installations are being placed at 20 ft intervals. Direct drive, sealed motor fans reduce maintenance and are effective. Note that fans and sprinklers are usually placed near the feed bunk. The coolest place in the barn should be near the feed bunk to encourage eating. Fans, but not sprinklers, may be placed over free stalls.

Supplemental cooling will improve cow performance during hot weather. In research done in Florida, Kentucky, Missouri, and Israel, cooling using fans and sprinklers improved DM intake by 7 to 9%, milk yield by 8.6 to 15.8% (4.4 to 7.9 lb/day), reduced rectal temperature by 0.8 to 1.0°F and reduced respiration rate by 17.6 to 40.6% (16 to 39 breaths/minute) [Bucklin et al., 1991].

Misters should be avoided because misted water may form an insulating layer which traps heat in the body and does not cool. However, high pressure fogger/fan systems are available which spray a fog at high pressure into the fan stream. This cools the air, does not wet the cow, and can cut water use as well as water going into the lagoon. This system can be used over free stalls because it does not wet the bedding. Fans should run 24 hours a day during hot weather, but foggers should run during the day when humidity is lower. Foggers should be turned on when temperature exceeds 78°F. Foggers require 5 micron filters to maintain water quality so that nozzles do not clog and have a significant maintenance requirement. When foggers are used, barns must have high eaves and ridge vents to remove high humidity air.

When to Use Cooling?

Lock up 10 cows on a hot day to measure temperature and count respiration rates. Use cooling if (Bray and Bucklin, 1996):

- Rectal temperatures exceed 102.5°F
- Respiration rates exceed 80 breaths/minute
- If dry matter intake and milk yield drop by 10% in hot weather

Impact of Cooling on Reproduction

Cooling should improve reproductive performance if body temperature can be lowered. Cows cooled by sprinkling for 30 seconds and using fans for 4.5 minutes for half hour intervals nine times per day had lower body temperature (0.9 to 1.6°F) and greater milk yield (5.7 lb/day)[Her et al., 1988]. Cows showing standing estrus improved from 45% of the noncooled cows to 70% of the cooled cows. Cows with silent or no ovulation comprised 33% of cows not cooled but only 12% of cooled cows. Conception rate did not improve with cooling, possibly because cows were cooled during a limited portion of the day. In Arizona, cows under evaporative cooling had a shorter calving interval and fewer days open (374 and 98 days respectively) than cows under shade only or foggers (391 and 114 days respectively)[Ray et al., 1992]. In arid climates, evaporative cooling may be superior to fans and sprinklers. In Saudi Arabia, cows under evaporative cooling had better pregnancy rates (34.5%) than those with fans and sprinklers (23.8%)[Ryan et al., 1992]. There was no comparison with cows that were not cooled, although one would speculate that their performance would be substantially less.

As mentioned earlier, heat stressed cows had smaller calves and produced less milk. When cows were cooled with fans and sprinklers during the dry period, they averaged 7.7 lb/day more milk than shade only cows for the first 150 days postpartum and delivered calves that were 5.9 lb heavier (Wolfenson et al., 1988). Managing the dry cow, and especially the transition cow, to minimize heat stress will result in improved comfort, improved hormonal status as it relates to the pregnancy, and will encourage more intake prior to calving when intake is normally depressed. Stress reduction in the dry and transition cow is the next area of progress for dairy producers in areas where significant heat stress occurs.

Don't Make Cows Walk Long Distances in the Heat

Did you know that exercise takes energy and creates heat? Cows walked about 0.5 miles prior to the afternoon milking had body temperatures well above normal. It took Holstein cows until the morning to recover to a normal body temperature following the exertion from walking. Avoid moving cows long distances during the heat of the day. If possible, graze cows at night.

Give the Cow Plenty of Water

Cows need an abundance of clean, cool water. In fact, one scientist was quoted as saying that if you wouldn't drink the water, you shouldn't expect your cows to drink it. Water is closely linked to performance, and cows consume 2 to 4 lb of water for each pound of feed intake and an additional 3 to 5 lb of water for each pound of milk produced. As the environmental temperature increased from 40 to 80°F, the water consumption of dry cows increased from 6 to 8.1 gal/day, for 40 lb/day milk producers from 15.8 to 16.4 gal/day, and for 80 lb/day milk producers from 26 to 45 gal/day. It is obvious that a large quantity of water must be available at all times.

Use Good Nutrition

Dry matter intake **(DMI)** is the key to good performance. Energy intake is directly related to DMI and practical approaches to greater DMI through feeding management changes include: 1) more frequent feeding, improved forage quality, use of palatable feeds, and good nutrient balance, and 2) greater nutrient (including energy) density.

Reformulate Rations

Feed intake declines with hot conditions and rations must be reformulated in an attempt to deliver an adequate quantity of nutrients. Determine what DMI is and reformulate the ration to increase nutrient density to support milk yield.

Protein

Inadequate dietary protein has an immediate impact on milk yield. Older Louisiana heat stress work (Hassan and Roussel, 1975) showed that crude protein **(CP)** at 14.3% (adequate) or 20.8% (high) improved milk yield by 6% at the higher CP level. However, excess protein takes energy to process and excrete. In one study where 19 and 23% CP diets were fed (Danfaer et al., 1980), milk yield was reduced by over 3.1 lb/day simply by feeding the high protein diet. In addition, excessive CP may impair reproductive performance. Cows were fed ryegrass pasture supplemented with corn silage, soybean meal, and a rumen undegradable protein **(RUP)** source so that diets contained moderate (about 17.5%) or high (23.1%) CP and the moderate CP diet plus high RUP (McCormick et al., 1999). Cows fed excess CP had lower first breeding pregnancy rates (24.1 versus 41.0%) and lower overall pregnancy rates (53.5 versus 75.4%) than cows on the moderate CP diet. Reproductive performance was similar between the moderate CP diet and the high RUP diet. Excessive CP resulted in high blood urea and ammonia concentrations, which reduced CR. Very high CP diets can impair the reproductive performance of the cow, so the practice of feeding high CP diets during hot weather to compensate for lower intake should be pursued with caution.

Results from Arizona research (Huber et al., 1994) suggest to keep rumen degradable protein below 61% of CP, and not to exceed NRC (1989) recommendations by 100 g/day of N (equivalent to about 3% CP in the diet). Protein quality was a very important factor, especially lysine. There is much yet to be learned about protein nutrition for heat-stressed cows, and the research continues. Programs are available today (CPM Dairy) which help to optimize dietary protein feeding.

Energy

The most limiting nutrient for dairy cows is usually energy. A common approach to increase energy density during hot weather is to reduce forage concentration in the ration and increase concentrates. The logic is that less fiber (less bulk) will encourage intake, while more concentrates increase the energy density of the diet. However, excessively high concentrate feeding (high non-structural carbohydrates **[NSC]**) should be avoided in dairy diets. The optimum NSC concentration appears to be in the range of 33 to 38% of dietary DM. When dietary NSC is too high, milk yield actually declines, despite high dietary energy density. The reason is what we often see on many farms: excessive grain feeding causes acidosis, forcing cows off feed and causing digestive upsets. Some general feeding recommendations follow.

Grain and Fiber Recommendations:

- ♦ Do not exceed 55 to 60% concentrate in rations
- ♦ Non-structural carbohydrates should be in the range of 35 to 40% of dietary DM
- ♦ Neutral detergent fiber in the range of 28 to 34% of dietary DM
- ♦ Maintain adequate forage particle size!

Another way to boost energy and maintain acceptable dietary fiber levels is to add fat to the diet. Fat contains 2.25 times as much energy as the same quantity of carbohydrate, does not add to rumen acidity, and is particularly valuable as an energy supplement when DMI is limited, as it is during hot weather. Fat sources include oilseeds (cottonseed, and soybeans), tallow, animal-vegetable fat blends, and rumen protected fats. Fats are used more efficiently by the cow, and improved efficiency means lower heat production, making fats particularly valuable during hot weather. However, just like other feeds, too much fat is not a good thing. Excessive fat can cause digestive upsets, off-feed conditions, and reduce fiber digestion.

Feeding Fats:

- ♦ Feed 5 to 7% dietary fat maximum (DM maximum)
- ♦ Avoid excessive vegetable oils
- ♦ Feed cottonseed at 12 to 15% of the diet
- ♦ Boost dietary fiber with high fat levels

Fiber Feeding:

Feeding high fiber diets during hot weather can limit DMI, result in a greater heat of digestion, and increase heat production in the cow. Proper forage and fiber feeding during hot weather is one of the greater challenges to proper nutrition. As mentioned earlier, low fiber diets are often fed to encourage greater intake. In addition, cows will often select their rations and eat less forage relative to concentrates. This results in an unbalanced ration which can cause acidosis.

Rations should contain a minimum 19% ADF, 28 to 34% NDF, and 75% of NDF should come from forage. The Penn State particle size recommendations for total mixed rations **(TMR)** are 6 to 10% or more of particles > 0.75", 30 to 50% in the 0.31 to 0.75 in. range, and 40 to 60% < 0.31 in. long. The greater the overall particle length, the less total forage required in the diet as long as it is consumed and not sorted from the ration. General forage feeding guidelines include: if fed separately, feed more forage at night, graze during cooler evening hours, keep silage and green chop fresh, clean feed bunks daily, feed TMR to minimize selection, and use high quality forages in summer.

Minerals:

Mineral needs for cattle change during hot weather. Cows sweat just like other mammals, but unlike humans who sweat more sodium, cow's sweat contains a large amount of potassium. Consequently, potassium requirements go up during summer. In addition, cows need more sodium and dietary magnesium needs to be boosted because of competition with potassium for absorption. General mineral recommendations for HS include:

- ♦ Potassium: 1.4 to 1.6% of DM
- ♦ Sodium: 0.35 to 0.45% of DM
- ♦ Magnesium: 0.35% of DM

Ration mineral content should be adjusted before the onset of summer so that the minerals are present when needed. Because it appears that high chloride content in the ration should be avoided, potassium supplementation with chloride salts is not recommended. Some research indicates that the use of buffers containing potassium and sodium are preferable to the chloride salts. Also, adjust trace mineral and vitamin supplementation for reduced intake to insure adequate consumption.

Additives:

There are several feed additives that may be beneficial during hot weather. Buffers, such as sodium bicarbonate, are especially useful in low fiber diets, diets based on corn silage, when cows can select against forage consumption, and particularly during hot weather. Fed at about 0.75% of dietary DM or 5 to 6 ounces/day per cow, bicarbonate can help keep cows on feed and maintain milk fat percentage.

Yeast cultures and fungal products help to maintain a stable rumen environment. Some have shown additional benefits during hot weather. Better protein use, stable rumen pH, and better fiber digestion are potential benefits of these products. One should rely on documented results and not testimonials when considering these products.

One should consider which cows will benefit before using a product. An example is a field trial evaluating the B vitamin niacin during summer in Pennsylvania. Six grams of niacin were fed to lactating cows, and when compared with controls, niacin fed cows gave only 2.0 lb/day more milk. However, when cows producing >75 lb/day of milk at the start of the study were compared, the higher producers yielded 5.3 lb/day more milk. The moral of the story is that an additive should be targeted at the cows which are most likely to respond and not be wasted on cows that won't give an economic return to its use. An additive is only good if it is needed!

Summary

- ♦ Use environmental modifications to encourage intake
- ♦ Cooling cows can improve reproductive performance
- ♦ Reformulate diets to deliver the quantity of nutrients needed
- ♦ Increase energy density
- ♦ Avoid excessive fermentable carbohydrates
- ♦ Use high quality forage, maintain adequate fiber
- ♦ Include adequate protein and use high quality protein
- ♦ Formulate for mineral needs during heat stress
- ♦ Provide plenty of water at numerous locations with easy cow access

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Effects of Facilities on Dairy Cattle Performance

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Abstract

Dairy facilities can have a dramatic impact on milk production and cow health. All components of the dairy must be sized correctly to create an environment that is ideal for the dairy cow and the employees who will operate the facility. Milking facilities should be constructed to minimize heat stress and the time cows are away from feed and water. Minimizing travel distances to the milking parlor are essential. A number of critical decisions have to be made concerning cow housing and grouping strategies. The goal should be to have the number of groups needed to implement the management and feeding strategies the producer wishes to use. Often, bottlenecks are built into a dairy facility that prevents use of some feeding and management techniques. Dairy facilities should be designed to maximize dry matter intake and minimize heat stress. Providing cow cooling in the holding pen and cow housing areas is essential.

Introduction

Dairy facilities can have a dramatic impact on milk production and cow health. Over the years, field observations and results from research trials have been used to improve dairy facilities. In the United States, producers try to minimize facility cost while trying to maximize milk production per cow, reproductive efficiency, and cow health. Producers often use employees to operate their milking parlors as many hours as possible, reducing their fixed cost per cow. Under these conditions, producers have to be extremely careful where they invest dollars into dairy facilities. This paper will discuss some of the issues faced by dairy producers.

Milking Parlors, Holding Pens, and Exit Lanes

Reducing stress on cows in the milking facility is very important. These facilities should be constructed to minimize the time that cows are away from feed and water. Travel time to and from the parlor can be reduced by correctly sizing travel and parlor exit lanes. Currently, herringbone, parallel, and rotary parlors are the three predominant types of parlors constructed. Expanding rotary parlors is difficult. The operator pit can be constructed in parallel and herringbone parlors to allow additional stalls to be added as the dairy expands.

Typically, milking parlors are sized so that cows can be milked once in 10 hours when milking 2x per day; 6.5 hours when milking 3x per day; and 5 hours when milking 4x per day. Using these criteria, the milking parlor will be sized to accommodate the cleaning and maintenance of the parlor. The facilities or cow groups are determined based on milking one group in 60 minutes when milking 2x, 40 minutes when milking 3x, and 30 minutes when milking 4x. Sizing groups of cows to be milked in these time frames will minimize the time cows are away from feed and water.

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The drip pen and wash pen are the most challenging environments that a dairy cow faces. Drip pen and wash pen cooling should be used to minimize heat stress in this area. Drip pens and wash pens are designed based on 15 ft^2 per cow, with a group size not greater than 200 cows. If the group size is greater than 200 cows, the area per cow should be increased to 16 to 17 ft^2 per cow. Ideally, both the wash pen and the drip pen should be sized to hold one group of cows. When a wash pen is not used, over sizing the holding pen by 25% allows a second group to be moved into the holding pen while the crowd gate is pulled forward and the first group is finishing being milked (Smith et al., 1997).

Exit lane width is dependent on the number of stalls on one side of the milking parlor. In parlors with 15 stalls or less per side, a clear width of 3 ft is acceptable. For parlors containing more than 15 stalls per side, a clear exit lane width of 5 to 6 ft is desired (Smith et al., 1997). The width of cow traffic lanes should be sized according to group size. When group size is less than 150 cows, 14 ft traffic lanes are typically used. Lane width is increased to 16 ft for group sizes from 150 to 250 cows, 20 ft for group sizes from 251 to 400, and to 24 ft when group size is greater than 400 cows (Armstrong, 2001).

Selecting Cow Housing

The predominant types of cow housing in the western United States are dry-lots and freestalls. This decision is based on climate, management style, and equity available for constructing dairy facilities. Typically, dry-lot facilities can be constructed where the moisture deficit (annual evaporation rate minus annual precipitation rate) is greater than 20 inches annually (Sweeten and Wolfe, 1993). However, frequency and severity of winter rainfall and blizzards are becoming important selection criteria. These facilities would need to provide 500 to 700 ft^2 per lactating cow depending on the evaporation rate and 40 to 50 ft^2 of shade per cow. Windbreaks are constructed in areas where winter weather is severe. It is important to realize that dry-lot housing does not allow managers the luxury of managing the risk that Mother Nature can present in the form of rain, snow, and severe wind-chill. The advantage of dry-lot facilities is the lower capital investment per cow as compared to freestall housing.

Freestall housing is usually selected to minimize the effect of weather changes, to improve cleanliness, and cow comfort. Providing a clean dry bed is essential to minimize the incidence of mastitis in the herd. The disadvantage of freestall housing is the cost of constructing freestall housing and the costs associated with maintaining the beds and manure management.

One of the critical decisions that producers make is the type of freestall barn they build. The most common types are either 4- or 6-row barns and many times the cost per stall is used to determine which barn should be built. Data found in Table 1 represent the typical dimensions of the barns, and Table 2 demonstrates the effects of overcrowding upon per cow space for feed and water. Grant (1998) suggested that feed bunk space of less than 8 in./cow reduced intake and bunk space of 8 to 20 in./cow resulted in mixed results. Even at a 100% stocking rate, the 6-row barn only offers 18 in./cow of feed line space. When over crowding occurs, this is significantly reduced. Four-row barns, even when stocked at 140% of the stalls, still provide more than 18 in./cow of bunk space. In addition, when water is only provided at the crossovers, water space per cow is reduced by 40% in the 6-row barn as compared to 4-row barns. Much of the current debate over the effect of 4- and 6-row barns upon intake is likely related to presence or absence of management factors which either reduce or increase the limitations of access to feed and water in 6-row barns.

Recommendations concerning access to water vary greatly. Current recommendations suggest a range of 1.2 to 3.6 linear inches per cow (Smith et al., 2000). In the Midwest, the typical rule is one waterer or 2 linear ft of space for every 10 to 20 cows. In the Southwest, the recommendation is 3.6 linear inches of space for every cow in the pen. Typically, water is provided at each crossover in 4 and 6-row freestall barns, and generally a 4 and 6-row freestall have the same number of crossovers. Thus, water access in a 6-row barn is reduced by 37.5% as compared to a 4-row barn (Table 1). When overcrowding is considered (Table 2), water access is greatly reduced and the magnitude of reduction is greater in 6-row barns. Milk is 87% water and water intake is critical for peak DM intake. When building 6-row barns or overcrowding either 4-row or 6-row barns, it is important to consider the amount of water space available. In warmer climates, 3.6 linear inches of waterer space per cow should be provided.

If construction costs are going to drive the decision between a 4- or 6-row freestall barn, overcrowding must be considered. Typically, 4-row barns are overcrowded 10 to 15% on the basis of the number of freestalls in the pen. Due to the limitations of bunk space, many times the 6-row barn is stocked at 100% of the number of freestalls. Thus, comparing the two buildings based on a per cow housed rather than a per stall basis would be more accurate. This will make the 4-row more cost comparable to the 6-row and maintain greater access to feed and water.

Grouping Strategies

The size and number of cow groups on a dairy farm are critical planning factors. Factors affecting the number and types of groups are largely associated with maximizing cow comfort, feeding strategies, reproduction, and increasing labor efficiency. Lactating cows are allotted to one of seven classifications:

1. Healthy lactating heifers
2. Healthy lactating cows
3. Fresh cows and heifers with non-sellable milk
4. Fresh cows with sellable milk
5. Fresh heifers with sellable milk
6. Sick cows with non-sellable milk
7. High risk sellable

Healthy lactating heifers and cows are typically housed in 8 to 10 groups. The cows in classifications 3 to 7 are typically housed in the special needs area along with close-up cows and heifers. Table 3 lists suggested pens and pen sizes for different classifications of dairy cattle to be housed in the special needs facility.

Heifers respond favorably when grouped separately from older cows. Heifers have lower DM intakes and greater growth requirements as compared to older cattle. In addition, mixing heifers with older cattle increases social pressure, resulting in less than optimal heifer performance.

Close-up dry cows and springing heifers differ in nutritional requirements. Close-up cows will have greater intakes and are much more likely to develop milk fever than heifers. Springing heifers may also benefit from a longer transition period than normally allowed for cows. Thus, heifers and dry cows should be separated.

Close-up cows should be moved into a close up pen 21 days prior to calving. The diet in this pen typically has greater concentrations of protein and energy as compared to the far off dry cow diet. In addition, the diet should be low in calcium and potassium or contain anionic salts with appropriate amounts of calcium and potassium to prevent milk fever. Milk fever is generally not a problem with heifers, but heifers may benefit from receiving the typical transition diet for 5 weeks rather than 3 weeks. Thus, feeding a diet with higher levels of protein and energy without anionic salts for 5 weeks prior to freshening would be beneficial for heifers.

Just prior to calving, close-up cows and heifers would be moved into a group pen (maternity) with a bedded pack where they would calve. Following calving, cows and heifers are typically co-mingled until the milk can be sold. Cows and heifers would be segregated when they move out of the fresh non-sellable pen into the fresh pens. Cows and heifers would be housed in the fresh pens for 14 days where rectal temperatures, DM intakes, and general appearance can be monitored on a daily basis. Other pens for mature cows and heifers in the special needs area would be a sick pen which would be used to house cows which had been treated with antibiotics and a high risk pen for lame cows and slow milkers who still produce a lot of sellable milk but need some extra attention.

It is important to realize that the group sizes in the special needs area have been increased to account for fluctuations in calvings and cow and heifer numbers. If these pens are sized for static or average numbers, there will be a considerable amount of time where the special needs facility would over stocked. Over stocking cows prior to or after calving can have a dramatic impact on milk production and cow health.

Freestall Surfaces

Sand is the bedding of choice in many areas. It provides a comfortable cushion that forms to the body of the animal. In addition, its very low organic matter content reduces mastitis risk. Sand is readily available and economical in many cases. Disadvantages may include the cost of sand and/or the issues with handling sand laden manure and separating the waste stream. In arid climates, manure solids are composted and utilized for bedding. Producers choosing not to deal with sand or composted manure bedding, often choose from a variety of commercial freestall surface materials. Sonck et al. (1999) observed that when given a choice, cows prefer certain materials. Occupancy percentage ranged from over 50 to under 20%. Researchers suggested that the increase in occupancy rate was likely influenced by the compressibility of the covering. Cows selected freestall covers that compressed to a greater degree over those with minimal compressibility. Cows need a stall surface that conforms to the contours of their body. Sand and materials that compress will likely provide greater comfort as demonstrated by cow preference.

Feed Barrier Design

The use of self-locking stanchions as a feed barrier is currently a debated subject in the dairy industry. Shipka and Arave (1995) reported that cows restrained in self-locking stanchions for a four-hour period had similar milk production and DM intake as those not restrained. Arave et al. (1996a) observed similar results in another study; however, a second study showed similar intake but 6.4 lb/cow/day decrease in milk production when cows were restrained daily for a four hour period (9 AM to 1 PM) during the summer. Increases in cortisol levels were also noted during the summer but not in the spring (Arave et al., 1996b), indicating increased stress during the summer as compared to the spring. Another report (Bolinger et al., 1997) found that locking cattle for 4 hours during the spring months did not affect milk production or feed intake. All of these studies compared restraining cows for four hours to no restraint, and all animals were housed in pens equipped with headlocks. The studies did not compare a neck rail barrier to self-locking stanchions nor address the effects of training upon headlock acceptance. The argument could be made that four hours of continuous restraint time is excessive and much shorter times (one hour or less) should be adequate for most procedures. These studies clearly indicate that mismanagement of the self-locking stanchions, not the stanchions, resulted in decreased milk production in one of three studies with no affect on intake in all studies.

Another study (Batchelder, 2000) compared lockups to neck rails in a 4-row barn under normal and crowded (130% of stalls) conditions. Results of the short-term study showed a 3 to 5% decrease in DM intake when headlocks were used. No differences in milk production or body condition score were observed. It was also noted that overcrowding reduced the percentage of cows eating after milking as compared to no overcrowding. In this study, use of headlocks reduced feed intake but did not affect milk production.

A study was conducted by Brouk et al. (2001) in the summer of 2000 to determine the effect of headlocks and neckrails on milk production and DM intake. This trial was conducted on a commercial dairy and included 216 lactating Holstein cows (55, 2 year olds and 53 mature cows per pen) previously exposed to headlocks. Headlocks did not adversely affect milk production or DM intake in this trial. In summary, it does not appear that headlocks adversely affect milk production if they are managed correctly.

The correct feed barrier slope is also important. Hansen and Pallesen (1998) reported that sloping the feed barrier 20° away from the cow increased feed availability because the cows could reach 5.51 inches further than when the barrier was not sloped. Pushing feed up more frequently could achieve the same affect. One disadvantage of sloping the feed barrier is that feeding equipment is more likely to come in contact with the barrier which may result in significant damage to both.

The feeding surface should be smooth to prevent damage to the cow's tongue. When eating, the side of the tongue, which is much more easily injured, often contacts the manger surface. The use of plastics, tile, coatings, etc. will provide a smooth, durable surface, reducing the risk of tongue injury.

Cow Handling Systems

The current cow handling systems are lock-ups, sort gates, palpation rails, chutes, and combinations of the systems listed previously. Sort gates require electronic identification. They work fairly well to sort groups of cows from the parlor that are to be moved, beefed, dried off, etc. Managing reproduction as cows leave the milking parlor using sort gates is very difficult. Often times, cows can not be processed fast enough, putting employees and veterinarians in a position where they have to watch the clock. Inevitability, a second holding pen is created, increasing the time that cows are away from feed and water. This also creates a situation where cows can very easily end up in the wrong pen after they are processed. Headlocks have been used in the western United States for many years. Headlocks are a very efficient way to handle a large number of cows; however, they can be mismanaged. Producers should strive to reduce lock-up times to 1 to 1.5 hours per day. Locking cows up in the afternoon during summer months should be avoided. Heifers should be exposed to and trained to use lockups prior to entering the close-up pen.

Enhancing Production Potential by Controlling Environmental Temperature

Mature dairy cattle generally have a thermal neutral zone of 41 to 68°F. This may vary somewhat for individual cows and conditions. Within this range, it is generally assumed that impacts on intake are minimal. However, temperatures below or above this range alter intakes.

Effects of Heat Stress

Heat stress reduces intake, milk production, health, and reproduction of dairy cows. Spain et al. (1998) showed that lactating cows under heat stress decreased intake 6 to 16% as compared to cows under thermal neutral conditions. Holter et al. (1996) reported that heat stress depressed intake of cows more than heifers. Other studies have reported similar results. In addition to a reduction in feed intake, there is also a 30 to 50% reduction in the efficiency of energy utilization for milk production (McDowell et al., 1969). The cow environment can be modified to reduce the effects of heat stress by providing for adequate ventilation and effective cow cooling measures.

Ventilation

Maintaining adequate air quality can be easily accomplished by taking advantage of natural ventilation techniques. Armstrong et al. (1999) reported that a 4/12 pitch roof with an open ridge resulted in lower increases in afternoon cow respiration rate as compared to reduced roof pitch or covering the ridge. They also observed that eave heights of 14 ft resulted in lower increases in cow respiration rates as compared to shorter eave heights. Designing freestall barns that allow for maximum natural airflow during the summer will reduce the effects of heat stress. Open sidewalls, open roof ridges, correct sidewall heights, and the absence of buildings or natural features that reduce airflow increase natural airflow. During the winter months, it is necessary to allow adequate ventilation to maintain air quality while providing adequate protection from cold stress.

Another ventilation consideration is the width of the barn. Six-row barns are typically wider that 4-row barns. This additional width reduces natural ventilation. Chastain (2000) indicated that summer ventilation rates were reduced 37% in 6-row barns as compared to 4-row barns. In hot and humid climates, barn choice may increase heat stress, resulting in lower feed intake and milk production.

Cow Cooling

During periods of heat stress, it is necessary to reduce cow stress by increasing airflow and installing sprinkler or soaker systems. The critical areas to cool are the milking parlor, holding pen, and housing areas. First, these areas should provide adequate shade. Barns built with a north-south orientation allow morning and afternoon sun to enter the stalls and feeding areas and may not adequately protect the cows. Second, as temperatures increase, cows depend on evaporative cooling to maintain core temperature. The use of sprinkler/soaker and fan systems to effectively wet and dry the cows will increase heat loss from the cow. Last summer, a study was conducted at Kansas State University to determine the effects of soak frequency and airflow on respiration rates and skin temperature of heat stressed dairy cattle. Sixteen heat-stressed lactating cows (8 primiparous and 8 multiparous) were arranged in a replicated 8x8 Latin Square design. Cattle were housed in freestall dairy barns and milked 2x. During testing, cattle were moved to a tie-stall barn for a 2-hour period from either 1 to 3 pm or 3 to 5 pm on eight different days in late August and early September. Afternoon temperatures ranged between 88 and 96 °F. During the testing period, respiration rates were determined every five minutes by visual evaluation. Skin temperature of three sites was measured with an infrared thermometer and recorded every 5 minutes. Treatments (Table 4) were 4 different soaking frequencies with and without supplemental airflow. Soaking frequencies were control (no soaking), every 5 minutes, every 10, or every 15 minutes. Supplemental airflow was either none or 700 cfm. Each wetting cycle provided similar amounts of water for all treatments. Initial data were collected for three initial 5-minute periods prior to the start of the treatments.

Cows soaked every 5 minutes with supplemental airflow (5 + F) responded with the fastest and largest drop in respiration rate, reducing the initial respiration rate by 47% at the end of 90 minutes of treatment (Figures 1 and 2). Soaking cows every 5 minutes without airflow (5) resulted in a similar response as soaking cows every 10 minutes with airflow (10+F). Soaking cows every 15 minutes with airflow (15+F) and soaking cows every 10 minutes without airflow (10) resulted in similar responses until the last 30 minutes of the study. Supplemental airflow without soaking (0+F) resulted in little improvement over no soaking or airflow (0). Wetting had a greater effect on respiration rate than airflow. However, the combination of wetting and airflow had the greatest effect on the respiration rate. When cooling heat stressed dairy cattle, the most effective treatment included continuous supplemental airflow and wetting every 5 minutes.

These data suggest that different cooling strategies could be developed for different levels of heat stress. Under severe heat stress, soaking every 5 minutes with fan cooling will be the most effective. Under periods of moderate stress, soaking every 10 minutes with fan cooling may be adequate. Reducing soaking frequency when temperatures are lower could significantly reduce water usage. Data clearly indicate that the combination of soaking and supplemental fan cooling are superior to either single treatment. If used singularly, soaking cows would have more impact than the use of fans only for cow cooling. These data indicate that about 1/3 of the total reduction in cow respiration rates was due to airflow and the remainder due to soaking. Under periods of severe heat stress, soaking every 15 minutes with airflow is not adequate and soaking frequency must be increased.

Cow cooling with soaking and supplemental airflow is very effective in reducing respiration rate. Many systems may be ineffective because they do not deliver adequate water to soak the cow and/or have an inadequate soaking frequency.

Cow Cooling in the Holding Pen

The holding pen should be cooled with fans and sprinkler systems, and an exit lane sprinkler system may be beneficial in hot climates. Holding pen time should not exceed one hour. Fans should move 1,000 cfm per cow. Most 30 and 36 inch fans will move between 10,000 and 12,000 cfm per fan. If one fan is installed per 10 cows or 150 ft^2, adequate ventilation will be provided. If the holding pen is less than 24 ft wide with 8 to 10 ft sidewall openings, fans may be installed on 6 to 8 ft centers along the sidewalls. For holding pens wider than 24 ft, fans are mounted parallel to the cow flow. Fans are spaced 6 to 8 ft apart and in rows spaced either 20 to 30 ft apart (36 in fans) or 30 to 40 ft apart (48 in fan) (Harner et al., 2000). In addition to the fans, a sprinkling system should deliver 0.03 gal. of water per square foot of area. Cycle times are generally set at 2 minutes on and 12 minutes off.

Cooling Cows in 4-Row Freestall Barns

Fans should be mounted above the cows on the feed line and above head-to-head freestalls in a 4-row freestall barn. If 36 inch fans are utilized, they should be located no more than 30 ft apart. If 48 inch fans are used, they should be located no more than 40 ft apart and operate when the temperature reaches 70°F. Fans should be mounted out of the reach of the cattle and in a manner that will not obstruct equipment movement. Fans should create an air flow of 800 to 900 cfm per stall or headlock. Feed line sprinklers should be utilized in addition to the fans. Feedline sprinkling systems should wet the back of the cow and then shut off to allow the water to evaporate prior to another cycle beginning. Application rate per cycle should be 0.04 inches/ft^2, and sprinklers should operate when the temperature exceeds 75°F.

Facility Bottlenecks to Cow Cooling

Often producers do not plan to cool cows when they are building new dairy facilities. This creates serious problems in cooling cows. The biggest bottleneck is water availability to soak cows on the feedline in cow housing areas. Another problem is the lack of provisions to provide electricity for fans. It is much more economical to put the electrical system necessary for fans when the structures are built versus retrofitting the wiring at a later date. The majority of the dairy farms being built today do not have water or electrical systems to meet the demands of cow cooling.

Supplemental Lighting

Supplemental lighting has been shown to increase milk production and feed intake in several studies. Peters (1981) reported a 6% increase in milk production and feed intake when cows were exposed to a 16L:8D photoperiod as compared to natural photoperiods during the fall and winter months. Median light intensities were 462 and 555 lux for supplemental and natural photoperiods, respectively. Chastain et al. (1997) reported a 5% increase in feed intake when proper ventilation and lighting were provided, and Miller et al. (1999) reported a 3.5% increase without bST and 8.9% with bST when photoperiod was increased from a range of 9.5 to 14 hours to 18 hours. Increasing the photoperiod to 16 to 18 hours increased feed intake. Dahl et al. (1998) reported that 24 hours of supplemental lighting did not result in additional milk production over 16 hours of light. Studies utilized different light intensities in different areas of the housing area. More research is needed to determine the correct light intensity to increase intake. In modern freestall barns, the intensity varies greatly based on the location within the pen. Thus, additional research is needed to determine the intensity required for different locations within pens.

Another issue with lighting in freestall barns is milking frequency. Herds milked 3x can not provide 8 hours of continuous darkness. This is especially true in large freestall barns housing several milking groups. In these situations, the lights may remain on at all times to provide lighting for moving cattle to and from the milking parlor. The continuous darkness requirement of lactating cows may be 6 hours (Dahl, 2000). Thus, setting milking schedules to accommodate 6 hours of continuous darkness is recommended. The use of low intensity red lights may be necessary in large barns to allow movement of animals without disruption of the dark period of other groups.

Dry cows benefit from a different photoperiod than lactating cows. Recent research (Dahl, 2000) showed that dry cows exposed to short days (8L:16D) produced more ($P < 0.05$) milk in the next lactation than those exposed to long days (16L:8D). Petitclerc et al. (1998) reported a similar observation. Based on the results of these studies, dry cows should be exposed to short days and then exposed to long days post-calving.

Lot Condition

Mud can have a significant negative impact upon DM intake. Fox and Tylutki (1998) suggested that every inch of mud reduced DM intake of dairy cattle 2.5%. Based on this assumption, feed intake of cattle in 12 inches of mud would be 30% less than those without mud. Based on our current knowledge of the impact of prepartum intake increases on subsequent lactation performance, dry cows housed in muddy conditions may be at greatest risk. However, significant production losses may also occur in lactating cattle housed under muddy conditions.

Impact of Facilities on Reproduction

A dairy farm design that facilitates grouping open cows together is ideal, allowing nonpregnant cows to interact during estrus, increasing the efficiency of heat detection (Helmer and Britt, 1985). In a trial conducted by Vailes and Britt (1990), cows given a choice spent 73% of their time on dirt versus concrete and mounting activity was 3 to 15 fold greater on dirt versus concrete. Duration of estrus and mounting activity is increased when cows are housed on dirt versus concrete (Britt et al., 1986; Rodtain et al., 1998). If possible, producers may want to allow open cows to have access to dirt lots for the purpose of estrus detection.

Summary: Management Opportunities to Improve Dairy Cattle Performance

Dairy producers have many opportunities to improve the performance of dairy cattle. Two of those opportunities are summarized below. The first would be the potential to reduce the impact of heat stress. Producers can follow the following list of priorities to reduce heat stress:

1. Improve water availability.
2. Provide shade in the housing areas and holding pen.
3. Reduce walking distance.
4. Reduce time in the holding pen.
5. Improve holding pen ventilation.
6. Add holding pen cooling and exit lane cooling.
7. Improve ventilation in cow housing areas (freestalls).
8. Cool close-up cows (3 weeks prior to calving).
9. Cool fresh cows and early lactation cows.
10. Cool mid & late lactation cows

The second opportunity is to increase the DM intake by making it easy for cows to eat. Listed below are some ideas of how to increase DM intake:

1. Avoid over stocking close-up cows and heifers.
2. Provide water and feed in the maternity area.
3. Don't over stock fresh cows.
4. Minimize lockup times and avoid afternoon restraint.
5. Train heifers to use lockups prior to entering the close-up pen.
6. When possible, cows returning from the parlor should walk past the feedline.
7. Fresh feed should be available all times
8. Push feed up as needed.
9. Provide a smooth eating service.
10. Minimize time away from feed and water.
11. Provide adequate light and dark hours.
12. Maintain hoof health (nutrition, trimming, and concrete surfaces).
13. Provide adequate resting areas to reduce the time that cows spend standing.

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Table 1. Average pen dimensions, stalls, cows and allotted space per animal.[1]

Barn Style	Pen Width (ft)	Pen Length (ft)	Stall Per Pen	Cows Per Pen	Per Cow Area(ft^2)	Per Cow Feedline Space (linear in.)	Per Cow Water Space (linear in.)
4-Row	39	240	100	100	94	29	3.6
6-Row	47	240	160	160	71	18	2.25
2-Row	39	240	100	100	94	29	3.6
3-Row	47	240	160	160	71	18	2.25

[1]Adapted from Smith et al., 2000.

Table 2. Effect of stocking rate on space per cow for area, feed, and water in 4 and 6-row barns.

Stocking Rate (%)	Area(ft^2/cow)		Feedline Space (linear in/cow)		Water Space (linear in/cow)	
	4-Row	6-Row	4-Row	6-Row	4-Row	6-Row
100	94.0	71.0	29	18	3.60	2.25
110	85.5	64.5	26	16	3.27	2.05
120	78.3	59.2	24	15	3.00	1.88
130	72.3	54.6	22	14	2.77	1.73
140	67.1	50.7	21	13	2.57	1.66

Table 3. Recommended groups and facilities for cows housed in the special needs area.

Group	Average Time in Facility (days)	Percent of Lactating Herd	Housing System
Close-up cows	21	6.0	Freestalls or loose housing
Close-up heifers	21	3.0	Freestalls or loose housing
Maternity cows	3	0.33	Loose housing
Maternity heifers	3	0.33	Loose housing
Maternity overflow	3	0.33	Loose housing
Fresh cows and heifers, non-sellable milk	2	1.0	Freestalls or loose housing
Fresh cows	14	3.5	Freestalls
Fresh heifers	14	1.5	Freestalls
Mastitis and sick cows, non-sellable milk	N/A	2.0	Freestalls or loose housing
High risk sellable milk	N/A	2.0 to 6.0	Freestalls or loose housing
Cull and dry cows	N/A	1.5	Loose housing
Calf housing	24 hours	---	Hutches or small pens

Table 4. Experimental treatments for a heat stress study at Kansas State University during the summer of 2001.

Treatment (F = fan)	Soaking Frequency*	Supplemental Airflow
0	None	None
0 + F	None	700 cfm
5	Every 5 minutes	None
5 + F	Every 5 minutes	700 cfm
10	Every 10 minutes	None
10 + F	Every 10 minutes	700 cfm
15	Every 15 minutes	None
15 + F	Every 15 minutes	700 cfm

*0.35 gallon/headlock applied in one minute.

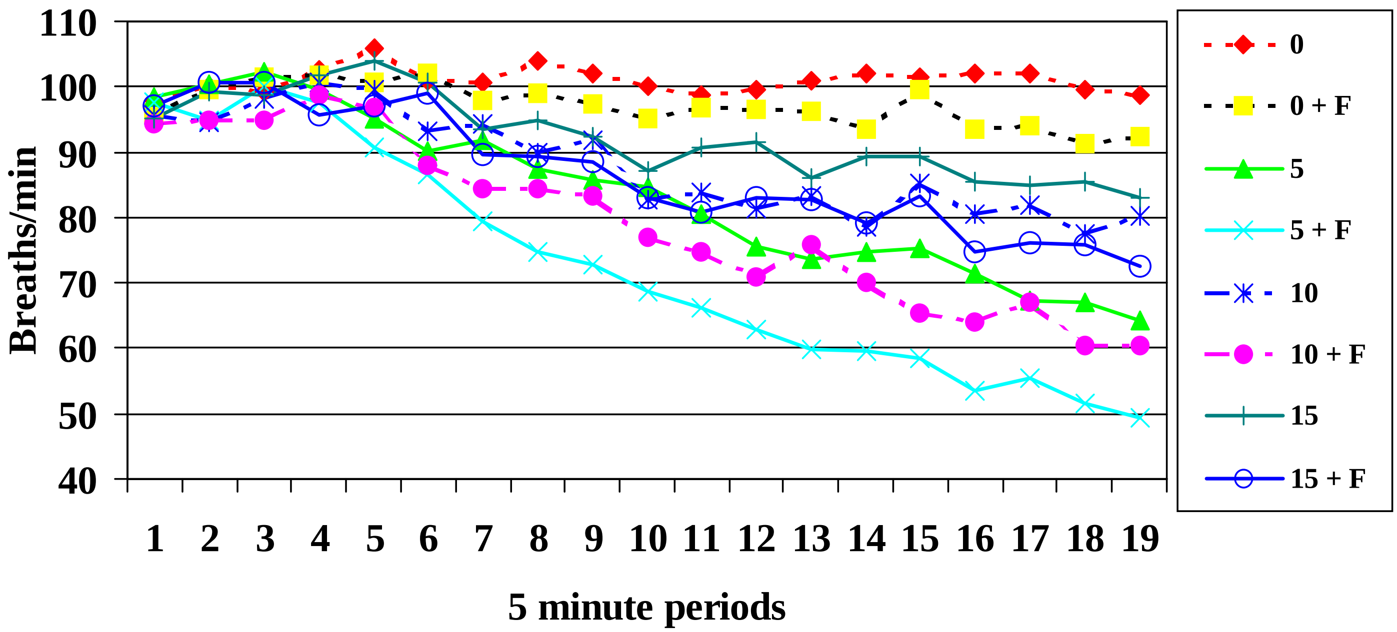

Figure 1. Effect of sprinkling frequency and airflow on respiration rate of heat stressed dairy cattle (see Table 4 for an explanation of treatments).

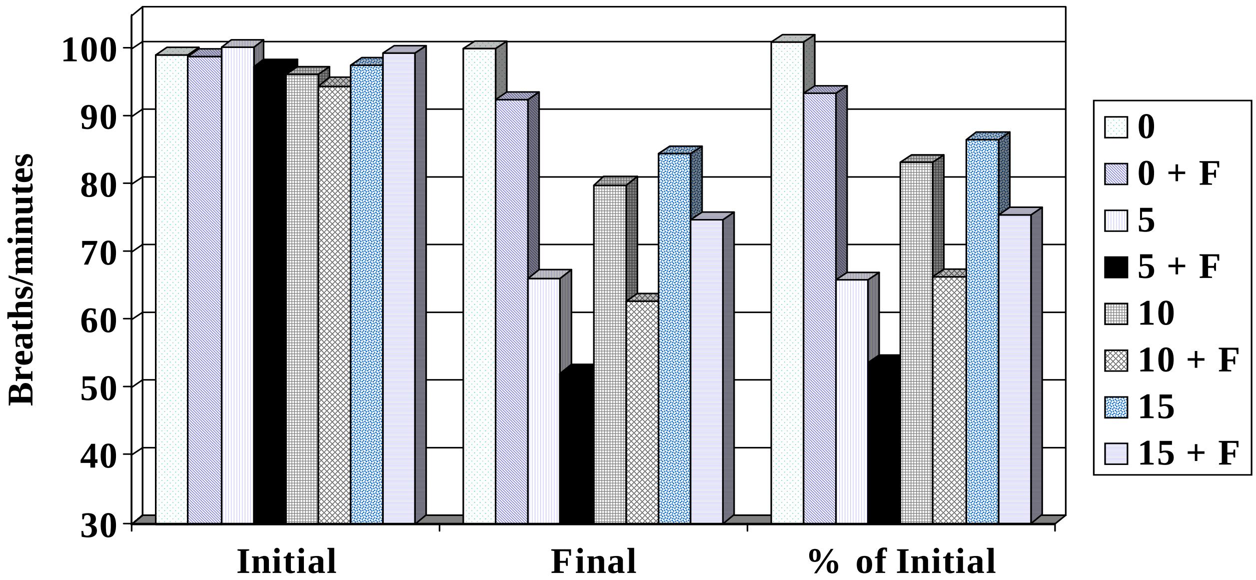

Figure 2. Initial, final, and percentage decrease in respiration rate of heat stressed dairy cattle (see table 4 for an explanation of treatments).

Prescription Rations for Pre- and Post-Fresh Cows

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Abstract

Transition cows must exquisitely coordinate their metabolism to meet tremendous increases in nutrient demand during early lactation, particularly the demand for glucose production by the liver. Excessive mobilization of nonesterified fatty acids **(NEFA)** from body fat during the transition period presents challenges to liver function, including the capacity of the liver to produce glucose. Strategies to either reduce the supply of NEFA to the liver or optimize the metabolism of NEFA by the liver include maximizing DM intake of well-formulated transition rations, dietary supplementation with choline, or short-term drenching strategies using propylene glycol. Supplementation of other nutrients (methionine analogs and conjugated linoleic acid) has been shown to improve performance during early lactation; however, their mode of action does not appear to be related directly to liver metabolism. Research investigating nutritional grouping strategies for dry cows indicates that the two-group dry cow system is preferred to a one-group dry cow system; however, there may be interactions of grouping system with body condition score on postpartum performance.

Introduction

The transition period of the lactation cycle in dairy cattle is clearly the most important phase of the lactation cycle because it represents the convergence of productive performance, reproductive performance, and health that directly impacts profitability of the dairy enterprise. We have reviewed previously the metabolic adaptations related to energy metabolism that must occur in order to allow production of large amounts of glucose by the liver to support lactose synthesis (Overton and Piepenbrink, 1999). The purpose of this paper will be to briefly review the key metabolic adaptations that must occur for cows to successfully transition to lactation, provide some insight into "managing metabolism" of transition dairy cows, and to provide some "bottom line" recommendations for "prescription" ration formulation and grouping of transition cows.

Metabolic Adaptations in Transition Cows

The primary series of metabolic adaptations that must occur to underpin a successful transition to lactation relates to increased glucose synthesis by the liver and decreased glucose oxidation by peripheral tissues at the onset of lactation. Glucose represents an overriding metabolic demand during the transition period because of the requirements of the mammary gland for lactose synthesis. Data in Figure 1 indicate that the predicted whole-body requirement for glucose increases from approximately 1,000 g/day during the late dry period to approximately 2,500 g/day during the first three weeks postcalving. The predicted supply of glucose based upon intake of digestible energy

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matches well with requirements during the late dry period but is below predicted requirements during early lactation. The actual supply of glucose measured in this experiment is much greater than the predicted supply, indicating that sources other than those accounted for by digestible energy intake are making contributions to liver glucose output during this time frame. Recent data (Overton et al., 1998) suggest that at least part of the additional glucose is being synthesized from amino acids during early lactation.

A second key metabolic adaptation relates to mobilization of body reserves, particularly body fat stores, in support of the increased energetic demands during early lactation paired with insufficient energy intake. This mobilization of body fat occurs through release of NEFA into the bloodstream (Figure 3). These NEFA are used for energy by body tissues and as precursors for synthesis of milk fat; however, available data suggest that the liver takes up NEFA in proportion to their supply (Emery et al., 1992). Unfortunately, the liver typically does not have sufficient capacity to completely dispose of NEFA through export into the blood or catabolism for energy (Figure 2), and thus, transition cows are predisposed to accumulate triglycerides in the liver tissue. As we have reviewed thoroughly (Overton and Piepenbrink, 1999), the consequence of this triglyceride accumulation appears to be impaired liver function, including decreased capacity for ureagenesis and gluconeogenesis.

Strategies to Manage Liver Metabolism in Transition Cows

Our guiding principle based collectively on these data is that management of NEFA during the transition period is an important factor influencing liver health, the capacity of the liver to make glucose, subsequent milk production, and incidence of metabolic disorders in transition cows. The two primary approaches that can be taken are:

1) decrease the supply of NEFA to the liver through diet and feeding management (perhaps use of glucogenic supplements), and
2) optimize capacity of the liver to dispose of NEFA either by burning them for fuel or exporting them as triglycerides in lipoproteins (very low desnity lipoproteins; **VLDL**).

Good closeup and fresh cow nutritional programs, combined with excellent feeding management to achieve high levels of DM intake throughout the transition period, achieves 80 to 90% of the potential of the first strategy and should always be the first area of focus for management. Contrary to popular belief, data supporting that niacin supplementation to the diet decreases plasma concentrations of NEFA are limited; nevertheless, a practical recommendation would be to include niacin (12 g/day) in diets fed to herds struggling with overconditioned cows. Glucogenic supplements, such as propylene glycol, are effective at decreasing concentrations of NEFA and B-hydroxybutyrate (**BHBA**; the predominant ketone body found in blood); however, propylene glycol must be drenched or fed such that it is consumed as a bolus in order to be effective in decreasing concentrations of NEFA and BHBA (Christensen et al., 1997), and thus, this presents both cost and labor challenges. The duration of treatment in most experiments reported in the literature ranges from 10 to 40 days per cow. Recently, two experiments have been conducted (Pickett et al., 2001; Stokes and Goff, 2001) that report beneficial effects of drenching propylene glycol beginning on the day of calving and continuing for one or two subsequent days (Figure 3) — these short-term treatments are much more acceptable from a cost and labor standpoint and have more potential for commercial application.

Recently, another strategy related to decreasing energy demands on the transition cow has been suggested to potentially decrease reliance on body reserves and thereby reduce the supply of NEFA to the liver. In typical midlactation cows, approximately 50% of the fatty acids secreted as milk fat are taken up by the mammary gland from the bloodstream as preformed fatty acids. The remaining 50% of fatty acids in milk are synthesized de novo in the mammary gland and account for approximately 50% of the energetic cost of milk synthesis (NRC, 2001). Conjugated linoleic acids **(CLA)**, specifically the trans-10, cis-12 isomer of CLA, have been discovered to be potent inhibitors of milk fat synthesis (Bauman et al., 2000). Giesy et al. (1999) fed cows 50 g/day of a mixture of CLA isomers (35% trans-10, cis-12 by weight) in a Ca-salt form from day 13 through 80 postpartum. They reported few effects of CLA supplementation on cow performance during day 14 through 28 postcalving; however, milk yield was increased, and percentage and yield of milk fat were decreased, during day 35 through 80 postpartum. Energy balance was not affected by treatment during either period. Given that supplementation with CLA in their experiment began after concentrations of NEFA have returned to relatively low levels in the blood (Overton and Piepenbrink, 1999), we hypothesized that supplementation of CLA during the entire transition period and early lactation would be more effective in terms of potentially decreasing energy demand during early lactation. Bernal-Santos et al. (2001) fed cows 42.8 g/day of a mixture of CLA isomers (29% trans-10, cis-12 by weight) in a Ca-salt form from 14 days before expected calving through 140 days of lactation. Results were similar to those of Giesy et al. (1999) in that milk yield and milk fat percentage during the first two weeks postpartum were not affected by CLA supplementation; however, milk fat percentage was decreased by 13% and milk yield tended to be increased (6.6 lb/day) during the entire postpartum period in cows administered the CLA supplement (Table 1; Figure 4; Figure 5). Energy balance and concentrations of NEFA and BHBA in plasma were not affected by treatment. Therefore, contrary to our hypothesis, CLA supplementation does not appear to substantially reduce reliance on body fat stores; however, energy spared from milk fat synthesis apparently was redirected to lactose synthesis and may offer the opportunity to use CLA as a management tool to increase peak milk yield.

Even when the first strategy is in place on individual dairy farms, we believe that there are opportunities to further improve liver health by employing nutritional strategies to optimize the capacity of liver to dispose of NEFA rather than accumulate them as fat in liver tissue. As mentioned above, the two disposal routes of NEFA from liver involve burning them for fuel and exporting them back into the blood as triglycerides in VLDL (Figure 2). We reviewed the background data and theory supporting the potential for several candidate nutrients (choline, methionine, and lysine) last year, and reported that choline supplementation to diets fed to transition dairy cows resulted in decreased rate of accumulation of fat in liver measured using an in vitro system (Piepenbrink and Overton, 2000). We now know that this decreased rate of accumulation of fat in liver was accompanied by a trend for increased capacity of liver to convert propionate to glucose. We also reported that milk production was sensitive (Table 2) to the supply of methionine as provided by its analog, 2-hydroxy-(4-methylthio)-butanoic acid **(HMB)**; however, the capacity of liver to metabolize NEFA was not affected by HMB supply (Piepenbrink et al., 2001). Further research must be conducted to determine the specific roles of choline, methionine, and lysine in liver fatty acid metabolism and to determine the interactions among supply of these nutrients.

Grouping Strategies and Diet Formulation for Closeup Cows

Modern dry cow nutritional grouping strategies involve a two-group system - a "far off" group consisting of cows from dry off through approximately 21 days prepartum and a "closeup" group consisting of cows from approximately 21 days prepartum through parturition. We would recommend energy densities of approximately 0.59 to 0.63 Mcal/lb of net energy for lactation (NE_L) for diets fed to cows in the far-off group. More detailed recommendations for diets fed to closeup cows, with differentiation of mineral composition based on anionic versus nonanionic approaches to manage hypocalcemia, are provided in Table 3.

More uncertain is the length of time that cows should be fed the closeup diet. Two experiments have been published recently that provide us with some insight on this topic. Robinson et al. (2001) fed cows and first-calf heifers either a control closeup diet or a closeup diet supplemented with additional energy and protein on commercial dairy farms in the West and determined that there was a significant increase in milk yield over a full lactation when heifers and cows were fed these diets for 15 days compared with 5 days (Figure 6). Additional supplementation of energy and protein to the diet yielded more milk during the full lactation only when it was fed for 15 days prepartum. This experiment, however, did not explore feeding the closeup diet for longer than the 21 days currently recommended. Mashek and Beede (2001) fed cows on two commercial dairy farms the closeup diet for an average of either 18 or 37 days prepartum. There was a slight improvement in energy status of cows fed the closeup diet for 37 days prepartum; however, differences in milk production during early lactation were not significant. Health effects were farm-specific — one farm had an increased incidence of retained placenta when fed the closeup diet for an average of 37 days prepartum.

We recently completed an experiment on two commercial dairy farms in New York involving nearly 400 cows in which we fed cows either a two-group dry cow program or the closeup diet for the entire dry period (Contreras et al., 2002). Differences in productive performance during the first five monthly test days were not significant among treatments. In looking at interactions of body condition score at dry off with performance during the subsequent lactation, we found that cows with initial body condition score less than 3.0 (mean = 2.8) tended to produce more milk (94.6 versus 90.9 lb/day) across the first five monthly test days than did cows with body condition score of 3.25 or greater (mean = 3.4). Furthermore, a trend existed for an interaction of body condition score at dry off such that thinner cows fed a two-group dry cow program produced the most milk (97.0 lb/day) during the first five monthly test days, cows fed the closeup diet for the entire dry period were intermediate (92.4 lb/day for both body condition score groups), and heavier cows fed a two-group dry cow program produced the least milk (89.3 lb/day) during the first five monthly test days. The implications of these data are that replenishment of body condition during late lactation to a body condition score of 3.25 or 3.50 as commonly recommended may not be as important for productive performance if cows are fed "modern" transition cow feeding programs. Secondly, these data also imply that perhaps heavier cows will benefit from spending the entire dry period in the closeup group. Certainly, more research investigating the interactions of body condition score and nutritional strategies for transition cows is merited.

Current Research and Implications for the Dairy Industry

Currently, our laboratory is engaged in experiments to elucidate the specific roles of individual nutrients in liver metabolism of transition cows and to determine the interactions of metabolism and health that likely provide the biological basis for the myriad of factors that we include in the category of "management" on commercial dairy farms. Collectively, this research will provide much of the basis for managing metabolism of transition dairy cows within transition cow nutrition and management programs in the future.

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Table 1. Dry matter intake **(DMI)** and yield and composition of milk from cows fed a control or a conjugated linoleic acid **(CLA)** supplement from 2 weeks prepartum through 20 weeks postpartum (Bernal-Santos et al., 2001).[1]

	Week 1 through Week 8					Week 1 through Week 20				
	Treatment			P-value		Treatment			P-value	
Item	Control	CLA	SEM	TRT	TRT* WK	Control	CLA	SEM	TRT	TRT* WK
DMI, lb/day	45.1	47.5	1.3	0.23	0.84	51.7	52.6	1.1	0.65	0.11
Milk, lb/day	93.7	99.4	2.6	0.14	0.07	97.0	103.4	2.0	0.12	0.48
Fat, %	3.84	3.46	0.11	0.01	0.62	3.61	3.15	0.08	0.01	0.06
Fat, lb/day	3.52	3.32	0.13	0.31	0.89	3.45	3.19	0.11	0.12	0.58
3.5% FCM, lb/day	97.7	97.0	3.1	0.99	0.88	97.9	96.6	2.9	0.74	0.98
True protein, %	2.87	2.89	0.06	0.79	0.44	2.77	2.74	0.04	0.60	0.28
True protein, lb/day	2.64	2.79	0.09	0.19	0.97	2.66	2.77	0.07	0.27	0.98
Lactose, %	4.69	4.73	0.05	0.58	0.15	4.74	4.74	0.05	1.0	0.05
Lactose, lb/day	4.40	4.71	0.13	0.58	0.15	4.60	4.88	0.13	0.15	0.89
Milk urea N, mg/dl	12.8	12.7	0.4	0.82	0.55	12.2	12.0	0.4	0.70	0.89

[1]FCM = fat-corrected milk, SEM = standard error of mean, TRT = treatment effect, and TRT * WK = interaction of treatment and week postpartum.

Table 2. Yields of milk and milk components by cows fed increasing amounts of 2-hydroxy-4-(methylthio)-butanoic acid **(HMB)** during the transition period and early lactation (Piepenbrink et al., 2001).[1]

	Treatment				Treatment effect, P <		
Item	Control	+HMB	++HMB	SEM	TRT Linear	TRT Quad.	TRT x week
Milk, lb/day	92.6	99.2	92.6	2.9	0.99	0.05	0.13
Fat, %	4.20	4.00	4.07	0.13	0.46	0.36	0.80
Fat, lb/day	3.79	3.88	3.70	0.11	0.59	0.32	0.40
3.5% FCM, lb/day	101.4	105.8	100.1	2.6	0.70	0.11	0.28
CP, %	2.80	2.77	2.84	0.06	0.65	0.33	0.26
CP, lb/day	2.56	2.69	2.58	0.09	0.77	0.22	0.69
Lactose, %	4.70	4.69	4.73	0.05	0.62	0.69	0.76
Lactose, lb/day	4.34	4.65	4.39	0.13	0.86	0.05	0.19
Total solids, %	12.46	12.22	12.38	0.19	0.78	0.36	0.94
Total solids, lb/day	11.40	11.99	11.35	0.31	0.94	0.09	0.53

[1]FCM = fat-corrected milk, SEM = standard error of mean, and TRT = treatment.

Table 3. General goals for diet formulation for closeup dry cows.

Item	Standard	Anionic
NE_L, Mcal/lb	0.72 to 0.74	
Metabolizable protein, g/day	1,100 to 1,200	
NFC, %	34 to 36	
Ca, g/day	100	140
Ca, %	0.90	1.2
P, %	0.3 to 0.4	0.3 to 0.4
Mg, %	0.4 to 0.42	0.4 to 0.42
Cl, %	0.3	0.8 to 1.2
K, %	< 1.3	< 1.3
Na, %	0.1 to 0.2	
S, %	0.20	0.3 to 0.4
Vitamin A, (IU/day)	100,000	100,000
Vitamin D, (IU/day)	30,000	30,000
Vitamin E, (IU/day)	1,800	1,800

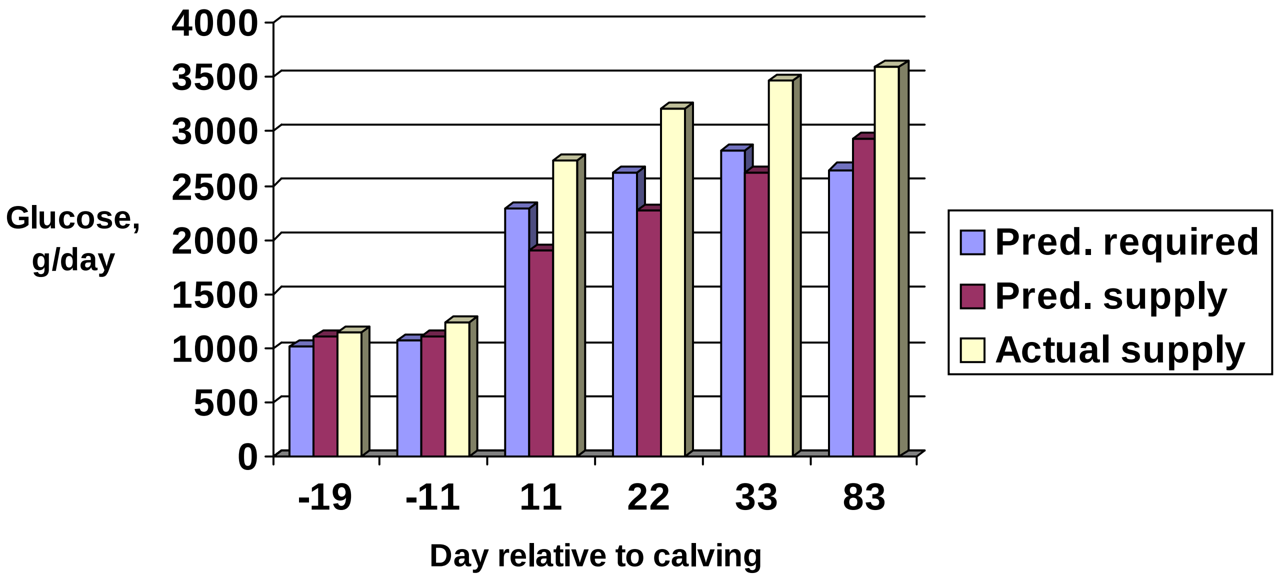

Figure 1. Predicted whole-body glucose requirements compared with predicted and actual supply of glucose by gut and liver during the transition period and early lactation. Data are from Reynolds et al. (2000). Predictions are as described by Overton (1998).

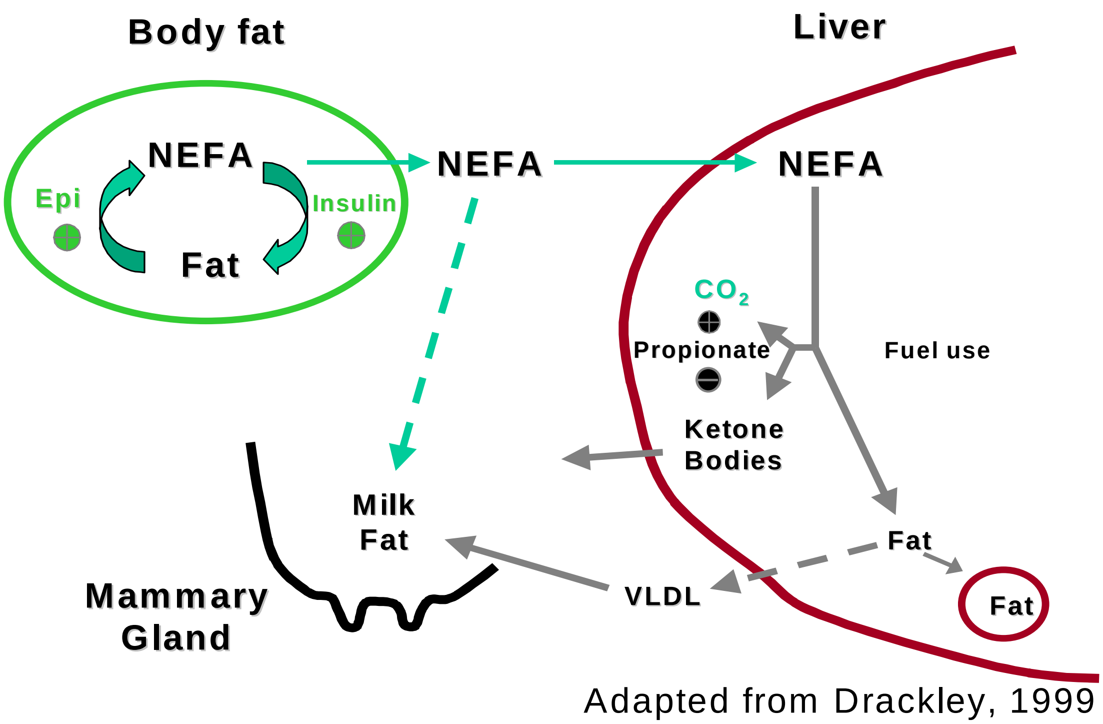

Figure 2. Schematic of metabolism of nonesterified fatty acids **(NEFA)** in the dairy cow (adapted from Drackley, 1999).

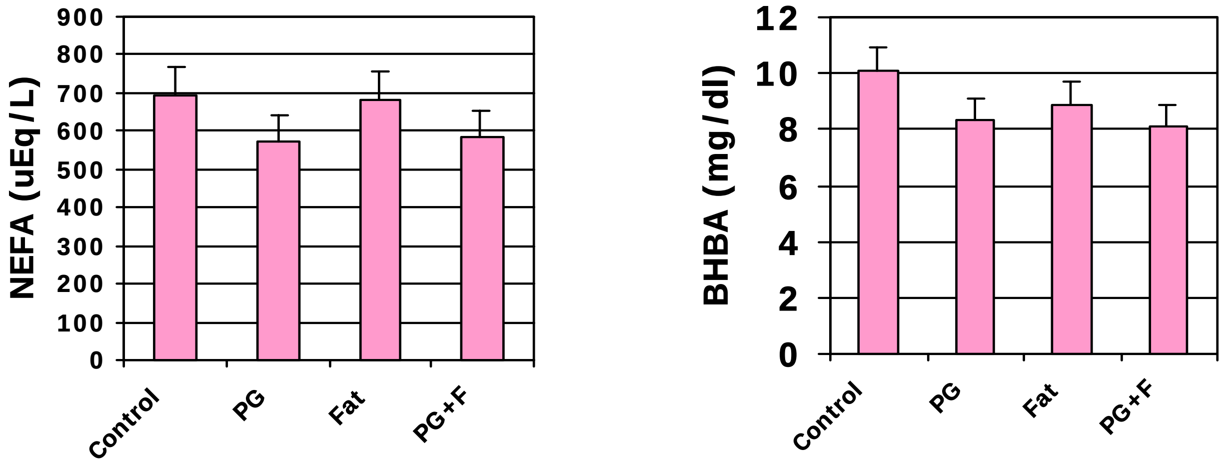

Figure 3. Concentrations of nonesterified fatty acids (NEFA; left pane) and B-hydroxybutyrate (BHBA; right pane) during day 2 through 7 postcalving for cows drenched with either a control, propylene glycol (500 ml/day; PG), fat (1.0 lb/day), or a combination of propylene glycol and fat for the first 3 days postcalving (trend for effect of PG; P < 0.11 for NEFA and P < 0.09 for BHBA)(Pickett et al., 2001).

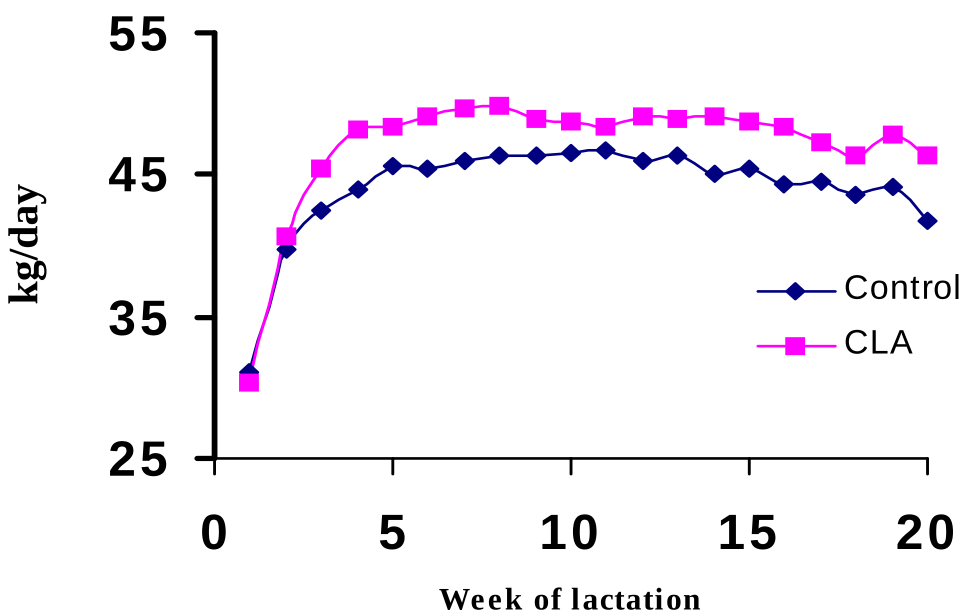

Figure 4. Milk yield by week of lactation for cows fed either a control or a conjugated linoleic acid **(CLA)** supplement (pooled standard error of mean = 0.9) (Bernal-Santos et al., 2001).

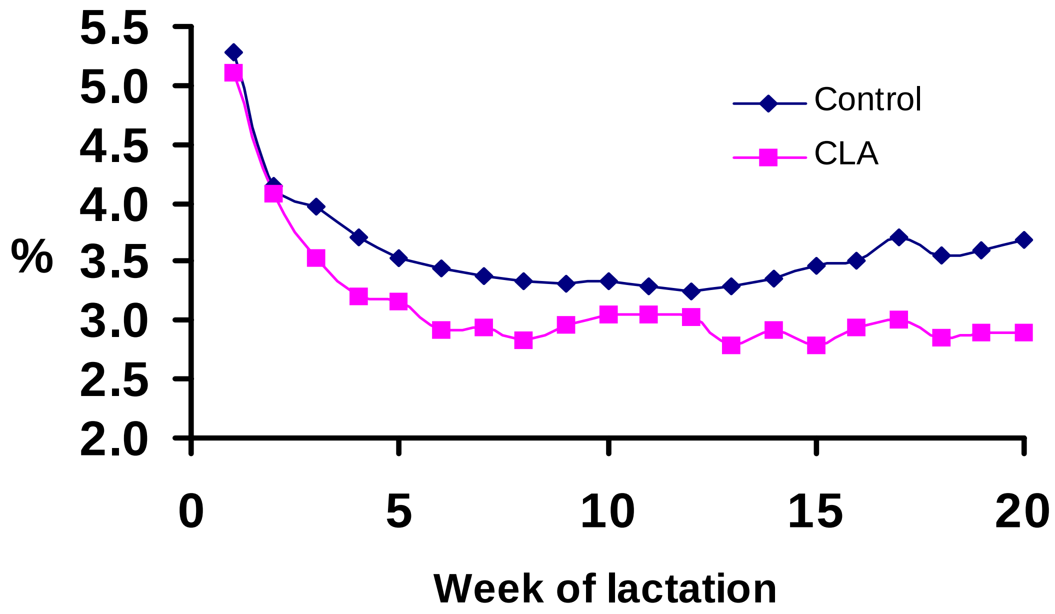

Figure 5. Milk fat percentage by week of lactation for cows fed either a control or a conjugated linoleic acid **(CLA)** supplement (pooled standard error of mean = 0.1) (Bernal-Santos et al., 2001).

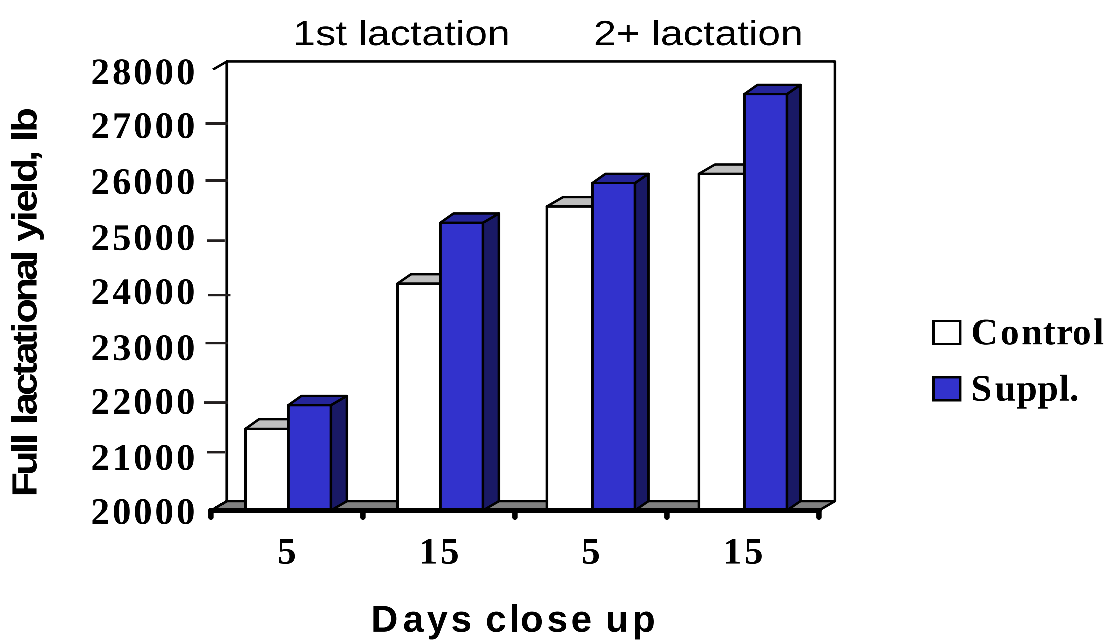

Figure 6. Full lactational milk yields of cows in first and second or greater lactation as affected by feeding either a control or supplemented (additional energy and protein) diet for either five or fifteen days closeup (Robinson et al., 2001).

Screening for Mycotoxins in Silage

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Abstract

Mycotoxins are chemicals produced by fungi that can seriously affect the health of dairy cattle. Mycotoxin-producing fungi do not compete well with the microbes responsible for silage fermentation. However, if proper moisture content is not maintained or oxygen is allowed into the silage, these fungi can grow and potentially produce mycotoxins. In addition, mycotoxins formed in the field can persist in the silo. The presence of mycotoxins in silage can only be determined by chemical analysis. Mycotoxins are analyzed by several methodologies, including immunochemical **(ELISA)** assays, thin-layer chromatography **(TLC)**, gas chromatography **(GC)** and high-performance liquid chromatography **(HPLC)**. Analyses can be obtained from commercial and State labs for aflatoxins, DON, T-2, DAS, zearalenone, fumonisins, and ochratoxin. Other mycotoxins can occur in silage, however testing for these is not currently available or difficult to obtain.

Mycotoxins in Silage

Mycotoxins are toxic chemicals produced by fungi. The most common mycotoxin found in silage is deoxynivalenol, also known as DON or vomitoxin (Whitlow and Hagler, 1997). DON is produced by several species of Fusarium including the most common producer F. graminearum. When present in dairy cattle feeds, DON does not appear to significantly affect milk production, milk quality, feed intake or animal health. Feeding studies utilizing DON contaminated feeds with early lactation (Ingalls, 1996), mid-lactation (Charmley et al, 1993) and non-lactating cows (Trenholm et al, 1985) all support this conclusion. Nonetheless, many producers have observed a correlation between DON in rations and problems with reduced milk production, feed intake and herd health. Thus DON appears to be an indicator for the presence of other possible toxins in feeds. Recommendations vary for the maximum level of DON in dairy cattle feed. Our search of the literature and Internet indicate a range as low as 300 micrograms per kilogram of silage (300 ppb) to as high as 6,000 ppb.

Other Fusarium mycotoxins that have been found in silage include T-2 toxin, diacetoxyscirpenol **(DAS)**, zearalenone, and fumonisins. T-2 toxin and the related mycotoxin DAS are potent mycotoxins produced by F. sporotrichioides and F. poae, which cause severe mycotoxicoses in animals including dairy cattle. Extreme cases can result in death. Fortunately, these two mycotoxins are not commonly found in silage produced in the Midwest. The maximum recommended levels of T-2 and DAS in dairy cattle feed range between100 micrograms per kilogram of silage (100 ppb) to 250 ppb. Zearalenone is produced by F. graminearum and is often present in DON-contaminated silage. Zearalenone has estrogenic effects in animals meaning that it can disrupt the reproduc-

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tive system. Large doses of the mycotoxin also may cause reduction in milk production. Zearalenone levels exceeding 500 micrograms per kilogram of silage (500 ppb) are of concern. Fumonisins are a group of mycotoxins produced by F. verticillioides and F. proliferatum. The most common fumonisin, FB1, has a variety of effects in animals many stemming from damage to the liver and kidney. The FDA has suggested that dairy cattle should not be fed more than 30,000 microgram total fumonisin (= FB1 + FB2 + FB3) per kilogram of feed (30 ppm) (http://vm.cfsan.fda.gov/~dms/fumongui.html).

In addition to the Fusarium mycotoxins, aflatoxin, ochratoxin, and ergot also occur in silage. Aflatoxins are potent liver toxins and carcinogens produced by Aspergillus flavus and A. parasiticus. Aflatoxins are of concern to dairy producers in particular because the FDA regulations require aflatoxin residues in milk to be less than 0.5 ppb. To prevent the carry over of aflatoxins into milk, silage and other feed components such as cottonseed should not contain greater than 20 micrograms aflatoxin per kilogram (20 ppb). Ochratoxin A is a nephrotoxin produced by several species of Penicillium and Aspergillus (CAST, 1989). Although this is a fairly toxic compound, concern for dairy cattle is somewhat moderated by the knowledge that rumen microorganisms are capable of metabolizing ochratoxin A (Hult et al., 1976). Ochratoxin levels in dairy cattle diet should not exceed 250 ppb. Ergot alkaloids are a complex group of mycotoxins produced by Claviceps purpurea and other related fungi (Kuldau and Bacon, 2000). C. purpurea infects nearly all grasses including barley, rye, wheat. This fungus infects through the flower and produces a structure called a sclerotium in the location where the seed would have formed. Ergot contamination is more common in haylage, however infected grassy weeds can be a source of contamination in corn silage. Pencillium roqueforti is a fungus commonly found in the acidic, low oxygen tension environment of silage. This fungus produces at least four mycotoxins (PR toxin, roquefortine C, patulin and mycophenolic acid) all of which have been documented in silage. The effects of these mycotoxins on dairy cattle are not currently well understood.

Screening for Mycotoxins

Producers will certainly think of mycotoxins as a contaminant in their silage when they observe spoilage or when their herds are showing reduced feed intake, reduced milk production or an appearance of poor health. However, the presence of mold does not mean mycotoxins are present and other chemicals such as nitrates can cause similar animal symptoms to those caused by mycotoxins (Adams et al., 1992). The only means of determining their presence is by analysis. Mycotoxins are analyzed by several methodologies, including ELISA assays, TLC, GC and HPLC. One advantage of the TLC method is that more than one mycotoxin can be analyzed at once. With the immunochemical assays, GC, and HPLC separate analyses must be performed for each mycotoxin or class of mycotoxin. Analyzing mycotoxins in silage can be a challenge due its complex nature. If proper protocols are not followed interfering compounds can be extracted from the silage leading to false positives for the presence of mycotoxins. This is especially true for the ELISA assays. ELISA tests are useful for screening samples and to indicate which samples warrant further attention. It is best to have positive results verified by other methods such as TLC, HPLC, or GC. For this reason, one should have a professional laboratory do the analysis. Most veterinary schools at State universities have diagnostic labs that routinely test for mycotoxins. There are also several private companies, many having Internet sites. Routine analyses can be obtained for aflatoxins, DON, T-2, DAS, zearalenone, fumonisins, and ochratoxin. Currently, one or two labs analyze for ergots, and none analyze for PR toxin, roquefortine C, patulin and mycophenolic acid.

As with mycotoxin analysis of any commodity, sample collection and preparation are an important source of error when testing silage. One must provide the analytical lab with a representative sample. Such a sample is routinely obtained by combining numerous small subsamples taken from the silage mass. Because mycotoxin production will occur in the area of silage exposed to air, samples from moldy silage should give an indication of the mycotoxins present. If sampling moldy silage for analysis, it is important to take a separate sample from an area that is not moldy. Care should be taken with handling samples to assure that mycotoxins do not accumulate in the sample during shipping or while in wait for analysis. Drying the sample at moderate temperature (60°C or less) will best assure that the fungus stops further growth and mycotoxin production. Freezing the sample and shipping on ice by a one-day delivery service is another option.

More Information

For more information regarding mycotoxins in silage, visit the Internet site for the NC129 North Central Regional Research project Mycotoxins in Cereal Grains at http://www.btny.purdue.edu/nc129. Links are provided to many sources of information related to mycotoxins and silage.

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Optimizing Rumen Fermentation

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We all know that we "feed the rumen" when we feed dairy cows. Yet, in today's production scenario, we need to be more aware of how and why we feed the rumen because of the greater array of feedstuffs available and because of environmental concerns. My current objectives are to integrate biological constraints with feeding practices to identify issues to improve your ability to reduce the variability and increase the efficiency associated with "optimizing rumen fermentation".

What Do We Know About Microbial Fermentation?

As a background, there are roughly 10^{15} bacteria and 10^{11} protozoa in a cow's rumen. Do you remember being asked as a kid how much money you would have if you started with a penny and doubled the amount every day for a year? One microbiologist calculated that, if you started with one bacterial cell, had a doubling time of 20 minutes, and could have unlimited substrate, then a single cell's mass would amplify to yield the mass of the earth in 34 hours. Those trillions of cells are therefore a result of their ability to compete and dominate in a ruthless marketplace for substrate that varies tremendously throughout a feeding cycle. Despite significant advances to meet a cow's daily requirements, all of our sophisticated models have limited ability to explain how this diurnal variation in growth conditions affects fermentation efficiency. Fortunately, the rumen microbial populations are self-regulating if we think about feeding the rumen instead of feeding the cow.

Substrate Availability

Probably the most important factor affecting microbial growth is the amount and synchrony of substrates needed. The primary energy substrate for ruminal microbes is carbohydrate. Much less energy can be obtained from protein or fat. Improved forage quality or more aggressive processing of grain can provide more substrate. For this reason, we typically relate efficiency of growth as the amount of microbial protein produced per amount of energy made available through fermentation. As more energy is obtained, more cell division can occur. More rapid cell division dilutes maintenance energy costs. Alternatively, microbes can store some glycogen-like polysaccharides or can recycle inside the rumen. We therefore need to separate net microbial protein production from its efficiency of production to "optimize" fermentation.

Just as with a cow, after energy is met, the microbes must have nitrogenous sources in high enough availability to use the energy for cell growth (division) to yield more protein to the cow. Rumen-degradable protein **(RDP)** (through conversion to microbial protein) is the cheapest source of protein, especially when considering its excellent amino acid profile (based on SESAME software; St-Pierre and Glamocic, 2000) [NRC (2001)].

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At this point, it is important to remember that microbes must expend energy to produce enzymes to break down any polysaccharide to sugars. This overhead cost is minor, though, using up only 3 to 5% of the cell's ATP (Hespell and Bryant, 1979). Some bacteria have some specialized ways to capture a high energy phosphate bond (ADP $\rightarrow$ ATP) as they break down disaccharides into monosaccharides, but microbes in the rumen growing on any carbohydrate source obtain energy primarily from intracellular fermentation of free sugars. This means that they get the same number of ATP from 100 moles of glucose in the form of starch or as free glucose. If cells grew on glucose and gained all of the ATP from not needing polysaccharide-degrading enzymes, this would still provide little, if any, benefit because one pound of starch has more glucose molecules than one pound of free glucose. Based on the loss of a water molecule as glucose molecules are combined in chemical bonds, Hall and Herejk (2001) calculated the monomer yield of starch and sucrose to be 1.11 and 1.05 relative to 1.00 for glucose, and pectin provided 0.89 glucose-equivalents relative to starch. Because all sugars enter the glycolysis pathway, they generally have the potential to yield the same amount of energy. If rumen-fermentable carbohydrate limits bacterial growth because of low digestibility or low feed intake, then provision of sugar should increase microbial growth just as should processing of corn.

As shown by Forsberg et al. (1997), species of bacteria can ferment glucose, maltose (a disaccharide with two glucoses), fructose, and sucrose (a disaccharide of glucose and fructose). Other sources of rapidly available carbohydrate have been outlined by M.B. Hall and this publication (http://www.animal.ufl.edu/hall/MkSnsNSC.htm) and others on the website have some very useful information outside the scope of this paper.

Rumen microbes need to survive periods of limited substrate availability. In fact, bacteria store glycogen or inactivate an autolysing (self-killing) enzyme to maintain viability until the next feeding, which allows for renewed exponential growth (Wells and Russell, 1996). A small amount of sugar (2 to 5%) fed with fiber can therefore help jump start fibrolytic bacteria (Hiltner and Dehority, 1983) and can yield microbial protein quicker (but not more) than starch (Hall and Herejk, 2001). In contrast, higher amounts of free sugar can decrease fiber digestibility through direct or low pH-mediated responses (Firkins, 1997). In meal-fed situations, starch would probably reduce the "feast-to-famine" cycling, causing increased efficiency of microbial growth with sugar versus starch (Piwonka et al., 1994), but multiple feedings and TMR pushups would lessen this response.

When carbohydrate availability is not limiting growth, then provision of more rumen-available carbohydrate, including sugar, often decreases efficiency of growth. A major cellulolytic bacterium has been shown not to regulate glucose transport inside its cell (Wells and Russell, 1996), and one can envision bacteria continually taking up unneeded substrate to keep "the competition" from getting it. As these sugars (including from starch or fiber breakdown) enter glycolysis pathways, a glycolysis intermediate can cause Streptoccocus bovis to produce more lactic acid (Bond and Russell, 1996). This can lower pH, which inhibits cellulolytic bacteria (Russell and Wilson, 1996). In addition, high lactate production was associated with increased energy "spilling" (intentional wastage of ATP through futile cycles), so production and subsequent utilization of lactate to a volatile fatty acid (**VFA**; usually propionate or butyrate) still could result in inefficient bacterial growth, even if pH was not decreased below 6.0. With excess carbohydrate, methyglyoxal production can "intoxicate" one of the major species of bacteria in the rumen (Wells and Russell, 1996). Therefore, mechanisms to spill energy become critical to maintain high cell numbers during gluttonous periods of substrate excess (Russell and Cook, 1995). In particular, as potential growth rate increases with increased substrate availability, the provision of peptides or amino acids to replace ammonia as a N source can decrease energy spilling and significantly increase efficiency of bacterial growth.

Rumen-Degraded Protein

Many researchers have documented that peptides are stimulatory for bacterial growth in vitro. Although bacteria can synthesize amino acids **(AA)** from carbon skeletons, the provision of preformed AA in the correct proportions also would be needed for optimal growth rate (Van Kessel and Russell, 1996). If growth rate is slowed by availability of a rate-limiting AA, then energy spilling would increase. They discussed the increasing importance of amino N as bacterial growth increased, especially above 0.4/hour (i.e., 40%/hour or a cell division time of < 2.5 hours). Because starch is generally degraded at rates from 0.1 to 0.5/hour (10 to 50%/hour) and sugars from > 0.4/hour, this documents an increasing need for amino N with more aggressive processing of grain and increasing sugar availability. Fiber is generally degraded < 0.10/hour, so amino N is probably much less stimulatory except to provide certain growth factors from deaminated AA. My survey of literature has generally shown these growth factors to be of sufficient concentration such that protein degradation typically would not limit fiber digestibility in vivo unless ruminal ammonia concentration is too low. Based on an OSU continuous culture study, Griswold et al. (unpublished data) noted that ammonia concentration was most critical for cellulose digestion, but hemicellulose digesters can be stimulated by increased ammonia availability and also the degradability of protein (to provide amino N). Yet, studies synchronizing RDP and rumen-degradable carbohydrate have quite mixed results, generally showing little interaction (Firkins, 1996; Firkins, 1997). That is, either energy or RDP can limit microbial growth, but synergistic action generally does not occur when they are synchronized.

Soluble protein can contain ammonia or urea as well as amino-N. Regardless of its makeup, it should be rapidly available. Yet, growth using ammonia (or urea, which is degraded to two ammonia molecules) as the major N source is associated with energy spilling in bacteria with high amounts of available carbohydrate. Therefore, soluble protein would be expected to be an important diagnostic in these types of diets only if the soluble protein contains a high amount of amino-N. In addition, as carbohydrate availability increases, more blood urea N can be recycled to rumen ammonia and trapped as bacterial N, further emphasizing the need for amino-N from either soluble protein or RDP with increasing rumen carbohydrate availability. Therefore, an ammonia N measurement should be combined with soluble N [(soluble N ammonia N) x 6.25].

Rumen Protozoa

A big variable not discussed thus far is rumen protozoa. They benefit the overall fermentation efficiency by engulfing small starch granules and sugars to decrease the rate of VFA production (and help maintain higher pH). On the other hand, they predate on bacteria and promote excessive turnover of microbial protein and wastage of ammonia (and the ATP used to resynthesize more microbial protein). Some protozoa have a chemical attraction toward sugars (Dehority, 1998) but are prone to lysis with increasing levels of sugars (Dijkstra et al., 1998). Therefore, some of the benefits of small amounts of sugars could be negated through increased growth and turnover of protozoa. Fat is inhibitory to protozoa (see later discussion on models predicting microbial protein flow to the duodenum).

Providing an Optimal Environment for Fermentation

Forage NDF and Rumen pH

At common feeding rates, ruminal buffers can help but cannot take the place of adequate effective fiber. Besides stimulating the cow to chew and produce roughly 3 to 4 gallons of saliva per each gallon of milk, fiber slows down the rate of carbohydrate degradation and helps to form a solid rumen mat to retain particles for enough time for adequate ruminal digestibility. In contrast, too much fiber can depress feed intake and slow passage rate. Faster passage rates wash out microbes such that a lower proportion of their energy is spent for maintenance, but faster passage also reduces digestibility and availability of substrate. Therefore, a moderate passage rate would optimize microbial protein flow to the duodenum. This means that forage and nonforage NDF should be within guidelines similar to those described by the NRC (2001). In the study of Harvatine et al. (2001), replacement of forage NDF with whole cottonseed linearly decreased efficiency of microbial protein synthesis, probably because of decreasing pH and decreasing passage rate. In this study, though, efficiency declined while microbial N flow to the duodenum increased because of increasing DM intake (and intake of rumen-fermentable carbohydrate). Based on our regression approach (Oldick et al., 1999), only DM intake and NDF percentage remained in the final model. Dry matter intake had the dominant effect, and microbial protein increased at a decreasing rate (limiting returns) with increasing DM intake. Therefore, carbohydrate availability and potential passage rate differences probably are explained satisfactorily by these two variables, and measurements of DM intake in the field can help a nutritional advisor to maintain microbial protein production and supply to the cow.

Microbial Additives

Microbial additives have received considerable attention. Newbold (1995) documented the variation among studies with regard to responses but also discussed potential modes of action. Direct-fed microbials can help to scavenge oxygen, provide metabolites to stimulate lactate utilization, and increase fiber digestibility, all of which could help stabilize or increase feed intake. Wang et al. (2001) recently showed that yeast culture tended to increase feed intake, milk yield, and milk fat percentage when included with 21 but not 17% forage NDF diets. At first, this seems to be contrary to the reported mode of action of stabilizing rumen pH, but the non-fiber carbohydrate **(NFC)** was decreased by about 4.5 percentage units and enzymatic nonsoluble carbohydrate **(NSC)** analysis was decreased by about 7 percentage units as forage NDF decreased from 21 to 17%. As with dietary buffers, a pH stabilization from microbial additives should help improve fiber digestion, as explained previously.

Feeding Management to Improve Microbial Growth

Rumen-Degradable Starch

First, I will go back to the beginning. When you feed the cow, you must feed the rumen. Attempts to shift starch digestion from the rumen to the intestine to improve efficiency of glucose metabolism have not been very effective (Huntington, 1997; Firkins et al., 2001). The best way to increase glucose supply past the liver seems to be to have an optimal amount of rumen-digestible starch **(RDS)**. The “optimal” amount is a balance between provision of substrate for propionate synthesis to be converted to glucose in the liver (Huntington, 1997) and excessive RDS to reduce fiber digestibility (Firkins et al., 2001) or DM intake (Allen, 2000). When we (Firkins et al., 2001) evaluated grain processing effects but adjusted the data to a common DM intake, processing to increase RDS had a moderate influence on total tract organic matter digestibility and milk production. However, if DM intake decreases, then the net benefit would be partly or fully negated. Increasing RDS tends to shift fiber digestibility to the large intestine, whereas lower RDS is partially compensated by higher post-ruminal starch digestion (Table 1). Wang et al. (2001) recommended a forage NDF:NFC ratio > 0.5, especially for cows in the first month of lactation. Firkins et al. (2001) discussed studies in which the forage NDF:RDS ratio was optimized at about 1.0 to 1.25:1. The RDS data in Table 1 could be used to maintain this ratio and it should be noted that an optimal ratio depends on bunk management and other factors.

The regression results from Firkins et al. (2001) show several important principles that can be related to optimal rumen fermentation (Table 1). We noted a depression in RDS of 1.21% with each 1 kg (2.2 lb) increase in DM intake. At the average of 46 lb/day of DM intake in the database, an increase to 51 lb/day would decrease RDS by 2.75%. At the average starch concentration of 31.4%, an increase in DM intake of 5 lb/day would still increase RDS intake by 0.3 lb/day. Second, DM intake was not associated with total chewing response. In fact, total NDF and forage NDF percentages were negatively correlated with DM intake but positively correlated with chewing time. Therefore, increased DM intake would likely promote increasing VFA production in the rumen with little or no increase in chewing to stimulate salivary buffering. In total, these regression responses support the results (Figure 1) reported by Shaver (2002).

Interestingly, diets with high-moisture corn were associated with more total chewing time than diets with dry shelled corn and numerically tended to have higher rumen pH, despite the increased RDS (Firkins et al., 2001). Therefore, the calculated lower efficiency of microbial growth for high-moisture corn (Table 1) was probably caused by increased energy spilling (intentional ATP wastage) in the rumen. Because VFA can be absorbed throughout the length of the gastrointestinal tract but AA are not absorbed from the cecum or large intestine, an "optimal" rumen fermentation should strongly consider microbial protein production.

Forage Particle Size

There is tremendous interest in forage particle size to ensure adequate effective fiber in the diet. Clearly, the scientific research has documented how a cow can crash with inadequate effective fiber. However, our research is typically done with individual cows. Just as benefits of increased feeding frequency seem to be less well documented with individually-fed compared with group-fed cows (Robinson, 1989), so might benefits of large particle size. For instance, conflicting results for chewing response were associated with the particle size of barley silage (Soita et al., 2000) or corn silage (Clark and Armentano, 1999). However, adequate particle size in group-fed cows should still be an important consideration. Prolonged mixing can decrease particle size variably for different mixers (Heinrichs et al., 1999). On farms, if particle size is too coarse and(or) the TMR is too dry, increased sorting can take place. One cow selecting for grain can decrease her digestive efficiency through subclinical acidosis or negative associative effects while decreasing the digestive efficiency of other cows forced to eat a diet higher in forage than expected. More importantly, I think, is the increased diurnal and day-to-day variability caused by such sorting. Shaver (2002) elaborated on the likely projection of under consumption of coarse particles in the first half of the day and over consumption in the second half. Recall that rumen microbes are opportunists prevented from tremendous bursts of exponential growth only by substrate availability. Wisconsin workers (Mourino et al., 2001) recently showed some interesting work supporting that it was the initial pH that affected fiber digestibility the most. A sudden surge in NFC availability associated with under consumption of coarse forage could depress fiber digestibility residually after the surge of VFA are absorbed, thus promoting passage of potentially digestible fiber; in contrast, the later consumption of coarser fiber of presumably poorer quality would have a greater residence time in the rumen but have digestibility that is limited by its chemical properties. In summary, particle size analysis has important ramifications on farms to optimize microbial fermentation, but the variability prevents me from recommending its use to assign physical effectiveness values, supporting the NRC (2001) procedure of relating minimum forage NDF to maximum NFC concentrations.

A forage particle size analyzer might have improved utility if it is used as a running baseline within a herd to monitor events like cow sorting across a feed bunk over time, length of mixing time needed for feed distribution with minimal particle reduction, different forage sources or proportions in the diet, etc. Shaver (2002) elaborated on uses of feed particle size, noting a larger impact with increased intake of rumen-fermentable organic matter. Also, he reported on-farm trials showing that a liquid feed containing molasses decreased cow sorting. In our studies with liquid feeds (Oldick et al., unpublished data), we noted comparable intakes and production. If care is taken to prevent excessive intake of rumen-degraded carbohydrate relative to forage NDF (see earlier), then liquid products can perhaps improve feeding management for group-fed cows while being a carrier for animal fat and helping to synchronize rumen degraded carbohydrate and RDP.

Models to Integrate Energy and Protein

Basis of Models to Predict Protein Supply to the Small Intestine. Most current models recognize the biological need to have rumen degradable carbohydrate in balance with a supply of RDP to meet the microbes' needs for preformed AA and ammonia. These models range from empirical (best statistical fit) to mechanistic (trying to quantitatively describe the biological processes) prediction of events from which feeding recommendations are based.

Empirical models are those that are derived from research that was already done to try to predict future responses. Generally, the user will balance for a percentage of ruminally degradable carbohydrate that is synchronized with an optimal percentage of RDP. Therefore, on average, these recommendations are likely to be consistent with actual data and also to be consistent with the user's "average" experience. However, an empirical model might be limited to help evaluate rations for specific circumstances that cannot be explained by the data set from which the equation was derived or for circumstances for which the user has limited experience. In practice, a diet with 42% NFC (100% - protein - fat - ash - fiber) on one farm could work fine but could contribute to acidosis symptoms on another. For instance, dry rolled corn with a ruminal starch digestibility of 50% would have the same NFC concentration in the total diet as would high-moisture corn with a ruminal starch digestibility of 75%. An empirical computer model might group responses according to dietary composition or a class of grain types (e.g., ground versus high-moisture corn), manually adjusting RDP constraints according to grain type. A more mechanistic model might try to account for this variability by combining the fraction of the diet as NFC with its rate of degradation (Figure 2). Typically, fractions of a nutrient are classified on the basis of differential solubility in various buffers, particle size, or degradability by microbial enzymes, but most are based on the same principle.

Rates of degradation (kd) can be integrated with the proportion of nutrient in its respective fraction (typically termed fraction A, B, or C; see Figure 2) and the rate of passage (kp) from the rumen based on a first-order, single compartment model as follows:

Predicted ruminal digestibility of B fraction =

$$\frac{kd}{kd + kp}.$$

The passage rate from the rumen depends on numerous processes that will not be discussed here. However, the NRC (2001) estimates kp for dry forages, silages, and concentrates with three separate equations. The most important factor in all three equations is DM intake. Higher producing cows eat more DM relative to their body weight, which would increase kp. Therefore, accurate DM intake and body weight inputs would improve the model's predictive ability. Similarly, because of feed variability, having accurate analyses for A, B, and C fractions and their kd would improve the model's prediction for specific feed sources. Therefore, some feed testing laboratories offer these services. Although the Cornell Net Carbohydrate and Protein System (**CNCPS;** Sniffen et al., 1992) or Cornell-Penn-Miner (CPM Dairy, 1998) versions base kd data on in vitro (ground feeds plus rumen fluid inoculum added to test tubes) procedures, the NRC (2001) based their feed library's kd (and the subsequent analyses to be performed by feed testing labs) on the in situ technique based on the large amount of published information for numerous feeds and the good statistical fit relative to data obtained with duodenally cannulated cattle. The CNCPS has three subfractions for B. Its feed library has been expanded considerably since its original publication (Sniffen et al., 1992), and many nutritionists have experience using it. To summarize for the NRC model:

$$RDP = A + B \left(\frac{kd}{kd + kp} \right)$$

RUP = Total crude protein - RDP

where RDP is expressed as a percentage of total protein, A is the percentage of the total protein that washes out of the dacron bags, B is the percentage of the total protein that is potentially degradable inside the bags, kd and kp are degradation and passage rates of the B fraction, and RUP is rumen undegraded protein (percentage of total protein). Models like the NRC or CNCPS integrate equations like this for all feeds in the diet; the CNCPS also subfractionates the B pool.

Ionophores probably alter kinetics of protein degradation or decrease RDP, so some adjustment might be needed if they get approved for lactating cows. Work with beef cattle has been interpreted to suggest a lower response to RUP sources when ionophores were fed (Firkins and Fluharty, 2000).

Estimation of Microbial Protein Flow to the Duodenum

The CNCPS based the optimal relationship of degradable carbohydrate and RDP on theoretical microbial growth yields (is more mechanistic), but the NRC based the relationship of energy and RDP on more empirical data from cattle studies. The best-fit relationship described by the NRC (2001) related microbial protein yield to the intake of total digestible nutrients **(TDN)** based on the large availability of data. First, it discounts (adjusts downward) the TDN concentration of the diet for increased associative effects and passage rate with increasing feed intake. Then, microbial protein flow to the duodenum is calculated as 0.130 x adjusted TDN intake (microbial protein has the same units as adjusted TDN intake). As forage quality or the ratio of grain:forage increase in a diet, increased ruminal carbohydrate availability should be predicted by the increase in TDN concentration. This calculation mechanistically ignores the site of digestion (rumen versus intestines), which should impact availability of energy for microbial protein synthesis in the rumen. However, empirically, this biological variability resulting from site of digestion appears to have a relatively low statistical impact on prediction of energy for ruminal microbial protein synthesis compared with the dominant statistical impact of DM intake.

Dietary Fat

Although fat increases TDN concentration, it should provide little energy for microbes. Oldick et al. (1999) presented an alternate, even more empirical, model than that adopted by the NRC (2001). It predicts microbial protein based on DM intake and NDF concentration. They reported that, when fat was fed, two separate equations were needed to predict microbial protein flow based on intake of NE_L (which is directly calculated from TDN). However, supplementing fat often increases the efficiency of microbial protein synthesis by decreasing protozoal numbers even though fat is not used as an energy source by rumen microbes (Firkins, 1996), or fat supplementation could decrease DM intake (Allen, 2000). Therefore, the net effect of fat supplementation on prediction of microbial protein from adjusted TDN intake would be less than would be predicted by the CNCPS (which does not adjust efficiency and therefore underpredicts microbial protein flow to the duodenum when fat is substituted for carbohydrate in diets; see Kohn et al., 1998). However, based on Oldick et al. (1999), the NRC also could slightly overpredict microbial protein flow when fat is fed at high levels in the diet. The user should consider this potential impact when trouble-shooting rations. Generally, dietary fat decreases milk protein percentage, and this result is probably related to decreased DM intake (Wu and Huber, 1994). Fat is fed to boost NE_L concentration and therefore energy intake; however, if DM intake is decreased, the supply of AA and gluconeogenic precursers should also be decreased relative to the increased energy availability. In such a case, matching the supply and requirement of metabolizable AA limiting milk protein synthesis should become more critical, explaining why several studies have documented responses to rumen-protected lysine or methionine for cows fed fat.

Integration of Microbial Protein Production and RDP Requirement

After energy-allowable microbial protein synthesis is calculated, the model determines if RDP intake was sufficient to support it (Figure 3a). If not, the RDP-allowable microbial protein calculation discounts microbial protein contribution based on the limiting effects of AA or ammonia (Figure 3b):

Microbial protein = RDP intake x 0.85

The 0.85 factor (rather than 1.0) empirically accounts for biological inefficiencies and the limitation of RDP for microbial growth during part of the feeding cycle. When RDP:RUP is too low, the ration cost is raised unnecessarily (protein sources higher in RUP are more expensive) or else milk protein production might decrease because of the "hidden" problem of decreased microbial protein production. The RDP requirement is set at:

TDN-allowable microbial protein synthesis x 1.18

When RDP does not limit microbial protein synthesis, RDP intake exceeding 118% (1/0.85 x 100) of predicted TDN-allowable microbial protein is wasted (Figure 3c).

The NRC model is based on best fit to actual data, so it is likely to predict average responses of microbial protein. However, although the increased complexity of other more mechanistic models can be useful to predict responses in atypical (deviating from average) situations that were not evaluated in the literature set, these mechanistic models also have many more parameters to solve. Often the result of one equation is used as an input into another equation. This construction leads to amplification of error or situations in which large deviations can occur for predicted relative to actual responses. Therefore, a user might consider a scenario something like that in Figure 4. The CNCPS, for example, might be used to predict specific responses to improve efficiency of protein usage, and the user can reduce incidences of inaccurate prediction by comparison with the NRC (2001).

Examples of On-Farm Uses for Evaluation Models

The NRC (2001) and other models should perhaps best be used to simulate responses to ration changes being considered prior to implementation of field trials or other assessment on farms. Care needs to be exercised when evaluating results from field trials, though, because of potential problems in design or interpretation (St-Pierre and Jones, 1999). Moreover, an alarming extension of the CNCPS (Sniffen et al., 1992; and will probably occur with the NRC model) is the conclusion by many users that, because a predicted response to the third decimal is printed, the prediction must be accurate to the same degree. All models are works in progress. All have error associated with the prediction and need proper evaluation for the circumstances of their use for formulation rather than their intended use for simulation or evaluation. Oldick et al. (1999) noted that the variation among individual studies was considerable, and the NRC (2001) AA supply equations were derived after accounting for the average trial effect. If effects due to trial (or experiment) are considerable, then variation among herds would be a logical extension. We feed cows in groups with variations imposed by cow interactions, feed interactions, and uncertainty in the model inputs. Therefore, predictions from models should be tempered with the user's experience and perhaps some trial feeding on the individual farm. Still, they can help nutritional advisors prioritize strategies and then to best implement these strategies to improve milk production or income over feed costs.

Models are very useful for trouble-shooting. If RDP intake is estimated to greatly exceed requirements for microbial protein synthesis, then this factor can be minimized as a potential problem. If energy-allowable milk (or energy-allowable microbial protein synthesis) is predicted to be much less than protein-allowable milk (or RDP supply), the nutritional advisor can focus on forage quality or other factors. If milk production is lower than expected but factors related to energy supply are not limiting, then protein digestibility or AA balance can be evaluated or selected for consideration in revised rations. Finally, the model could alert the user to non-nutritional problems such as water quality, silage quality, or bunk management.

If a producer excludes ruminant and non-ruminant animal proteins from consideration, digestible lysine would become a critical limiting nutrient for high producing cows. Faldet et al. (1992) noted that the optimal roasting method for soybeans would maximize metabolizable lysine but decrease the availability of lysine by 15 to 22% compared with its theoretical supply without irreversible binding. Firkins and Fluharty (2000) discussed similar concerns for other processing methods for soybean meal. Data such as this can be used to modify the NRC model to simulate conditions to make better informed decisions regarding protein supplementation.

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Table 1. Adjusted means for digestibility and microbial N flows to the duodenum for corn processed in different ways.[1]

	Corn Processing Method			
	Dry, rolled or cracked	Dry, ground	Steam-flaked	High-moisture
Rumen digestibility, %				
Starch, apparent[a]	44.6	52.3	56.9	86.8
NDF	48.1	44.9	41.9	47.1
OM, true	52.3	48.6	52.8	60.1
Microbial N, g/day	276	257	296	236
Microbial efficiency[b]	25.2	25.3	26.8	18.8
Total tract digestibility, %[c]				
Starch, apparent	85.0	90.7	94.2	94.2 (98.8)
NDF	52.0	49.0	48.2	50.0 (50.4)
OM, true	66.6	67.8	68.6	71.9 (73.9)

[1]All data were adjusted for among-experiment effects and other variables remaining in backward multiple regression (Firkins et al., 2001).

[a]Apparent basis = not corrected for microbial contributions. Note that the steam-flaked corn included all densities and digestibility would be higher for the recommended processing procedure. Also, high-moisture corn was probably of optimal moisture compared with some sources on farms.

[b]Data were calculated as grams of microbial N flow / (20.9 kg/day average DM intake x % OM truly digested/100).

[c]Data in parentheses are for ground rather than rolled corn.

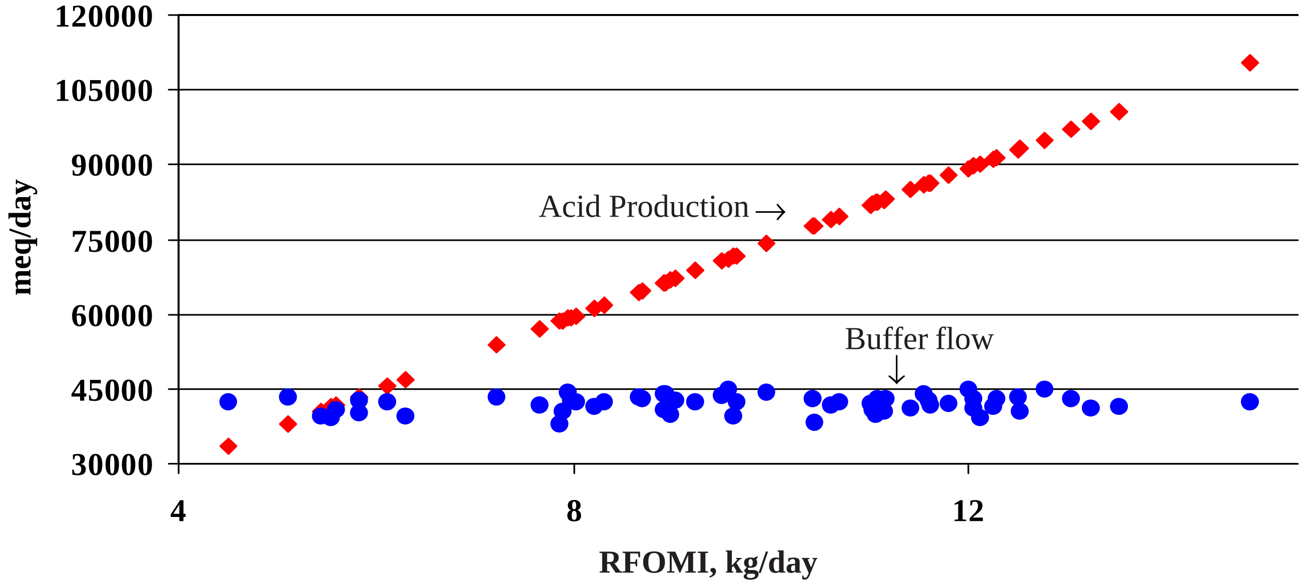

Figure 1. The relationship between predicted acid production (milliquivalents/day) from rumen-fermented organic matter intake **(RFOMI)** and predicted salivary buffer production to neutralize those acids (borrowed with permissions from Shaver, 2002). Note increasing RFOMI for high producing cows would be predicted to depress ruminal pH.

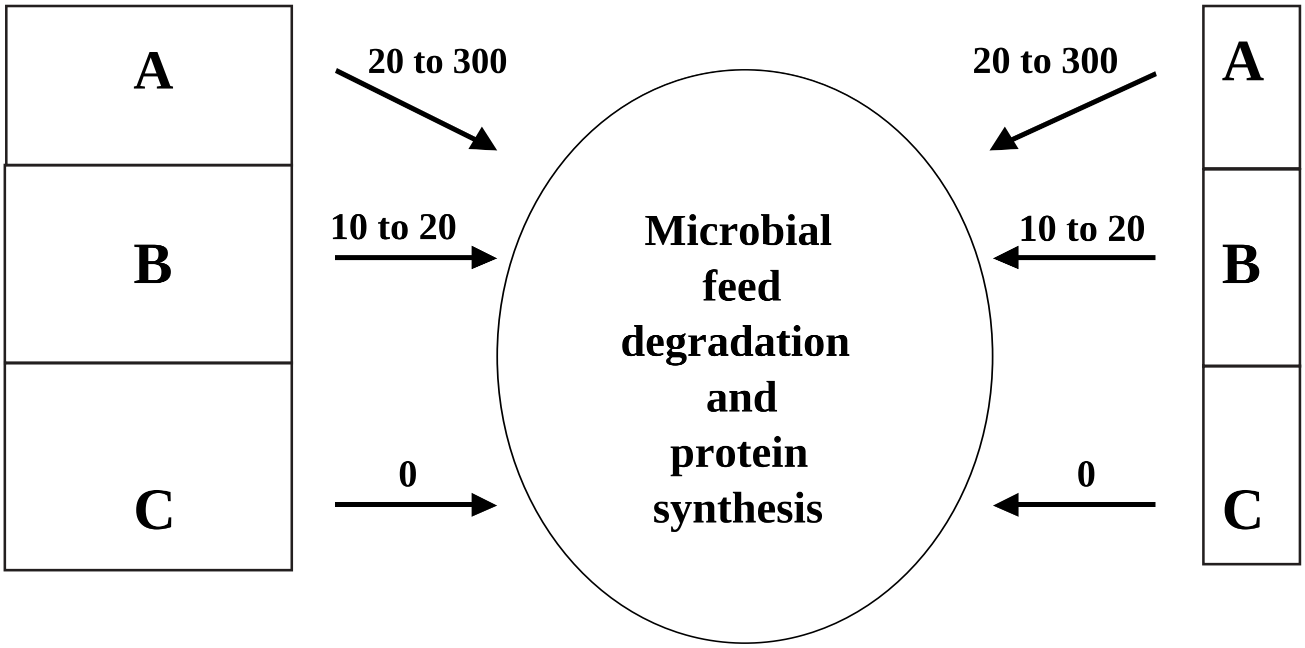

Figure 2. Schematic representation of a model integrating pools (sizes are proportional to box area) and degradation rates (arrows; percentage of the pool turnover per hour) of the respective A, B, or C pools to synchronize carbohydrate and protein availability for optimal microbial activity.

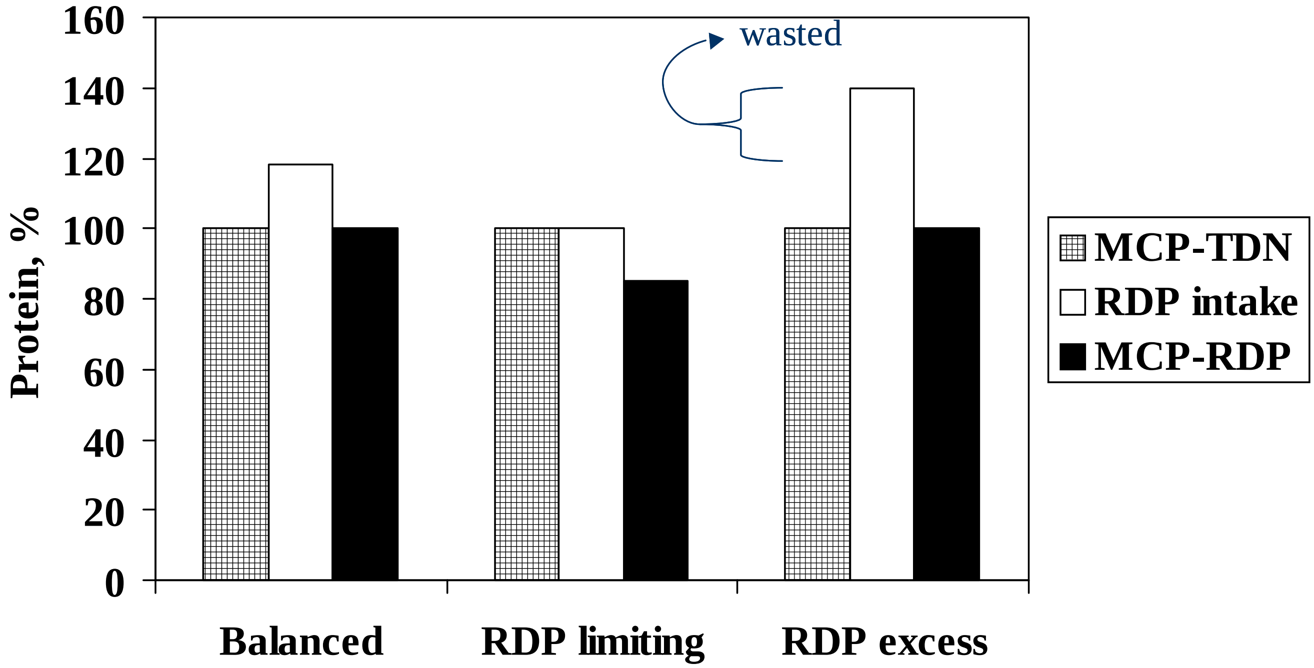

Figure 3. Predicted microbial crude protein **(MCP)** flow to the duodenum based on intake of total digestible nutrients **(TDN)** or on intake of rumen-degraded protein **(RDP)**. Examples: a) perfectly balanced so that RDP intake is 118% of MCP predicted from adjusted TDN intake; b) although TDN intake is adequate to support MCP production, MCP production is limited to 85% of RDP intake; and c) RDP intake greater than 118% of TDN-allowable MCP production is wasted.

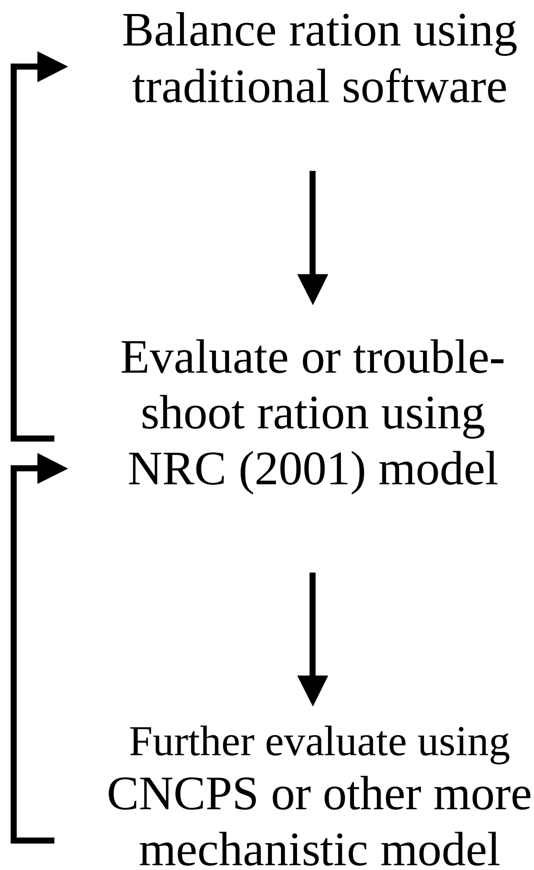

Figure 4. Schematic representation of decision analysis for using models to optimize supply of metabolizable amino acids for high producing dairy cattle (CNCPS = Cornell Net Carbohydrate and Protein System).

Rumen-Protected Choline: Potential for Improving Health and Production in Dairy Cows

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Introduction

Choline is a trimethylated hydroxide that is found in biological tissues in a free form and as a component of lecithin, acetylcholine, certain plasmalogens, and sphingomyelnins, the components of nervous tissue (Figure 1). By strict definition choline is not a vitamin however it is an essential nutrient. Despite the fact that most animals synthesize choline it must be consumed in the diet because de novo synthesis is inadequate to maintain health. Choline is mainly found as a component of specialized fat molecules known as phospholipids, the most common of which is called phosphatidylcholine or lecithin (Figure 1).

Choline is crucial to brain, neuromuscular signaling, and normal nerve transmission. Choline is required for synthesis of phospholipids which are essential components of all membranes and is an important source of labile methyl groups. Choline deficiency in nonruminants is not common except under the most severe circumstances because choline is widely distributed in plant and animal tissues. However, choline deficiency induced experimentally is manifested as fatty liver, hemorrhaging kidneys, elevated blood pressure, and impaired neurological function. In nonruminants, choline deficiency can be avoided by supplying dietary sources of other methyl donors, such as betaine, methionine, and folic acid, in conjunction with adequate vitamin B12.

One of the earliest signs of choline deficiency in nonruminants is a reduction in lipoprotein assembly and secretion of triglycerides from liver to plasma. Addition of other methyl donors such as methionine serves to prevent the accumulation of liver lipid in rats, perhaps as substrates for choline synthesis. Currently, there is considerable interest in use of choline and related compounds to reduce fatty liver associated with the onset of calving in transition dairy cattle.

Dietary Need for Choline in Dairy Cows

One of the primary roles of choline is in synthesis of phosphatidylcholine, an essential component of cell membranes. In addition to the structural component of cell membranes, phosphatidylcholine is required for the secretion of very-low density lipoprotein **(VLDL)** from liver. It is well established that the rate of VLDL synthesis in ruminants is low compared to other species and that fatty liver associated with calving is not uncommon. Choline deficient rats show three-fold increases in hepatic triglyceride concentrations and reduced plasma methionine as well as phosphatidylcholine concentrations compared to rats fed a choline adequate diet (Pomfret et al., 1990; Yao and Vance, 1988). Choline status therefore has been suggested as a factor in alleviating the severity and incidence of fatty liver and may have some application in the transition dairy cow.

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There is an estimated requirement for gram quantities of choline for normal tissue metabolism and milk production in lactating dairy cattle (Erdman, 1992), yet very little dietary choline escapes ruminal degradation (Dawson et al., 1981). Therefore choline supply may potentially also limit milk production. Increasing the postruminal supply of choline by infusion of choline into the abomasum has increased milk production and milk fat yield in some (Erdman and Sharma, 1991) but not all experiments. Part of the lack of consistency in response to rumen-protected choline may be due to the supply of other methyl donor sources, including methionine and folic acid.

It is interesting to note that the Food and Nutrition Board of the Institute of Medicine established a dietary reference intake for choline rather than a recommended daily allowance **(RDA)** because scientific evidence was insufficient to calculate an RDA (Pitkin et al., 2000). The main criterion for establishing an adequate intake level **(AI)** is for the prevention of liver damage due to insufficiency. The AI for adult men, age 19 and over is 550 milligrams (mg)/day and for adult women, age 19 and over is 425 mg/day. Likewise, choline requirements have not been established for the lactating cow. The recommended concentration of choline in milk replacer diets is 1000 mg/kg at a feeding rate of 0.53 kg per 45 kg calf or ~ 530 mg/day (NRC, 2001). It is interesting to note that the requirement for choline in the calf and the AI for humans is very similar on a body weight basis. These data confirm that an estimate of the minimum choline needed in dairy cows for maintenance functions (based on metabolic body size) is approximately 4 to 6 g/day.

Relationship Between Methionine and Choline

Inadequacy of choline supply is manifested by decreased concentrations of choline, betaine, phosphatidylcholine, methionine, and S-adenosyl ethionine and increased triglyceride concentrations in liver (Pomfret et al., 1990). Deficiencies lead to reductions in circulating lipoproteins as a direct result of impaired secretion by liver (Lombardi et al., 1968). Choline deficient rats show three-fold increases in hepatic triglyceride concentrations, and reduced plasma methionine and phosphatidylcholine concentrations compared to choline adequate rats (Pomfret et al., 1990; Yao and Vance, 1988).

Choline and methionine metabolism are closely associated and as much as 28% of absorbed methionine is used for choline synthesis (Emmanuel and Kennelly, 1984). Methionine plays a direct role in VLDL synthesis in bovine (Auboiron et al., 1995) and acts to reduce plasma ketones during early lactation (Durand et al., 1992). Active synthesis of phosphatidylcholine is necessary for VLDL secretion from rat hepatocytes (Yao and Vance, 1988). Thus supplying choline directly may enhance synthesis of phosphatidylcholine and increase VLDL synthesis or serve to increase methionine availability for lipoprotein synthesis to indirectly alter liver triglyceride clearance as VLDL.

It is well documented that methionine supplemented in the rumen protected form increases milk protein production (Donkin et al., 1989; Rulquin and Delaby, 1994) and often coincidentally increases milk fat coincidentally (Rulquin and Verite, 1993), although the latter response is variable. The maximal quantity of amino acids mobilized during early lactation is between 15 and 21 kg of body protein (Botts et al., 1979; Komaragiri and Erdman, 1997) which amounts to approximately 1 kg of lysine and .22 kg of methionine over 5 weeks or 28 g of lysine and 6 g of methionine each day. More closely matching the quantity and pattern of amino acids supplied in relation to the animal's needs (specifically methionine and lysine) during the transition period may retard the rate of breakdown of labile protein. The potential for choline to spare methionine catabolism may depend on the supply and profile of amino acids absorbed from the small intestine of the dairy cow. Feeding soy protein diets to growing rats leads to lipid accumulation that is reduced by the addition of either choline or methionine (Aoyama et al., 1992) and suggests potential for controlling the severity of fatty liver in transition dairy cows by modulating postruminal amino acid supply.

Methionine, Choline, and Folic Acid

As much as 50% of the methione required by ruminants must be synthesized through the remethylation of homocysteine to methionine (Figure 2) and this need may be greater during lactation (Xue and Snoswell, 1985ab). It has been estimated that as much as 30% of the methionine absorbed by dairy cows is used for choline synthesis (Erdman, 1992); therefore, a potential also exists to improve amino acid nutrition of the transition cows through changes in choline status. Methionine remethylation requires either betaine or 5-methyl tetrahydrofolate (5-THF) and is dependent on vitamin B12 (Figure 2). In sheep, the primary transmethylating partner in this reaction is 5-methyl tetrahydrofolate, a form of folic acid. The adequacy of folic acid in lactating and transition dairy cows should be questioned. There is a 40% decrease in serum folate observed during the late gestational and immediate prepartum periods (Girard et al., 1989; Girard et al., 1994). The greatest demand for folic acid in dairy cattle appears to be during gestation (Girard and Matte, 1995) and serum levels are responsive to dietary supplementation (Girard et al., 1994). Folic acid may also play a role in modulating methionine status in the transition dairy cow. Calculations relative to folic acid use and supply indicate a slight deficit at DM intakes approximating those of the transition dairy cow (Donkin, 1997).

Choline and Carnitine and Fatty Acid Oxidation

Decreased fatty acid oxidation and carnitine in liver have been reported due to choline deficiency (Carter and Frenkel, 1978). Choline serves as a methyl donor in the synthesis of carnitine from methionine and lysine (Griffith, 1987). Carnitine is necessary for the translocation of long-chain acyl moieties across the inner mitochondrial membrane of liver cells. The addition of carnitine to bovine liver slice incubations increased the rate of palmitate oxidation (Drackley et al., 1991) and infusing carnitine into the abomasum of lactating dairy cows numerically decreased ($P = 0.11$) plasma nonesterified fatty acid concentrations (LaCount et al., 1996). Therefore choline indirectly may act to reduce the accumulation of liver lipid by providing carrnitine to enhance hepatic fatty acid oxidation.

When Should Rumen-protected Choline Be Fed?

In addition to its role as a methyl donor for choline synthesis, methionine may play a direct role in lipoprotein metabolism. The L-methionine added to milk fed to calves stimulates VLDL synthesis (Auboiron et al., 1995), and feeding the hydroxy analog form of methionine increases circulating lipoproteins and milk fat percentage in lactating dairy cattle. Furthermore, methionine and lysine infusions in lactating dairy cows reduced plasma ketones during the second week of lactation (Durand et al., 1992). Providing choline may act to spare methionine catabolism in transition cows. Dietary choline must be protected from rumen degradation to be effective. The supply of methionine from the diet, or rumen bacterial synthesis, folic acid status, vitamin B12 status, and potential for fatty liver developments all play a role is determining the effectiveness of choline supplementation in the transition cow.

Early Studies to Evaluate the Potential Benefits of Choline supplementation

A series of studies performed using rumen-protected forms of choline or duodenal choline infusions indicate an increase in milk production with increased postruminal choline supply (Erdman and Sharma, 1991). Early studies examined the degradation of choline in the rumen and noted almost complete catabolism of methionine in the rumen (Neill et al., 1979). One of the early experiments using unprotected choline chloride indicated as much as an 8 lb increase in fat corrected milk production when 50 g/day of choline was fed (Erdman et al., 1984). These data are surprising in light of subsequent experiments that indicated the complete degradation of choline chloride using in vitro incubations (Sharma and Erdman, 1989). However animal differences, differences in basal diets, level of intake, and experimental design may have influenced the outcome of these early trials. More consistent response to choline is observed when supplied postruminally via infusions or the rumen-protected form although the effect(s) are not always consistent or repeatable. A summary of the effects of choline on milk production and composition are presented in Table 1. Choline increased milk yield in 4 of 7 studies when choline was infused abomasally or fed in the rumen protected form. The maximum response in milk production was 7 lb/day (from 47.3 to 54.3 lb/day) and 8.4 lb day for fat-corrected milk yield (Sharma and Erdman, 1989).

Effects of Rumen Protected Choline in Transition cows

Four separate studies that have addressed the potential for using rumen protected choline to improve health and productivity of transition dairy cows and have been reported as either peer reviewed publications (Hartwell et al., 2000; Hartwell et al., 2001) or in abstract form (Piepenbrink and Overton, 2000; Siciliano-Jones and Putnam, 2000; Vazquez et al., 1999). All studies used Reashure™, a rumen-stable choline manufactured by Balchem Corp. (Slate Hill, NY). At least one treatment for each study included 60 g/day of the product. A summary of the highlights of these data is presented in Table 2.

Milk production was improved with rumen protected choline feeding in two of the three studies reported. One of the trails (FI and BC) was a field study and rumen-protected choline increased milk production in one-half of the six herds used in the trial (Putnam, 2001). While these data suggest a benefit to the inclusion of rumen-protected choline, information is not yet complete on the mode of action of choline or feeding conditions and management factors that complement its use. It is noteworthy that the percentage increase in milk production during the first 56 to 60 days of lactation is similar for the Purdue and FARME Institute / Balchem study (106% of control) and is of a similar magnitude of response to the early choline feeding studies (Table 1).

Rumen protected choline is beneficial for transition cows fed 10% rumen degradable protein **(RDP)** and 4.0% rumen undegradable protein **(RUP)** (% of dietary DM), but it decreased milk production in cows fed 10% RDP and 6.2% RUP during the prepartum period (Hartwell et al., 2000). Liver fatty acid oxidation is not altered by rumen protected choline although liver triglycerides may be reduced with rumen protected choline in some instances (Piepenbrink and Overton, 2000). The latter suggests an increase in triglyceride export to reduce fatty liver in transition cows fed rumen protected choline.

Studies at Purdue University have demonstrated the negative effects of feeding increased protein to transition cows and the carryover effects on feed intake post-calving (Greenfield et al., 2000; Hartwell et al., 2000). It is well established that over conditioning at calving leads to decreased production and reduced postpartum intakes and increased severity of fatty liver (Reid et al., 1986). Rumen protected choline served to reduce liver lipid in dairy cows when prepartum body condition score was 3.75 or greater and high protein diets (10% RDP and 6.2% RUP) were fed prepartum (Hartwell et al., 2000). On this basis, targeted supplementation with rmen protected choline is recommended even for moderately over conditioned cows (3.8 body condition score) during the transition period (-28 to +28 days relative to calving. The response to rumen protected choline may vary depending on protein sources of the basal diet, energy concentration in the transition diet, yield of microbial protein, methyl donors for the remethylation of methionine, and supply of vitamin B12 and folic acid.

Summary

Rumen protected choline holds promise for modulating metabolism in transition cows to reduce incidence and severity of fatty liver at calving (Figure 3). The milk production response to rumen-protected choline is 5 to 7 lb day during the first 56 to 60 days of lactation. The frequency of a significant positive milk production response to rumen-protected choline is observed in 50% of the studies conducted. Metabolic responses to rumen-protected choline have been equivocal. A predictable response to rumen protected choline feeding may depend on the basal diet, supply of other B vitamins and related factors, and other management factors, including the body condition score of cows entering the transition period.

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Table 1. Summary of reported response to rumen protected choline feeding in transition cows.

	Percent of Control[1]				
Experiment	DMI	Milk	FCM	% Milk Fat	% Milk Protein
Sharma and Erdman (1989)[2]					
Experiment 1 (50 g/day)[3]	106	114*	122*	113	97
Experiment 2 (60 g/day)	102	97	106	104	101
Experiment 3 (40 g/day)	98	105*	104	98	98
Erdman and Sharma (1991)[4]					
Experiment 1 (51 g/day)	100	102	105	101	98
Experiment 2, 13% CP (57 g/day)	104	110*	101	87	99
Experiment 2, 16.5% CP (58 g/day)	98	106*	100	91	98
Grummer et al., 1987, (22 g/day)[2]	97	102	100	93	98

[1]Percent of control:the mean value of the appropriate control within each experiment. DMI = dry matter intake and FCM = fat-corrected milk.
[2]Abomasal choline infusion
[3]Level of supplement choline
[4]Feeding rumen protected choline (Showa Denko, Tokyo).
* Reported means differ statistically ($P < 0.10$).

Table 2. Summary of reported response to rumen protected choline feeding in transition cows.

	Trial Location			
Parameter	PU[1]	CU[2]	LSU[3]	FI & BC[4]
Prepartum intake, lb/day				
Control	28.4	28.1	23.3	NR[a]
60 g/day RPC[5]	27.7	27.4	23.3	NR
Postpartum intake, lb/day				
Control	50.8	40.4	51.7	NR
60 g/day RPC	49.1	40.2	51.7	NR
Milk yield, lb/day (0 to ~ 60 days)				
Control	84.9	86.6	NR	76.6
60 g/day RPC	90.6*	88.4	NR	82.9*
Liver lipid, % of DM				
Control	8.2	9.9	ND[a]	ND
60 g/day RPC	11.4	8.3	ND	ND
Liver glycogen, % of DM				
Control	NR	0.79	ND	ND
60 g/day RPC	NR	1.12*	ND	ND

[1]Purdue University; Hartwell et al. (2000, 2001). Data for 14.1% CP, 4.0% rumen undegradable protein (DM basis) and 60 g/day rumen protected choline product for 0 to 56 days in milk
[2]Cornell University; Piepenbrink and Overton (2000); Overton et al. (2000).
[3]Louisiana State University; Vazquez et al. (1999).
[4]F.A.R.M.E Institute and Balchem Corp.; Siciliano-Jones and Putnam (2000).
[5]Rumen protected choline as Reashure™, Balchem Corp., Slate Hill, NY.
[a]NR = Not reported, ND = not determined.
*Indicates means differ based on reported values.

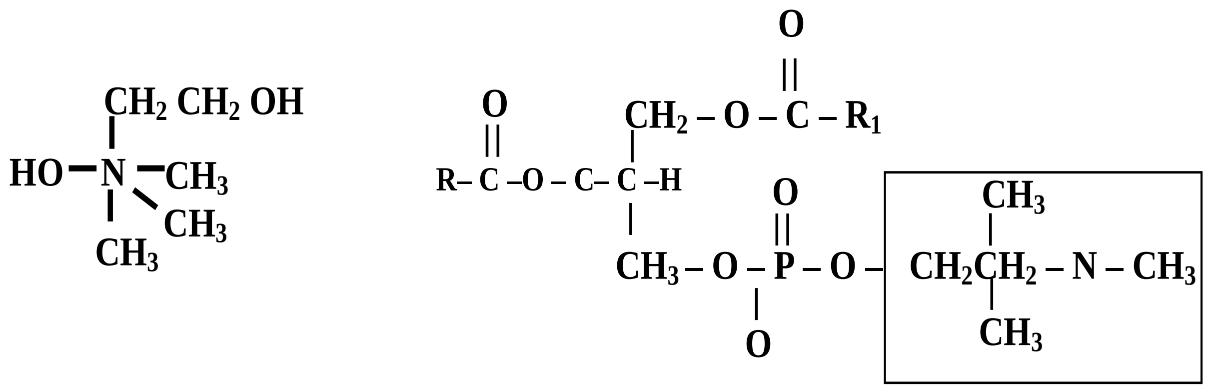

Figure 1. Chemical structure of choline (left) and phosphophtidyl choline (right). The boxed area indicates the portion of phosphophtidyl choline that is derived from choline. The synthesis of choline potentially consumes 3 methionine as a donor for methyl (CH_3) groups.

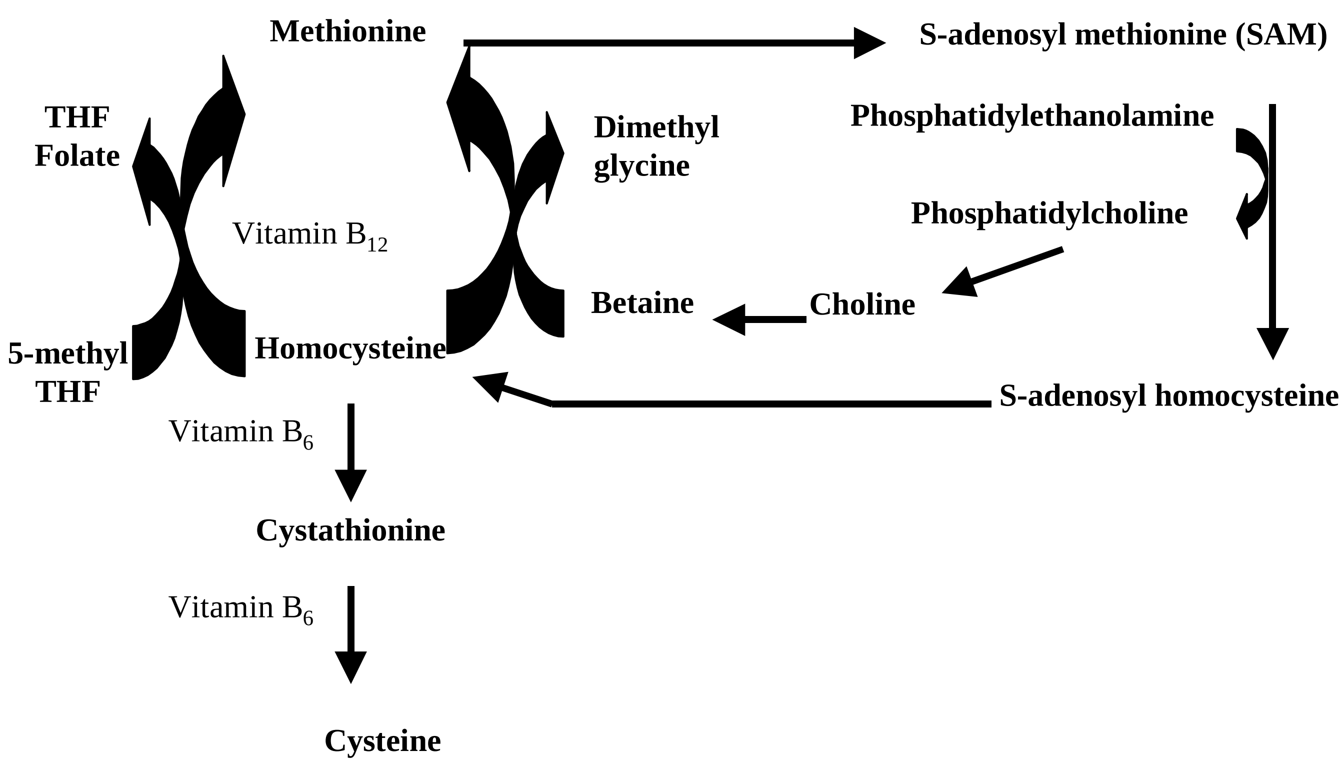

Figure 2. The relationship between methionine, choline, folate, and betaine. The methyl donor **(SAM)** is synthesized from methionine and is used to transfer a methyl group, in the formation of phosphatidylcholine. Once SAM donates a methyl group it becomes S-adenosyl homocysteine, which is metabolized to homocysteine. Homocysteine can be converted to methionine in a reaction that requires methyl tetrahydrofolate **(THF)** and vitamin B-12. Alternately, betaine (a metabolite of choline) may be used as the methyl donor for the conversion of homocysteine to methionine. The primary methyl donor for the regeneration of methionine from homocysteine in ruminants is 5-methyl THF (Xue and Snoswell, 1985ab).

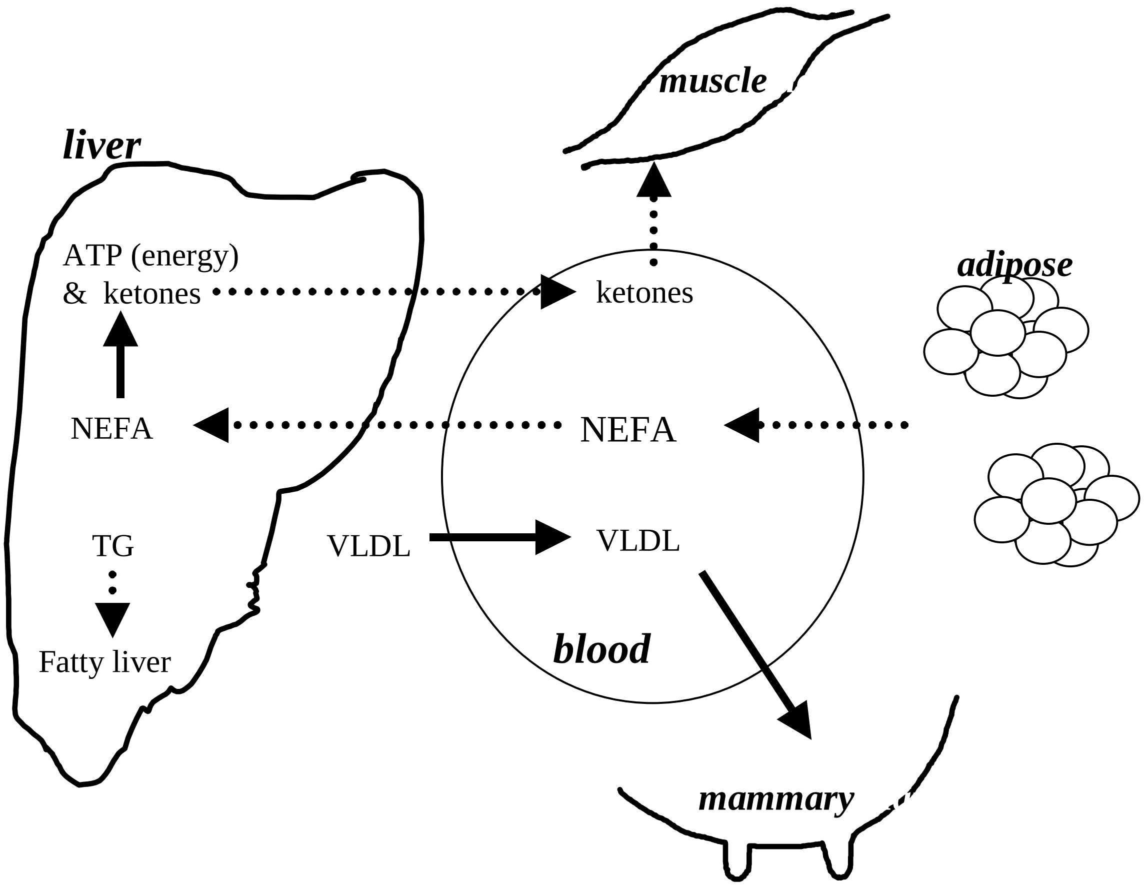

Figure 3. Proposed mechanism of choline action in lactating dairy cows. Adipose tissue lipolysis results in the release of nonesterified fatty acids **(NEFA)** into blood. the NEFA extracted by liver are either esterified to triglyclycerides **(TG)** or partially oxidized to ketones to provide energy **(ATP)** for liver metabolism. Ketones are released into blood and further oxidized by muscle. Alternatively, liver TG can be stored as droplets (fatty liver) or packaged into very low density lipoproteins **(VLDL)** and exported into blood. Choline may affect the synthesis of the apolipoprotein components of VLDL to increase TG export from liver or the metabolism of ketones by peripheral tissues. The solid lines indicate locations where choline may act to modify lipid metabolism.

Jejunal Hemorrhage Syndrome

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Abstract

Jejunal hemorrhage syndrome **(JHS)** is an acute severe enteric disease of mature dairy cows. Typically, a distinct segment of the jejunum of affected animals is obstructed by clotted blood. Despite medical or surgical intervention or a combination thereof, the case mortality rate is very high. While there are previous reports of JHS, the incidence has increased in recent years. *Clostridium perfringens* type A has been implicated to be involved in the development of the disease, though this has not been conclusively demonstrated. Possible risk factors for the development of JHS include level of DM intake, total mixed ration **(TMR)** feeding, subacute rumen acidosis, acute rumen acidosis, nutritional or other changes leading to increased levels of carbohydrate in the small intestine, presence of *Clostridium perfringens* type A in feedstuffs, parity, stage of lactation, herd size, breed, and season.

Introduction

Since JHS is an emerging disease, the terminology is not yet well established. Synonyms include "intraluminal hemorrhage of the small intestine", "intraluminal intestinal hemorrhage syndrome", "hemorrhagic bowel syndrome", and "acute hemorrhagic enteritis of the small intestine". A survey (Godden et al., 2001) of Minnesota bovine practitioners revealed that between 50 and 59% of respondents (the "survey" was actually two surveys - one by mail and one at the annual conference of the Minnesota Veterinary Medical Association- thus the range of responses) had diagnosed at least one case of JHS during the preceding 12-month period. Between 40 and 56% of the respondents reported the diagnosis of multiple cases in individual herds. According to the same report, veterinary diagnostic laboratories in New York, Pennsylvania, Washington, Wisconsin, Minnesota, Colorado, Illinois, and Iowa have reported a sharp increase in the number of cases of JHS submitted for evaluation.

The cause of JHS remains unknown. A bacterium, *Clostridium perfringens* type A, has been isolated from the affected area of the intestine of a substantial fraction of cases. However, *Clostridium perfringens* type A is present in the jejunum (small intestine) of all adult cattle and is well known to proliferate rapidly post-mortem. The risk factors for the development of JHS are likewise unknown. Nutritional as well as other factors are suspected to be involved in the development of the disease.

The Disease Syndrome

Clinical Signs

Jejunal hemorrhage syndrome is an acute to peracute disease. Affected animals may be found dead with no prior abnormal signs. Clinical signs that have been observed in affected animals (Godden et al., 2001; Kirkpatrick et al., 2001; St. Jean and Anderson, 1999) include:

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- Acute anorexia
- Acutely decreased milk production
- Dehydration
- Shock
- Pale mucous membranes
- Abdominal distension
- Colic
- Bruxism
- Weakness / recumbency
- Rectal temperature is generally normal to decreased.
- Simultaneous auscultation and percussion may reveal a “ping” on the right side of the abdomen.
- Succussion (simultaneous auscultation and ballotment) may reveal a fluid “slosh” on the right side of the abdomen.
- Fecal output may be decreased or cows may have diarrhea. Feces may be black (melena) or contain frank blood or blood clots.
- Rectal examination may reveal intestinal distension.

Treatment

Treatment is generally unrewarding. Surgical intervention is the treatment of choice (St. Jean and Anderson, 1999). However, even with resection of the affected area and anastomosis of apparently healthy jejunum, animals often do not recover. This may be due to decreased viability of the bowel (even though it appears to be healthy) at the anastomosis site, ongoing decreased intestinal motility following surgery, or other factors. Medical treatment alone has generally been unsuccessful. The prognosis for an affected animal is grave.

Necropsy Findings

The characteristic post-mortem finding is a distinct section of jejunum (variable in length but typically two to six feet of intestine affected) that is moderately to severely distended and dark red to purple. The affected area contains clotted blood that is obstructing the passage of ingesta. More than one such area may be present in the intestine of some cases.

Epidemiology

The morbidity rate (fraction of animals affected with the disease) on farms where the disease occurs is generally less than 1 to 2% per year. However, there have been outbreaks on individual farms with several animals simultaneously affected or affected over the course of a few days. The syndrome may be underreported due to the fact that a necropsy examination is not performed on all cows that die acutely on all farms. Indeed, the association between larger herd size and JHS may simply be an artifact of the greater likelihood that an animal that dies suddenly will be necropsied on a larger dairy. The mortality rate (fraction of animals that die) among affected animals approaches 85 to 100% (Kirkpatrick et al., 2001).

The results of the survey of Minnesota bovine practitioners (Godden et al., 2001) suggested that the following may be risk factors for the development of JHS:

- Parity: much greater frequency of JHS in second lactation or greater cows
- Stage of lactation: greater frequency of JHS in cows in early lactation
- Season: greater frequency of JHS in fall and winter
- Herd size: greater frequency of JHS in larger herds
- Feeding management system: greater frequency of JHS in herds fed a TMR

However, the authors cautioned that the survey should only be considered a first step toward identifying possible risk factors deserving of further investigation.

Pathogenesis

Clostridium perfringens type A has been associated with JHS. In a review of cases presented to the Veterinary Diagnostic Laboratory at the University of Minnesota between 1999 and 2000 (Godden et al., 2001), *Clostridium perfringens* type A was isolated from 19 of 22 cases. Kirkpatrick et al. (2001) stated that "Suspect JHS cases presented to the Iowa State University Diagnostic Laboratory have consistently yielded *Clostridium perfringens* type A in high numbers." However, *Clostridium perfringens* type A is ubiquitous both in the environment and in the gastrointestinal tract of cattle (Songer, 1999). The organism proliferates rapidly post-mortem. Thus, while *Clostridium perfringens* type A has been isolated post-mortem from clinical cases of JHS, this is not sufficient evidence to establish that the organism plays a role in the pathogenesis of the disease.

Researchers (Ivany et al., 2001) attempted unsuccessfully to reproduce the syndrome by inoculating *Clostridium perfringens* type A organisms recovered from a clinical case into the abomasum and the jejunum of cows. It is possible that other factors (for example, intestinal hypomotility in an area of the jejunum with a transiently high level of available luminal carbohydrate) are primarily involved with subsequent opportunistic *Clostridium perfringens* type A proliferation, leading to the acute pathology characteristic of the syndrome.

Nutritional Factors Related to Jejunal Hemorrhage Syndrome

Dry Matter

The owner of the herd studied by Kirkpatrick et al. (2001) expressed the opinion that all affected animals were "aggressive eaters". Evidence to support the hypothesis that DM intake is a risk factor is indirect. In that study, there was an association between milk production and JHS. Also, JHS is generally much more common in second lactation and greater cows than in first lactation cows. Higher levels of DM intake would be expected in both cows with higher levels of milk production and individuals of greater than first lactation status.

Feeding of a TMR

The Minnesota survey (Godden et al., 2001) found that a higher percentage of affected herds were fed a TMR than fed component rations (83 versus 17%). The significance of TMR feeding as a risk factor is enhanced by the fact that only approximately 38% of the herds in Minnesota at the time of the survey were fed a TMR.

The herd studied by Kirkpatrick et al. (2001) also fed a TMR. In that study, the long fiber fraction of the TMR as measured using a Penn State particle separator was 11.1% (top screen). However, when the TMR refusal was analyzed, the long fiber fraction was 23.4%, suggesting that some degree of sorting was occurring. The low morbidity of JHS is relevant in that it is a disease of individuals. As such, it is possible that individual cows that tend to sort a TMR may be at increased risk for developing the disease. Additionally, in the same herd, on days –4 and –3 prior to an outbreak of JHS in which there were four individuals affected, the long fiber fraction of the TMR dropped to 6%.

Acidosis

Clostridial organisms that inhabit the rumen of animals that are chronically exposed to diets that lead to low or transiently low rumen pH become adapted to survive at a lower pH than "normal" clostridia (Songer, 2002). If an event occurs that acutely increases the rate of passage of ingesta out of the rumen, then these bacteria may flow out of the rumen and survive passage through the abomasum. It is possible, therefore, that subacute rumen acidosis may be a risk factor for the development of JHS.

Kirkpatrick et al. (2001) found no evidence that subacute rumen acidosis was involved in the pathogenesis of JHS in the herd studied. However, following the feeding of corn silage that had only been ensiled for one week, the herd experienced an outbreak. Such a feedstuff would be expected to have a tendency to cause rumen pH to drop. Nevertheless, introduction of such a feedstuff would also tend to have multiple effects in addition to lowering rumen pH.

Soluble carbohydrate levels, effective fiber levels, and other factors are important determinants of rumen pH. It may be that subacute rumen acidosis does not lead to JHS but that other factors put an animal at risk of developing both diseases. For example, as effective fiber levels decrease, both the pH of the rumen will change and the nature and quantity of carbohydrate presented to the jejunum will change.

Organism Present in the Feedstuff

Two outbreaks of JHS in the herd studied by Kirkpatrick et al. (2001) occurred coincident with feeding alfalfa haylage from an upright silo. Alfalfa haylage was the only forage tested on the farm from which *Clostridium perfringens* type A was isolated microbiologically. No outbreaks occurred during times when alfalfa haylage was not in the ration or when the haylage used had been stored in plastic bags. Notwithstanding the ubiquitous nature of the organism, it is possible that the presence of *Clostridium perfringens* type A in a feedstuff may be a risk factor for the development of JHS.

Summary

Jejunal hemorrhage syndrome is an emerging disease of dairy cattle. Due to the rapidity with which cows succumb to it and the rapidity with which the *Clostridium perfringens* type A organism proliferates post-mortem, determining the role, if any, of this organism in the pathogenesis of the disease may prove difficult. While some nutritional risk factors for the development of the disease are suspected, much remains to be learned. Given that, at present, the disease cannot be reproduced for study and the sporadic nature of it, cooperation between those in the field (dairy farmers, nutritionists, veterinarians, and others) and the researchers studying it will be essential toward elucidating the etiopathogenesis of the disease.

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Optimal Protein and Energy Levels for Heifers

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Abstract

Current NRC (2001) metabolizable protein **(MP)** requirements for dairy heifers were developed with data from slaughter trials done with beef heifers from the 1970's. The use of the beef heifer data from the 1970's to determine MP requirements is invalid given the large difference in genetics compared with current rapidly growing dairy heifers. Furthermore, the MP supply is determined by estimates of microbial protein production and bypass protein flows to the small intestine, which are affected by many nutritional and management factors and can not be accurately predicted. Thus balancing heifer rations based on MP is inaccurate and leads to rations with an insufficient quantity of protein. However, the protein needs of the heifer can be estimated with an alterative method, the dietary crude protein to metabolizable energy (CP:ME) ratio. The dietary CP:ME ratio needs of the rapidly growing heifer is more a function of growth rate than body weight **(BW)** and will vary little from weaning to calving. Several nitrogen balance and performance studies have been conducted in the last five years. These studies have consistently shown the benefits of feeding a ration to heifers with a dietary CP:ME ratio of 63 to 70 (g/1.0 Mcal).

Introduction

It is well known that increased caloric or energy intake in growing heifers leads to increased growth rates. However, if a dietary deficiency occurs in protein or any vitamin and mineral in the rapidly growing heifer, the utilization efficiency of the consumed energy will be reduced. Mineral and vitamin supplementation is relatively inexpensive compared to protein, which allows for small amounts of vitamins and minerals to be over-supplemented to prevent possible deficiencies. Furthermore, the absorption and metabolism of minerals is more simplistic than protein. Providing the correct level of protein supplementation is complex but can be estimated by evaluating the response of heifers to differing levels of protein in various research models.

Crude Protein Versus Metabolizable Protein in Formulating Heifer Rations

Meeting the protein needs of the growing heifer is essential to her structural development and feed efficiency, but the protein needs can be hard to estimate and over-supplementation is expensive. Indeed, the growing heifer has a requirement for MP, which is the predicted quantity of protein absorbed by the heifer at the small intestine. To meet and balance a heifer's diet for her MP requirement, one must predict the MP supply or quantity of microbial protein and bypass protein available at the small intestine. However, it can be difficult to determine these protein flows to the lower tract. There are several reasons why attempts that have been made to accurately model or predict microbial

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and bypass protein availability at the small intestine have failed. First, microbes in the rumen utilize carbohydrates and rumen degradable protein to produce their own microbial protein. The diet of the young heifer has more fermentable carbohydrates and less forage than the older heifer. The increased dietary concentration of non-fiber carbohydrate is stimulatory to microbial growth but can also lead to a lower ruminal pH, which can depress fiber digestibility, making it difficult to predict the quantity of microbial protein production. Furthermore, as the heifer matures, passage rates of feed leaving the rumen decrease, leading to increased digestion of carbohydrates and protein in the rumen and more microbial protein production. Passage rates change substantially and are impossible to predict accurately in the young heifer. Without accurate equations to predict passage rates in the heifer, it is difficult to estimate microbial protein production and subsequent MP supply.

The DM intake by the heifer is also needed to predict the amount of substrates available for microbial protein production and bypass protein, thereby allowing us to model the quantity of MP available to the animal. Lastly, the farm feeding program and ration ingredients can have a large effect on the passage of microbial and bypass protein to the small intestine. Many different types of forage and feeding programs exist along with limited and ad libitum feeding situations. These feeding programs can vary greatly in the quantity and quality of bypass protein, which affects the balance of the amino acids delivered to the small intestine and the utilization efficiency of MP. Thus, the prediction of a heifer's protein requirements and balancing diets to meet those requirements based on MP will be difficult given the changing diet and physiology of growing heifers, unique farm feeding programs, and lack of subsequent heifer DM intake information.

Dietary Protein to Energy Ratio

Even though balancing diets based on MP is not practical, we can estimate the protein needs of the heifer with an alternative method by evaluating the diet for the protein to energy ratio. As heifers mature, they require a less nutrient dense diet, allowing for increased fiber consumption and lower non-fiber carbohydrate and protein levels. The rate of decline in nutrient density needed by the growing heifer for energy and protein is very similar. In fact, the ratio of CP:ME is more a function of rate of gain than BW (Preston, 1966). Furthermore, research recommends an age at first calving of 22 to 24 months (Heinrichs, 1993), requiring a rate of gain from 6 months of age until calving near 1.8 lb/day. Thus, the CP:ME ratio will be similar for heifers of all ages.

Formulating diets with a balance of protein and energy is not a new concept, having been used as far back as the 1950's to evaluate heifer protein requirements. Several studies evaluating the heifer's protein needs were conducted in the 1960's and 1970's, while only a couple of studies were conducted in the 1980's and 1990's. The studies that were conducted in the 1960's and 1970's evaluated the protein needs of the weaned calf. Thus, you may ask two questions, namely where do the requirements from the 2001 Dairy NRC originate and how do we estimate the requirements of older heifers? The answer would be that the 2001 Dairy NRC utilized the 1996 Beef NRC equations, which are based on a single slaughter trial conducted with beef heifers, not dairy heifers. Additionally, the beef heifer data was published 20 years ago (Garrett, 1980) and clearly does not represent the body composition or metabolism of the Holstein heifer from the new millennium. Not surprisingly, the protein requirements for Holstein heifers in the 2001 NRC (2001) are low.

We became interested in evaluating the dietary CP:ME ratio needs of growing heifers when we noticed discrepancies in the 1989 and 2001 Dairy NRC. The 2001 Dairy NRC protein requirements for growing heifers from 2 to 6 months of age is 14 to 19% and 10 to 12% for heifers older than 6 months of age. The subsequent CP:ME ratios are 64 to 87 for heifers younger than 6 months of age and 48 to 55 (g/1.0 Mcal) for heifers older than 6 months of age (NRC, 2001). We hypothesized that identifying an optimal ratio of protein to energy would increase the utilization efficiency of nutrients and improve structural growth rates.

Given the synergistic nature of protein and energy utilization in the rumen, CP:ME ratios appear as a means by which dietary requirements can be formulated to receive optimum utilization of nutrients and growth. Utilization of nutrients has been studied by two methods, nitrogen balance and performance studies. Nitrogen balance studies measure the quantity of nitrogen consumed and excreted to estimate the quantity of nitrogen retained by the animal. Whereas, performance trials can be used to determine the dietary profile where the least amount of feed is required to produce the recommended rate of gain, while maximizing rates of structural growth.

Nitrogen Balance Studies

The two purest methods of determining protein requirements for a heifer are to perform slaughter or nitrogen balance trials. In a nitrogen balance trial, increasing levels of protein are fed and the quantity of nitrogen retained by the animal is measured. When the quantity of retained nitrogen plateaus, the dietary protein requirements have been met. Two recent nitrogen balance studies were conducted at Cornell (Marini and Van Amburgh, 2001) and Penn State (Gabler et al., 2001). Both of these studies were conducted with young heifers. In the Penn State study, heifers were fed a traditional corn and alfalfa silage diet at 2.0% of BW; whereas, heifers in the Cornell study were fed a diet at 2.2% of BW containing a complete pelleted feed without roughage.

The Cornell researchers reported that retained nitrogen plateaued and protein requirements were met with dietary CP:ME ratio of 70 (g/1.0 Mcal). However, on a more traditional diet, we found that retained nitrogen peaked between a dietary CP:ME ratio of 63 and 68 (g/1.0 Mcal). Possible explanations for the discrepancy between the two university trials could include the differences in diets being fed (traditional forage based diet versus pelleted diet), the higher DM intake of the heifers on the Cornell study (2.2 versus 2.0% of BW), and a higher growth rate for heifers in the Cornell study, which would raise their protein requirement on a CP:ME ratio basis compared with the heifers in the Penn State trial.

Growth Rates, Feed Efficiency, and Structural Growth

Another method that can be used to evaluate the protein requirements of a heifer is via performance trials. In performance trials, growth rates and feed efficiencies are evaluated in response to increasing levels of dietary protein with all other variables held constant. Some trials have also recorded changes in structural growth and body condition for the different protein levels. Most of these studies have been conducted recently.

We conducted two trials with two different ages of heifers and differing protein levels within each trial while maintaining all other variables. In the first trial, heifers were fed diets with CP:ME levels of 46, 54, and 61 (g/1.0 Mcal) from 7 to 11 months of age (Lammers and Heinrichs, 2000). We found a linear increase in growth rates through the highest protein level. Subsequent to this trial, we fed heifers from 4 to 9 months of age a larger range of dietary CP:ME levels of 48, 59, 68, and 77 (g/1.0 Mcal) (Gabler and Heinrichs, 2001). In the later trial, we were more interested in the effect of nutrient utilization than rate of gain, and we controlled rate of gain with the amount of feed offered, which minimized a rate of gain response. In this second trial, we found that efficiencies of growth were maximized near 63 grams of CP per Mcal of ME. Furthermore, at ADM Alliance Nutrition, we conducted a similar study with dietary CP:ME ratios of 64 and 72 (g/1.0 Mcal) and found no advantage in average daily gain with the higher protein diet compared to the lower diet (unpublished). Collectively, our data suggest that growth rates can be increased with dietary CP:ME ratios up to 63 but plateau at higher CP:ME ratios.

Feed efficiency is an effective method of evaluating the effects of protein supplementation on utilization efficiency of dietary energy. In fact, improvements in feed efficiency allow for increased rate of gain and structural growth. In our studies conducted at Penn State and ADM Alliance Nutrition, we found that feed efficiency was optimized near a dietary CP:ME ratio of 65 (g/1.0 Mcal) (Figure 1). Improved feed efficiency results in optimal growth and development of the heifer and decreased feed costs and nutrient excretion.

When heifers are fed a diet that is substantially deficient in protein, one can often visually observe heifers that are short in stature and have excess body condition. By monitoring structural growth rates of the heifer, we can determine if sufficient protein is being fed to maximize lean tissue growth. In the trials conducted at Penn State and ADM Alliance Nutrition, we found that wither and hip heights were maximized with a CP:ME ratio near 70 (g/1.0 Mcal) (Figure 2). However, the increase in structural growth below 63 was more rapid than between 63 and 70 (g/1.0 Mcal).

The growth rates and feed efficiencies observed in these performance studies indicate the need for balancing growing heifer rations with a CP:ME ratio of 63 (g/1.0 Mcal). Furthermore, the improvements in feed efficiency offset the additional cost of the supplemental protein, thereby allowing the grower to feed the heifer for optimal efficiency, maximal structural development, and future profitability without additional costs.

Dietary Protein to Energy Ratio and Mammary Development

Mammary development in Holstein heifers undergoes allometric or rapid growth from 4 until 11 months of age. This prepubertal allometric mammary growth phase is critical to future mammary secretory tissue growth. It could be described as the foundation from which the mammary secretory tissue will grow after puberty and during pregnancy. During this allometric growth period for mammary secretory tissue, it has been shown that accelerated heifer growth rates can decrease mammary secretory tissue development and subsequent milk production.

Researchers from the USDA evaluated the effects of accelerated prepubertal growth rates of 2.1 lb/day and dietary CP levels of 16 or 22% on mammary development and subsequent milk production (Capuco et al., 1995). They found that the heifers fed the high protein diet had increased DNA and RNA content of the parenchymal tissue by 70 and 59%, respectively, and the epithelial tissue occupied 67% more of the mammary parenchyma at puberty. However, the dietary protein level had no effect on first lactation milk yield.

Some research studies that have reported a drastic decrease in mammary development or subsequent milk production due to accelerated prepubertal heifer growth rates were considerably low in dietary protein. Furthermore, recent studies have not observed the earlier drastic decreases in mammary development or milk production due to accelerated prepubertal growth rate when an adequate level of dietary protein was fed. In our studies, we found that accelerated prepubertal heifer growth rates of 2.20 versus 1.54 lbs/day only decreased first lactation milk production by 7% when a dietary CP:ME ratio of 60 (g/1.0 Mcal) was fed (Lammers et al., 1999).

Logic suggests that if body composition or protein and fat accretion rates change in the heifer that is protein deficient, a protein deficiency would also likely affect the development of the mammary secretory tissue. The growth rates of many tissues of the heifer's body are influenced by a milieu of hormones, which have been shown to be responsive to levels of dietary protein. Thus a diet that is deficient in protein may adversely affect mammary development, especially in the rapidly growing prepubertal heifer whose mammary development is particularly sensitive to these hormones.

The reduction in milk production from accelerated prepubertal growth rates can be substantial and costly. Additionally, heifers that are fed a ration that has a low protein to energy ratio may be at greater risk for impairments in mammary development. Until more information becomes available, we recommend feeding prepubertal heifers for a moderate growth rate to prevent any inhibitory effects on mammary development and sufficient dietary protein to energy ratio to meet the nitrogen balance and performance needs of the heifer, which is likely linked to optimal mammary development.

Recommendations

Because the CP:ME ratio for a heifer is more a function of growth rate than BW, the recommended dietary CP:ME ratio does not change much from 4 months of age until a month prior to calving. After 4 months of age, the heifer should be fed and managed to grow at rates of 1.8 lbs/day. Thus to optimize the efficiency of nutrient utilization and structural growth, we recommend feeding a diet with a dietary CP:ME ratio of 63 (g/1.0 Mcal) from 4 until 10 months of age, which is summarized in the Table 1. After 10 months of age, no data exist regarding the optimal CP:ME ratio except for the NRC (2001) recommendations, which are based on beef heifer slaughter data. However, given what we know about the protein needs of the heifer and CP:ME ratio, we can extrapolate to the yearling heifer. Yearling heifers have slower rumen passage rates and higher ruminal organic matter digestibilities, which would allow the rumen microbes to produce more microbial protein per unit of feed versus a young heifer. Thus as a heifer matures beyond 10 months of age, her CP:ME ratio requirement may decrease slightly and possibly reach a dietary CP:ME ratio of 60 (g/1.0 Mcal) at 22 months of age.

Summary

Balancing diets of dairy heifers for MP is not practical given the difficulty in predicting the flow of microbial protein and bypass protein to the small intestine. Microbial protein and bypass protein flows to the small intestine and MP cannot be accurately predicted nor balanced in the ration due to the changing diet and physiology of the growing heifer, unique farm feeding programs, and lack of subsequent heifer DM intake information. The protein needs of the heifer can be estimated by evaluating the dietary CP:ME ratio. The dietary CP:ME ratio is more a function of growth rate than BW. Thus, the dietary CP:ME ratio will change very little for a growing heifer.

Nitrogen balance studies have been used to estimate the point where protein needs of the heifer are met. These nitrogen balance studies have shown that protein utilization plateaus between a dietary CP:ME ratio of 63 to 70 (g/1.0 Mcal). Performance studies have also been conducted to evaluate the effects of CP:ME ratios on growth rates, feed efficiency, and structural growth. Heifer nutrient utilization and structural growth rates were optimized with a dietary CP:ME ratio of 63 (g/1.0 Mcal). The improved nutrient utilization or feed efficiency offsets the increased cost of supplemental protein. Additionally, heifers that are fed a ration that has a low protein to energy ratio may be at greater risk for impairments in mammary development that can occur in rapidly growing heifers between 4 and 11 months of age.

Because the improved feed efficiency offsets the increased cost of supplemental protein, a heifer grower can feed heifers with the optimal CP:ME ratio of 63 (g/1.0 Mcal) and gain the benefits of maximal average daily gains and structural growth rates without additional costs. For these reasons, we recommend feeding heifers from 4 to 10 months of age a diet that will support a 1.8 lbs/day rate of gain and a dietary CP:ME ratio of 63 (g/1.0 Mcal).

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Table 1. Protein and energy recommendations for Holstein heifers.[1]

Age (months)	CP:ME (g/1.0 Mcal)	ME (Mcal/kg)	NEg (Mcal/lb)	CP (%)
4	63	2.70 (1.23)[2]	0.53	17.0
6	63	2.60 (1.18)	0.49	16.4
8	63	2.55 (1.16)	0.47	16.1
10	63	2.50 (1.14)	0.46	15.8
12	62	2.45 (1.11)	0.44	15.2
16	61	2.40 (1.09)	0.42	14.6
18	60	2.35 (1.07)	0.40	14.1
22	60	2.30 (1.05)	0.38	13.8

[1]CP:ME = crude protein:metabolizable energy, ME = metabolizable energy, and NEg = net energy for growth.
[2]Numbers in parentheses are ME (Mcal/lb).

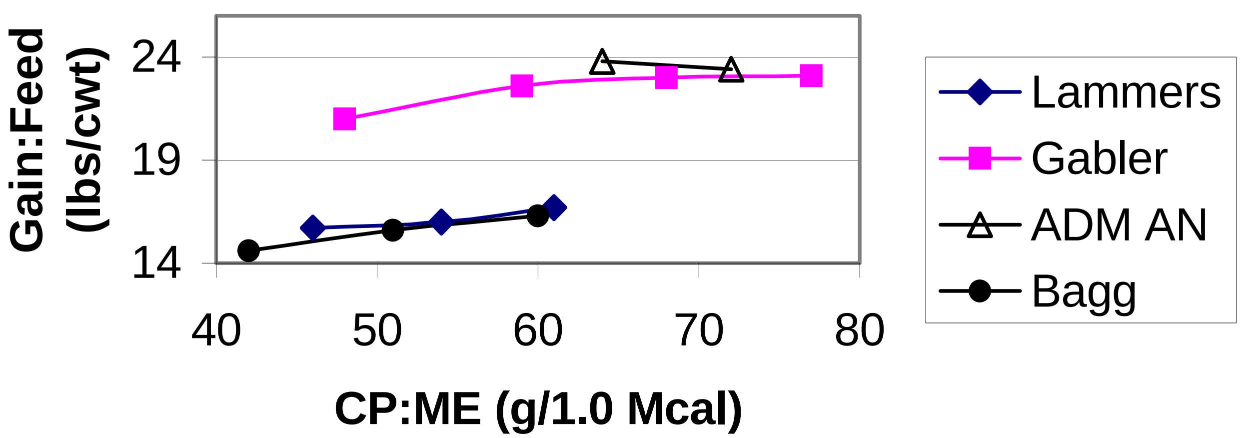

Figure 1. Effect of dietary crude protein:metabolizable energy (CP:ME) ratio on feed efficiency [data taken from Lammers and Heinrichs (2000), Gabler and Heinrichs (2001), ADM Alliance Nutrition, Inc. (1999, unpublished), and Bagg et al. (1985)].

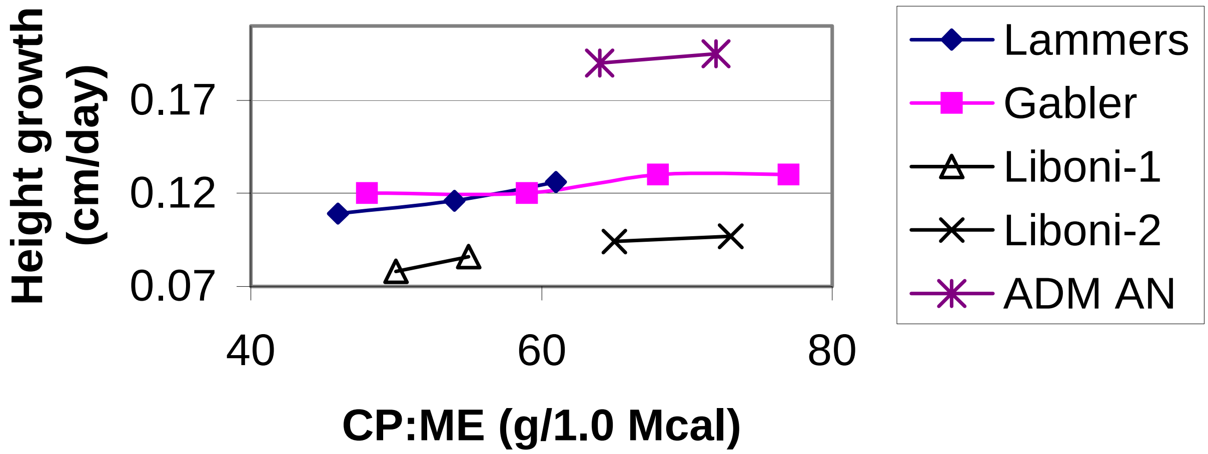

Figure 2. Effect of dietary crude protein:metabolizable energy (CP:ME) on structural growth [data taken from Lammers and Heinrichs (2000), Gabler and Heinrichs (2001), Liboni et al. (2001), and ADM Alliance Nutrition, Inc. (1999, unpublished)].

Energy and Protein in the 2001 Dairy NRC: Challenges for a Ration Formulation Program

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Abstract

The 2001 version of the Nutrient Requirements of Dairy Cattle by the National Research Council **(NRC)** is a substantial work and contributes significantly to the science of nutrition in dairy cattle. In my opinion, there are serious problems with the energy system, but most of these problems have to do with trying to use the model in formulating rather than evaluating diets. Data are lacking for the development of an accurate system for discounting the energy value of feeds fed to high producing cows. The 2001 NRC makes a good first attempt at a discount system and makes significant improvement in calculating microbial protein yield.

Introduction

The word "requirements", defined broadly, describes the amounts and types of feeds needed to meet the nutrient needs of an animal. In this way, requirements include consideration not only of an animal's nutrient requirements but also of the supply of nutrients an animal receives from a specific diet. The goals of this paper are to explain the major changes in the 2001 version of the Dairy NRC compared to the 1989 version and to illustrate the challenges in using the new model for ration formulation, in contrast to ration evaluation.

At the outset, I want to temper criticism with praise. I commend the committee responsible for the 2001 Dairy NRC with a job well done. Their task was difficult. They were challenged to substantiate their model with published data, yet their resources were limited (time, financial support, and data). The new NRC takes some very important steps in moving us forward toward a better understanding of the complexities of feeding dairy cattle.

Energy

1989 NRC

The energy system of the 1989 Dairy NRC is shown in Figure 1. It is relatively simple and is based on a few critical assumptions. The net energy requirement of an animal is a function of their metabolic body weight **(BW)**, fat-corrected milk **(FCM)** yield, BW gain per day, parity, whether or not they are pregnant, and whether or not they are grazing. The supply of net energy for lactation **(NE_L)** from feeds is a fixed user-entered value that is based on the total digestible nutrients **(TDN)** value of a feed and considers all animals as eating at 3X maintenance intake. The digestibility of all feeds therefore is discounted at ~8%.

2001 NRC

The energy system in the 2001 Dairy NRC is shown in Figure 2. A comparison of the two models is given in Table 1, and the major changes are discussed. Feed energy values are

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directly tied to their composition, so rather than editing the energy value directly, the digestible energy **(DE)** value of a feed at maintenance is a function of the amount and digestibility of its neutral detergent fiber **(NDF)**, protein, fat, and nonfiber carbohydrate **(NFC)**. The DE values of digestible carbohydrates, CP, and fatty acids are 4.2, 5.6, and 9.4 Mcal/kg, respectively. A value for metabolic fecal energy is subtracted. The DE value of a feed is used to calculate the metabolizable energy **(ME)** and NE_L values, using equations similar to ones discussed in the 1989 NRC.

As with the 1989 NRC, a single digestibility discount is applied to each feed within a diet, but the discount is not fixed at 8%. Rather, the digestibility discount in the 2001 NRC is dependent on feed intake and initial digestibility. The discount is a total diet calculation, so it applies equally to all feeds within a diet but changes depending on the animal eating it. As intake increases, the energy value of feeds decreases. In addition, as the initial digestibility of the diet increases, the discount per multiple of maintenance increases, so the depression in digestibility is greatest for diets with the highest fat-free TDN value. In other words, adding corn (starch) to a diet will increase the discount so that digestibility is depressed more for a high corn grain diet than a high forage diet. Adding fat will actually decrease the discount because it replaces feeds that contain fat-free TDN. Thus, the discount cannot be calculated without knowing the total amount and the blend of feeds consumed. The multiple of maintenance for calculating the discount is a function of the TDN intake using the TDN value for an animal at maintenance intake **(TDN1X)** divided by the amount of TDN needed for maintenance.

Some energy requirements also are altered. The energy requirements for milk are dependent on composition of not only fat but also protein and lactose. Energy requirements for pregnancy increase with day of gestation. The energy requirements associated with body tissue changes are dependent on whether the changes are associated with growth or with changes in body condition. Requirements for growth depend on the phase of growth (size of an animal relative to its mature size). The energy for body condition repletion or depletions depend on the beginning and ending body condition—a one unit change in body condition score is associated with more energy in a fat than in a thin animal. Grazing increases the requirement for energy, and precise equations are included that are based on the distance a cow must walk per day. This generally increases NE_L requirements by 1 to 3 Mcal/day. Interestingly, however, if the pasture is "hilly", the requirement jumps another 4 Mcal and "hilly" is a very subjective word.

Protein

1989 NRC

The protein system of the 1989 Dairy NRC is shown in Figure 3 and Table 2. The protein requirement of an animal in the 1989 NRC is a function of their BW, DM intake, milk protein yield, BW gain per day, parity, and whether or not they are pregnant.

The supply of metabolizable protein **(MP)** from microbial protein is a function of the NE_L intake of the animal. Microbial crude protein **(MCP)** is considered to be 80% true protein and 80% digestible. The equation for MCP yield has a negative intercept, which results in unreasonably low MCP yields and thus high requirements for rumen-undegraded protein **(RUP)** in young heifers. The RUP fraction of protein is a constant for each feed and is considered to have a digestibility value of 80%.

2001 NRC

The protein system in the 2001 Dairy NRC is shown in Figure 4 and compared to the

1989 NRC in Table 2. The protein requirement of an animal is similar to that of 1989 NRC, but the metabolic fecal protein requirement was decreased, a requirement for secreted gut proteins was added, the protein requirement for pregnancy increases with day of gestation, and the protein required for growth or body condition gain is affected by BW as a percentage of mature BW and the actual body condition score of the animal.

The fraction of protein that is RUP is a function of its protein fractions (A, B, and C) and the competition of digestion and passage for fraction B. All of the C fraction is assumed to be RUP, and all of the A fraction is assumed to be rumen-degraded protein **(RDP)**. The RUP value of the B fraction depends on its digestion rate (k_d, which is a fixed value for each feedstuff) and the passage rate (k_p) for the feed. Feed passage rates depend on whether the feed is a wet or dry forage, its NDF concentration, the DMI of the cow, and the percentage of concentrate in the total diet. In using the model, however, you will discover that the RUP values of feeds are relatively insensitive to the factors that affect passage rate. So in the end, this is not much different than using a fixed RUP value for each feed, as in the 1989 NRC.

A major improvement is that the percentage of RUP that is digested is no longer assumed to be 80% for all feeds but is a fixed value for each feedstuff. The supply of MP from MCP is a function of the fat-corrected, discounted TDN intake of the animal. As in 1989, MCP is considered to be 80% true protein and 80% digestible. The equation for MCP yield has no intercept, so it works much better for young heifers. Finally, the new NRC also considers amino acid requirements and supply.

Feed Intake

A feed intake equation is included. The equation is based on animal factors (BW, milk yield, and days-in-milk) but not feed factors (Table 3). So for example, fiber and fat concentrations do not alter the prediction for voluntary feed intake. Predicted feed intake also is not altered by grazing or growth. Thus, increasing the work level of a cow can greatly increase the required energy density in the diet if the predicted intake is used for formulating a diet (Table 4). The heifer DMI prediction is dependent on the energy density of the diet, but energy density has very little impact on the prediction within the range of diets normally fed to heifers in the US.

Comments on the New System and Challenges in Using It for a Ration Formulation Program

Some nutritionists consider the fact that the new NRC is more mechanistic to be a major improvement. More mechanistic models are good for teaching about the principles of nutrition and metabolism, but the more important factor for a field model of nutrition is accuracy. Importantly, more mechanistic models are not always more accurate. All models have some combination of empirical and mechanistic relationships, but they are aggregated at different levels. The important question for any field model is: Does it work better or not? In the case of the Dairy NRC, the new model does work better than the 1989 model as a ration evaluator—in other words, when examining expected responses in milk to any diet changes. However, there are some major problems when using it as a ration formulator.

Together the energy and protein requirements and the predicted feed intake seem reasonable in the 2001 NRC and are an improvement over the 1989 version (Table 4). Increasing the milk yield of a cow requires diets that are more energy and protein dense, with reasonable plateaus for high-producing cows. For example, a cow at maintenance would require a diet with 0.8 Mcal NE_L/kg (0.4 Mcal/lb) and as milk yield increased, the required energy density would move toward 2.0 Mcal/kg (0.9 Mcal/lb). For the maintenance of a cow, a diet of 0.8 Mcal/kg that provided 40 g MP/Mcal NE_L would be ~5% CP, and as milk yield increased, the diet would move toward 19% CP (assuming reasonable values for RUP). In the new NRC model, grazing in a hilly pasture can dramatically increase the required energy density while decreasing the amount of protein needed per unit of energy. I find the approach in the Horse NRC to exercise more appealing—for horses, the protein requirement per unit energy is the same for work as for maintenance and so as workload and energy density of the diet increase, the protein density increases proportionally. The effects of pregnancy and growth also seem reasonable. Importantly, the amount of protein required per unit of energy is higher for growth in young animals than in older heifers or young cows. This is consistent with the fact that as an animal matures, the composition of gain shifts toward a higher proportion of fat relative to lean tissue. Overall, I think the animal requirements in the new NRC are an improvement.

My major criticism of the 2001 NRC is in its system for calculating the NE_L supplied from a diet. In calculating the overall energy balance of a cow, the new system is better than the 1989 system. However, in ration evaluation and especially in formulation, there are several problems and challenges with the new system. The three major issues I will discuss are the digestibility discount factor, the energy value of NDF, and the energy value of protein. I also will briefly critique the new protein system and the models for heifers and dry cows.

The Digestibility Discount

When considering the depression (or discount) in digestibility that occurs as cows eat greater amounts of feed, there are several challenges in building an energy model. One problem is that we have very little data on cows eating at levels of 4X maintenance or greater. The other problem is that feeds have "associative effects"—in other words, increasing the amount of grain in a diet can effect the digestibility of long forage and vice versa. Another problem is that some feeds, such as byproduct feeds high in NDF with short particle size, are especially susceptible to depressed digestibility when fed at higher intakes.

The new system likely does a better job of handling the associative effects of feeds in estimating the digestibility of a diet than in previously proposed discount systems using fixed discounts for each feed (Van Soest et al., 1992; VandeHaar, 1998). Hence, diets with the greatest digestibility at 1X maintenance are given the greatest depression in digestibility as intake increases (Figure 5). However, perhaps these associative effects are less important in practice than they are in theory. Here is why: for cows eating at less than 3X maintenance intake, the total diet depression in digestibility is relatively unimportant. Although diets may vary widely in their TDN1X concentration and associative effects are important, a system using fixed energy values for each feed works reasonably well. (Note for example, that the energy supply model for heifers does not incorporate digestibility discounts and instead NE_m and NE_g are calculated directly from DE1X.) For cows eating at 4X maintenance, the associative effects might in fact be very important, and the digestibility depression is certainly important, but the composition of diets that enable intakes at 4X maintenance does not vary much. Most high-producing cows (>100 lb/day of milk) eat diets with minimal forage. So in practice, the cows for which digestibility discounts matter most are fed a range of diets in which the fat-corrected TDN1X concentration is relatively constant. For high-producing cows, the issue of whether the fiber is short or long is probably more important than the ratio of forages and concentrates in considering the digestibility discount, and the 2001 NRC does a poor job in this regard. In their defense, the 2001 NRC committee had very little data on discounts for high-producing cows and very little data regarding discounts for individual feeds.

For example, with the new system, the digestibility discount for a diet with 35% soyhulls would be less than the digestibility discount for a diet in which the soyhulls were replaced with 35% cracked corn because soyhulls have a lower TDN1X value than does cracked corn (67 versus 85%). Thus, when feeding a cow producing 50 lb/day of milk, the NE_L values might be 0.78 and 0.74 Mcal/lb for a corn grain and a soyhull diet, respectively. For cows at 100 lb/day of milk, the NE_L values would drop to 0.73 and 0.71 Mcal/lb, and for a cow at 150 lb/day of milk, both diets would provide 0.68 Mcal/lb of NE_L. However, there is good reason to believe that soyhulls should be discounted more than corn grain (Coppock, 1987; Van Soest et al., 1992). As long as both diets have adequate effective fiber, presumably the soyhull diet should be discounted more than the corn grain diet.

I have previously discussed the importance of the assumptions regarding digestibility discounts (VandeHaar, 1995; VandeHaar, 1998) and believe that the system proposed by others, such as Van Soest and coworkers (1992), has merit. The 2001 system is valuable in that it does a reasonable job of handling the associative effects of different feedstuffs, but some combination with individual discounts for each feed would have been helpful, especially for diets with high fiber byproduct feeds.

Some of the more important decisions in feeding cows are what type of grain to feed, how much forage and concentrates to include in the diet, and whether to replace some of the forage or grain with high fiber byproduct feeds. Does the new NRC system improve our ability to make these decisions? I am not sure that it does.

In evaluating a ration, one can generally assume that the diet is reasonable for the animal being fed. But a ration formulator must cover a much wider range of possibilities. For example, it is quite unlikely that a cow producing 125 lb/day of milk could do so on a diet of only alfalfa hay, thus when evaluating the ration of a high-producing cow, I am starting with a reasonable diet. However, because the DMI equations do not include a feed factor, and because digestibility is depressed more for higher energy feeds, when I balance a diet for a high producing cow, a mostly forage diet looks nearly as good in the model as a diet of 30% corn grain (Figures 5 and 6, Table 5). Replacing corn with soyhulls in a high-producing cow diet also has little impact on the overall energy balance. With the new system, the most effective ways to meet a high-producing cows energy requirements, while also meeting her needs for fiber, are to supplement with fat or increase the amount of protein supplements (Figure 6). Protein is discussed later. Because the new NRC model includes nothing regarding possible depressions in intake when adding fat to diets, the model design will increase the amount of fat fed to high-producing cows. This increased use of fat, however, may not benefit the cows, especially if the fat is high in unsaturated fatty acids (Allen, 2001). As Allen (2001) explains, the best sources of fat for increasing energy intake are probably those that provide more saturated free fatty acids, less unsaturated fatty acids, and less saturated triglycerides to the small intestine. The new NRC does favor using fat sources with less saturated triglycerides because digestibility is included in the model.

Importantly, the digestibility discounts predicted in the 2001 NRC are only valid for cows producing less than 100 lb/day of milk, which corresponds to 4X maintenance intake for cows weighing 1430 lb. In most cases, this is not a problem, but as milk yield continues to increase, balancing diets with target milk yields of 125 lb/day may become common place. In addition, another problem with using this discount system for balancing diets (in contrast to evaluating diets) is that the discount is dependent on the diet and feed intake, which are in turn dependent on the energy value of the diet, which is dependent on the discount. This circular argument creates special challenges for linear programs (computer autobalancers).

The Energy Value of NDF

Another problem with the 2001 energy system is that lignin is used to calculate the digestibility of NDF without regard to the type of feed under consideration. The idea of using a universal equation to calculate NDF digestibility, and thus the energy available from NDF, is appealing, but it is not based on sound science. Certainly lignin is a major component of fiber that limits its digestibility, but it is only a crude indicator of NDF digestibility and it is only useful within a forage type (Allen and Oba, 1996). Environmental factors can have a major impact on the relationship between lignin and NDF digestibility. For example, Allen and Oba (1996) showed that lignin was strongly correlated to NDF digestibility in first-cutting alfalfa and in corn silage grown in a normal Michigan year but that no relationship existed for fourth-cutting alfalfa or corn silage grown in a drought year. For the first-cut alfalfa, in vitro digestibility dropped from 60 to 30% as lignin increased from 13 to 18% of NDF, but for the normal corn silage, in vitro digestibility dropped from 50 to 38% as lignin increased from 5 to 8% of NDF. Thus, at the very least, the equation for calculating NDF digestibility should be different for legumes than for grasses and corn silage.

The Energy Value of Protein

Another problem with the 2001 NRC is that all protein is assumed to be used at 100% efficiency, and therefore, the energy value of digested protein is assumed to be 5.6 kcal/g. Although this seems like a good assumption, the new NRC uses the same equation for converting DE to ME and ME to NE for all non-fat feeds. Moreover, both of the these equations have negative intercepts so that non-fat feeds with higher initial DE values will have greater efficiencies for converting DE to NE_L. Thus, the inherent assumption in the new NRC is that protein is used with efficiency equal to that of starch or that about 60% of the digested protein will be incorporated into body, milk, or fetal proteins. In fact, 30 to 40% efficiency is a more reasonable number (Hannigan et al., 1998), so the 1989 NRC probably handled the true energy value of protein just as well as the new NRC. The old NRC undervalued it, but the new NRC overvalues it. At first, this may seem like an insignificant problem, but for high producing cows, energy is the first limiting nutrient, and with the new discount system, meeting the energy requirements of high-producing cows will be an even greater challenge. One way to enhance the NE_L value of a diet in the new NRC system is to replace cereal grains with protein supplements. With the 1989 NRC, protein supplements were added to meet the protein requirement. There was no benefit to replacing corn grain, for example, with soybean meal. With the new system, however, a linear program might add soybean meal in place of corn grain to also meet a cow's energy requirement. For example, replacing all the corn grain in a diet with protein supplements can increase the NE_L density of a diet from 1.53 to 1.64 Mcal/kg and decrease the predicted energy shortage for a high-producing cow by 3.0 Mcal/day (Figure 6, Table 5). The system could be improved by either including an energy cost of wasted protein or decreasing the energy value of digested protein. But without it, high protein diets might be favored in situations when high energy diets are needed.

Meeting Protein Requirements

The model calculates %RUP and %RDP based on fractions A, B, and C and the digestion and passage rates (k_d and k_p) for fraction B. The passage rate is a function of feed type, level of intake, and forage to concentrate ratio. Changing the concentrate in a diet from 0 to 50% decreased the RUP value of dry forages about 1 unit and concentrate feeds 2 to 3 units (for example, the %RUP of CP for expeller soybean meal dropped from 68 to 65%) for a cow eating at 3% of BW; this effect decreased as intake increased. Increasing intake from 3 to 4% of BW with a 50% concentrate diet increased the RUP value of forages about 1 unit and concentrates 2 to 4 units. These two effects counter each other somewhat, and in the end, the RUP value of diets is not very sensitive to the factors that alter passage rates. Thus, the complexity of the program, and the possibility of errors when entering feed data into complex models with many variables, was increased significantly without a lot of benefit.

In my opinion, the committee could have used a much simpler and fool-proof approach. For example, one possibility would be to give an estimated %RUP of CP for each feed at 1X or 3X intake and let the model adjust this up or down depending on the actual intake. A change in the digestion rate for protein fraction B of a feed can have a significant impact on the diet RUP and RDP supply. In addition, the methodology of estimating k_d and k_p has major problems. Moreover, the %RUP for a feed is not reported in the program as a reference, so the user has no idea what are the consequences of entered values for A, B, C, and k_d. This reporting problem can be overcome when other groups incorporate the NRC model into their own programs, but the whole system seems unnecessarily complicated.

The new equation for predicting MCP yield is similar in approach to that of the 1989 NRC, and because the new equation has no negative intercept, it should work much better for young heifers. However, as illustrated in Figures 5-6, 5-7, and 5-8 of the 2001 NRC, there is still considerable unaccounted variation with the new equations. Moreover, according to Figure 5-6 in the 2001 NRC (page 66), the new model grossly underpredicts (by ~20%) MCP yield for the highest producing cows. However, work by St-Pierre (2001) suggests that the analysis of the equation was flawed, and in fact, the model does a better job than initially thought. In any case, predicting MCP yield is still far from an exact science.

All of the problems in modeling protein are aggregated for the amino acid **(AA)** submodel. In addition, inconsistency in the AA composition of feeds further complicates the accuracy of balancing for AA. Although the plots of predicted versus measured duodenal flow of methionine and lysine (Figures 5-9 and 5-10 on page 79 of 2001 NRC) suggest that the AA model is quite accurate, the same data set was used to develop the model and to evaluate it. In my opinion, no model can accurately predict whether methionine or lysine should be supplemented to a diet. Whenever possible, the animal response to any dietary change, and especially one which includes addition of AA supplements, should be used to determine whether the cost of the supplement is warranted.

Heifers and Dry Cows

Substantial changes were made in the heifer and dry cow requirement submodels, and I think these were some of the more important and beneficial changes made in the model. In general, the program seems to give reasonable diets for young heifers and calves. Dry cow requirements increase with day of pregnancy and are an improvement over the 1989 version.

So How Should We Balance Diets?

Models give guidelines. They may be precise, but they are only rough approximations and generalized to meet the needs of most farms—they cannot be used to fine-tune a ration. Too often, people get caught in the details of a model. They try to balance the diet to meet absorbed methionine or rumen-peptide needs to four decimal places. They wonder why the model failed, or worse yet, they never bother to determine if it failed or not.

When feeding high producing cows, the approach one should follow is to minimize NDF, with a target of 25 to 30% NDF. This optimal NDF percentage will depend on several factors, such as length of the fiber, day to day variation in diet composition, feed availability, feed mixing, and fermentability of the starch (Allen, 2001). Because of the problems with accurately estimating the energy value of feeds, the exact NE_L density of a diet is not very useful, but the goal should be to maximize NE_L intake while ensuring adequate fiber. To determine whether cows should be fed fat or other supplements, the best approach is to try the supplement and to monitor the cows. We recommend measuring and recording DM intake, estimated energy intake, milk yield, body condition, and health.

Summary

In summary, of course, I recommend that you balance diets with a computer program, but remember that the computer model, no matter how simple or complex, is based on prediction equations that in many cases are inaccurate. Consequently, the predicted values for nutrient balances, although having the appearance of accuracy, may be consistently inaccurate. Too often field nutritionists lose sight of the big issues, like communication with the feeder, and focus on the details with “sophisticated” models. This may impress a client in the short run, but nutrition is seldom that easy and no computer monitor can substitute for a cow. So pay attention to the cows!

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Table 1. Comparison of the energy systems in the 1989 and 2001 NRC[1].

	1989 Dairy NRC	2001 Dairy NRC
	Mcal NEL	*Mcal NEL*
Requirements		
Maintenance	$0.08 \times$ kg $BW^{0.75}$	same
Milk	kg milk × (0.3512 + 0.0962 × %fat)	kg milk × (0.0929 × %fat + 0.0547 × %CP + 0.0395 × %lactose) (%CP = true protein/0.93) [for most Holsteins, this equals 1989 requirement]
Grazing activity	add 10 to 20% to maintenance requirement	walking: 0.00045 × kg BW × distance to parlor × # trips/day eating: 0.0012 × kg BW plus 0.006 × kg BW if pasture is "hilly"
Pregnancy	$0.024 \times$ kg $BW^{0.75}$	= 0.64 × (0.00318*days pregnant - 0.0352) × Calf Birth Wt / 0.14
Body reserves	5.1 × kg BW gain (use 4.9 if BW loss)	Gain: 0.85 × (9.4 × kg change in body fat + 5.6 × kg change in body protein) Loss: use 0.82 instead of 0.85 (body fat and protein changes are a function of BW and body condition change)
Growth	add 20% of maintenance requirement in lactation 1 and 10% in lactation 2	retained energy (RE) for growth $= 5.668 \times$ kg BW $gain^{1.097}$ $\times$ (current $BW^{0.75}$ / mature $BW^{0.75}$) NE_L for growth = RE for growth / 0.7
Energy supply		
NE_L supply	Each feed has a fixed NE_L concentration	Calculated from the ME and fat concentrations.
ME supply	not needed	Calculated from the DE and fat concentrations
DE supply	not needed	Calculated from DE1X supply and the digestibility discount
Digestibility discount	8% no matter what animal is being fed	A function of the fat-free TDN1X content of the diet and the energy intake as multiple of maintenance requirement
DE1X	not needed	Digestible carbohydrates × 4.2 Mcal/kg + digestible CP × 5.6 Mcal/kg + digestible fatty acids × 9.4 Mcal/kg minus 0.3 Mcal/kg of fat-free dry matter intake (for metabolic fecal energy losses)
TDN1X	not needed	Digestible carbohydrates + digestible CP + 2.25 × digestible fatty acids minus 7 kg/kg of fat-free dry matter intake (for metabolic fecal energy losses)
NDF digestibility	not needed	A function of lignin content
NFC digestibility	not needed	A fixed value dependent on feedstuff
CP digestibility	not needed	A function of Acid Detergent Insoluble CP for forages and concentrates and a fixed value for animal products
Fat digestibility	not needed	A fixed value dependent on fat source

[1]NE = net energy, ME = metabolizable energy, DE = digiestible energy, TDN = total digestible nutrients, NDF = neutral detergent fiber, NFC = nonfiber carbohydrates, CP = crude protein, and BW = body weight.

Table 2. Comparison of the protein systems in the 1989 and 2001 NRC[1].

	1989 Dairy NRC	**2001 Dairy NRC**
Requirements	Metabolizable Protein (kg)	Metabolizable Protein (kg)
Maintenance scurf urinary	 + 0.0002 × $BW^{0.6}$ / 0.67 + 0.00275 × $BW^{0.5}$ / 0.67	 same same
Metabolic fecal	0.03 × kg DMI	+ 0.03 × kg DMI - (0.125 × 0.64 × MCP)
Gut proteins	no	0.4 × 0.0119 × 6.25 × kg DMI /0.67
Milk	(%protein /100) × kg milk / 0.7, where %protein is assumed to be 1.9 + 0.4 × %fat	kg milk × %true protein /0.67 (milk true protein = milk CP/0.93)
Grazing activity	no	no
Pregnancy	1.136 × kg $BW^{0.7}$ / 0.5	(0.00069*Days Pregnant - 0.0692) × Calf Birth Wt / 0.33
Body reserves	0.256 × kg change in BW maximum loss is 0.188 kg/day	Gain: kg change in body protein / 0.492 Loss: kg change in body protein / 0.67 (body protein change is function of BW and body condition change)
Growth	20% of maintenance requirement in lactation 1 and 10% in lactation 2	kg growth gain × (0.268 - 0.0294 × RE for growth / kg growth gain)
MP Supply		
Energy-potential microbial protein yield	0.072 × Mcal of NE_L - 0.193	0.130 × kg of fat-free TDN adjusted for level of intake
N-potential microbial protein yield	90% of rumen available protein supply	85% of rumen degraded protein supply
Microbial crude protein (MCP)	the lesser of energy and N-potential MCP yield	same
MP from MCP	80% × 80% × MCP yield	same
RUP	each feed has a fixed RUP	RUP calculated for each feed based on its protein fractions A, B, and C, and the k_d and k_p of its B fraction. The k_d is unique to a feed but k_p is calculated based on whether the feed is a wet or dry forage, the feed's % NDF, and on the DMI of the cow and the % concentrate in the total diet.
RUP digestibility	80%	Unique to each feed
Endogenous (gut) proteins	no	0.4 × 0.0119 × 6.25 × kg DMI
Amino acids (AA)	not considered	Regression equations based on AA as a percentage of the diet and RUP flow as a percentage of total duodenal protein flow are used to calculate flow of AA to the small intestine.

[1]MP = metabolizable protein, RUP = rumen undegradable protein, BW = body weight, DMI = dry matter intake, NE_L = net energy for lactation, CP = crude protein, RE = retained energy, TDN = total digestible nutrients, and NDF = neutral detergent fiber.

Table 3. Feed intake prediction in the 2001 Dairy NRC.[1]

DMI prediction	DM intake (kg)
Maintenance	$0.0968 \times BW^{0.75}$
Milk	$0.372 \times$ 4% fat-corrected milk
Early lactation multiplier	$(1 - EXP(-0.192 \times (\text{Days-in-milk}/7 + 3.67))) \times 100$
Grazing activity	no
Body reserves	no
Growth	no
Heifer	$(0.2435 \times NE_m - 0.0466 \times NE_m^{2} - 0.1128) / NE_m \times BW^{0.75}$ where NE_m is in Mcal/kg DM
Dry cow	$(1 - 0.38 \times e^{-0.16 \times \text{Days-til-fresh}}) \times 100$

[1] The 1989 Dairy NRC did not predict feed intake, although one could interpret the equations to mean that feed intake will be the NE_L requirement divided by NE_L density of the diet, where the NE_L requirement includes that needed for maintenance, milk, growth, work, and body weight **(BW)** gain or loss. This equation was difficult to use in practice.

Table 4. Effect of various body functions on intake, energy requirement, required energy density, protein requirement, and required protein per unit of energy in the 2001 Dairy NRC[1].

	Dry matter intake	NE_L required	NE_L required (Mcal/kg DMI)	Metabolizable protein required	Metabolizable protein required (g/Mcal NE_L)
↑ body weight	↑	↑	0.83	↑	40-50
↑ milk	↑	↑↑	2.0	↑	~67
↑ days pregnant	↓	↑	↑↑↑↑	↑	~140
↑ work (grazing)	—	↑	↑↑↑	—	0
↑ growth rate	—	↑	↑↑↑	↑	50-170 (NE_L equivalent basis) higher for youngest animals

[1]Number of arrows indicate relative magnitude of response.

Table 5. Changes in energy and protein calculations with diet adjustments in the 1989 and 2001 versions of the Dairy NRC. Requirements were calculated for a lactating mature cow weighing 650 kg (1430 lb), at a body condition score of 3.0 at 60 days in milk producing 57 kg (125 lb) of milk with 3.5% fat and 3.1% true protein. Requirements for NEL and metabolizable protein (MP) were nearly identical in the two versions with NEL requirements at 49.5 and 49.8 Mcal/day and MP requirements at 3.70 and 3.65 kg/day in the 1989 and 2001 versions, respectively. The 2001 NRC predicted intake was 29.0 kg (63.8 lb), and this predicted intake was used for calculations in both systems.

	Half forage	High forage	High soyhulls	High fat	High protein
Ingredients, % of DM					
Legume silage, immature #82[1]	27.6	55.2	27.6	27.6	27.6
Corn silage, normal #35	27.6	27.9	27.6	28.3	27.6
Corn grain, ground #27	29.0	——	——	24.1	——
Soybean hulls #103	——	——	29.0	——	——
Hydrolyzed tallow #41	——	——	——	3.4	——
Soybean meal 48% #107	3.4	3.4	3.4	3.4	24.5
Soybean meal, expelr #104	6.9	6.9	6.9	6.9	10.3
Blood meal, ring dried #14	2.4	3.4	2.4	3.1	6.9
Mineral-vitamin supplement	3.1	3.1	3.1	3.1	3.1
Diet characteristics					
% forage	55	83	55	56	55
% CP	19	24	20	19	33
% NDF	27	35	42	27	27
% fatty acids	2.4	1.8	2.0	5.7	1.7
% protein captured in milk	35	28	32	34	20
NRC 1989 calculations					
NEL density, Mcal/kg	1.66	1.53	1.61	1.79	1.65
NEL balance, Mcal/day	-1.26	-5.12	-2.94	2.45	-1.56
NEL allowable milk, kg/day	55.2	49.6	52.7	60.6	54.7
MP from RUP, kg/day	1.66	1.79	1.63	1.74	3.12
MP from microbes, kg/day	2.09	1.91	2.01	2.26	2.07
MP balance, kg/day	0.05	-0.01	-0.06	0.29	1.49
MP allowable milk, kg/day	58.0	56.9	55.7	63.1	88.2
NRC 2001 calculations					
TDN (1X intake), %	72.3	64.8	66.5	76.1	71.1
Fat-corrected TDN1X, %	71.5	64.8	66.5	68.4	71.1
Intake multiple of maintenance	4.7	4.2	4.3	4.9	4.6
Energy digestibility adjuster, %	87	93	92	89	87
NEL density, Mcal/kg	1.53	1.51	1.50	1.72	1.64
NEL balance, Mcal/day	-5.32	-6.00	-6.41	-0.07	-2.28
NEL allowable milk, kg/day	49.3	48.3	47.8	56.9	53.7
MP from RUP, kg/day	2.00	2.09	2.04	2.07	4.11
MP from microbes, kg/day	1.64	1.60	1.61	1.60	1.64
MP balance, kg/day	-0.01	0.04	0.00	0.02	2.10
MP allowable milk, kg/day	56.9	57.9	57.1	57.4	102.4

[1]Entry number for feeds in Table 15-1 of the 2001 NRC.

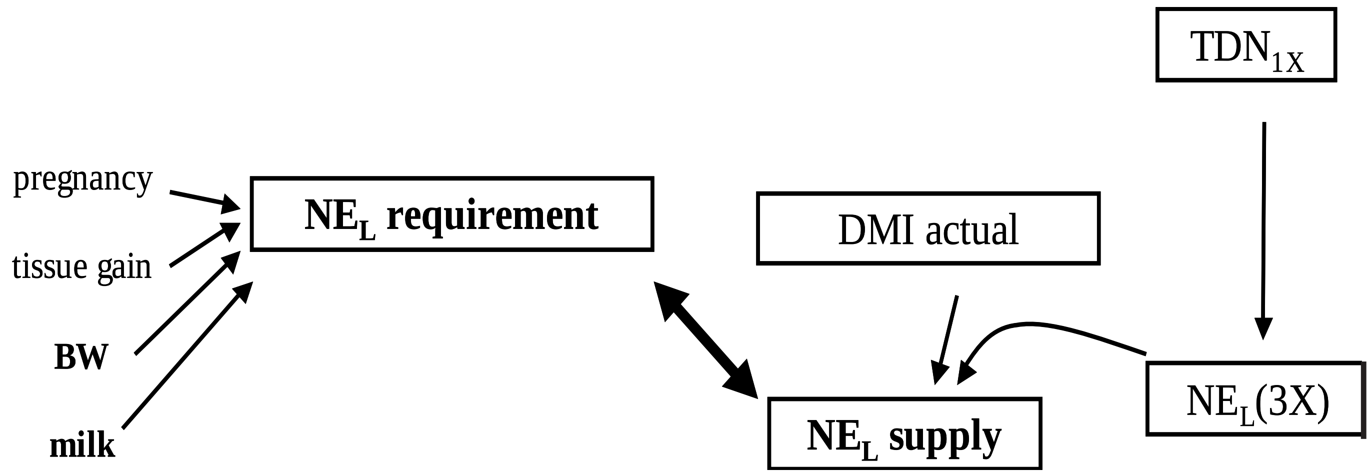

Figure 1. The energy system for cows in the 1989 Dairy NRC. BW = body weight, DMI = dry matter intake, TDN_{1X} = total digestible nutrients at maintenance intake, and $NE_L(3X)$ = net energy for lactation concentration when the diet is fed at 3 times maintenance intake.

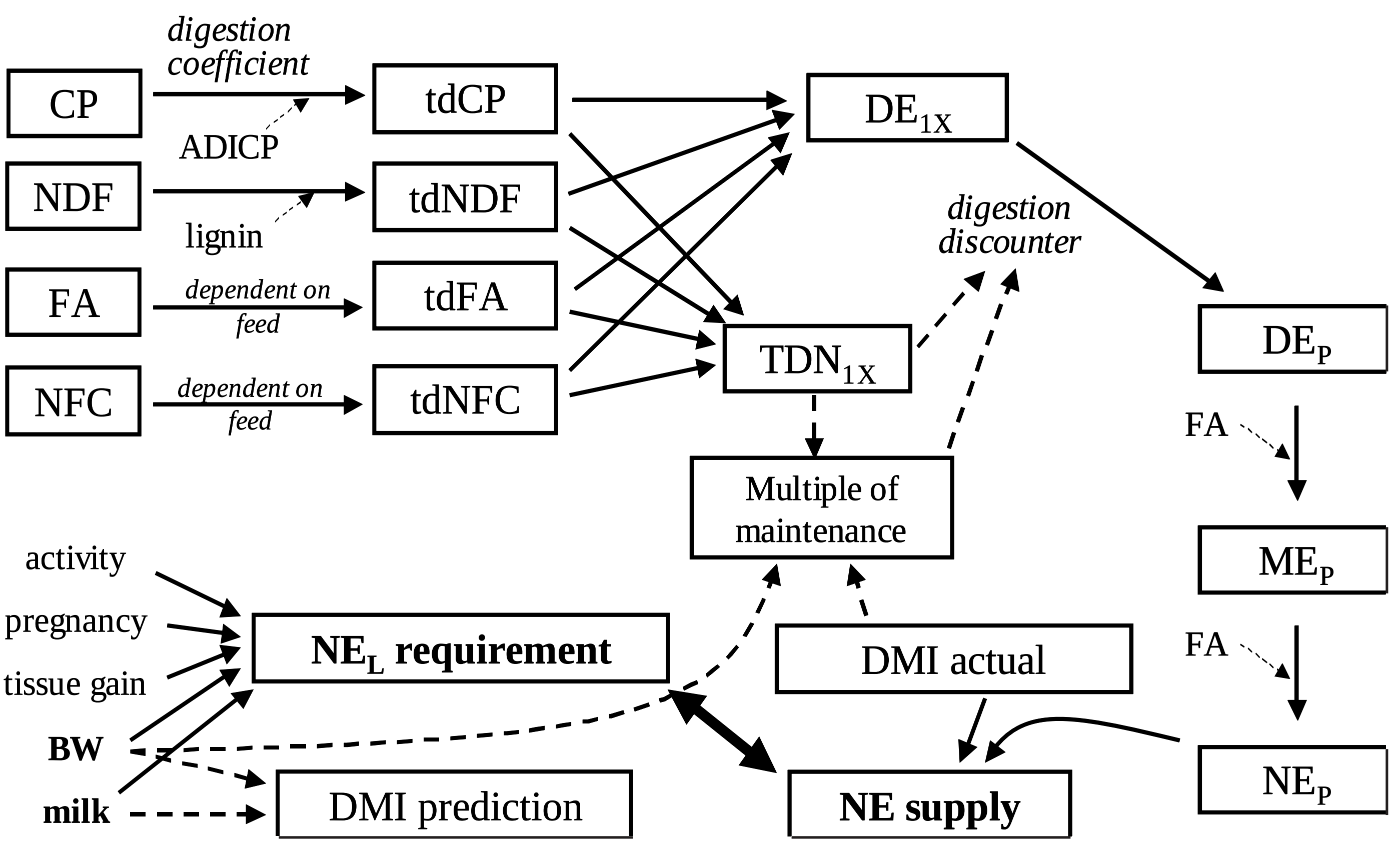

Figure 2. The energy system for cows in the 2001 Dairy NRC. CP = crude protein, NDF = neutral detergent fiber, FA = fatty acids, NFC = nonfiber carbohydrate, ADICP = acid detergent insoluble CP, td = total digestible, DE_{1X} = digestible energy at maintenance intake, TDN = total digestible nutrients, DE_p = DE at the multiple of maintenance for current production, ME = metabolizable energy, NE = net energy, NE_L = NE for lactation, DMI = dry matter intake, and BW = body weight.

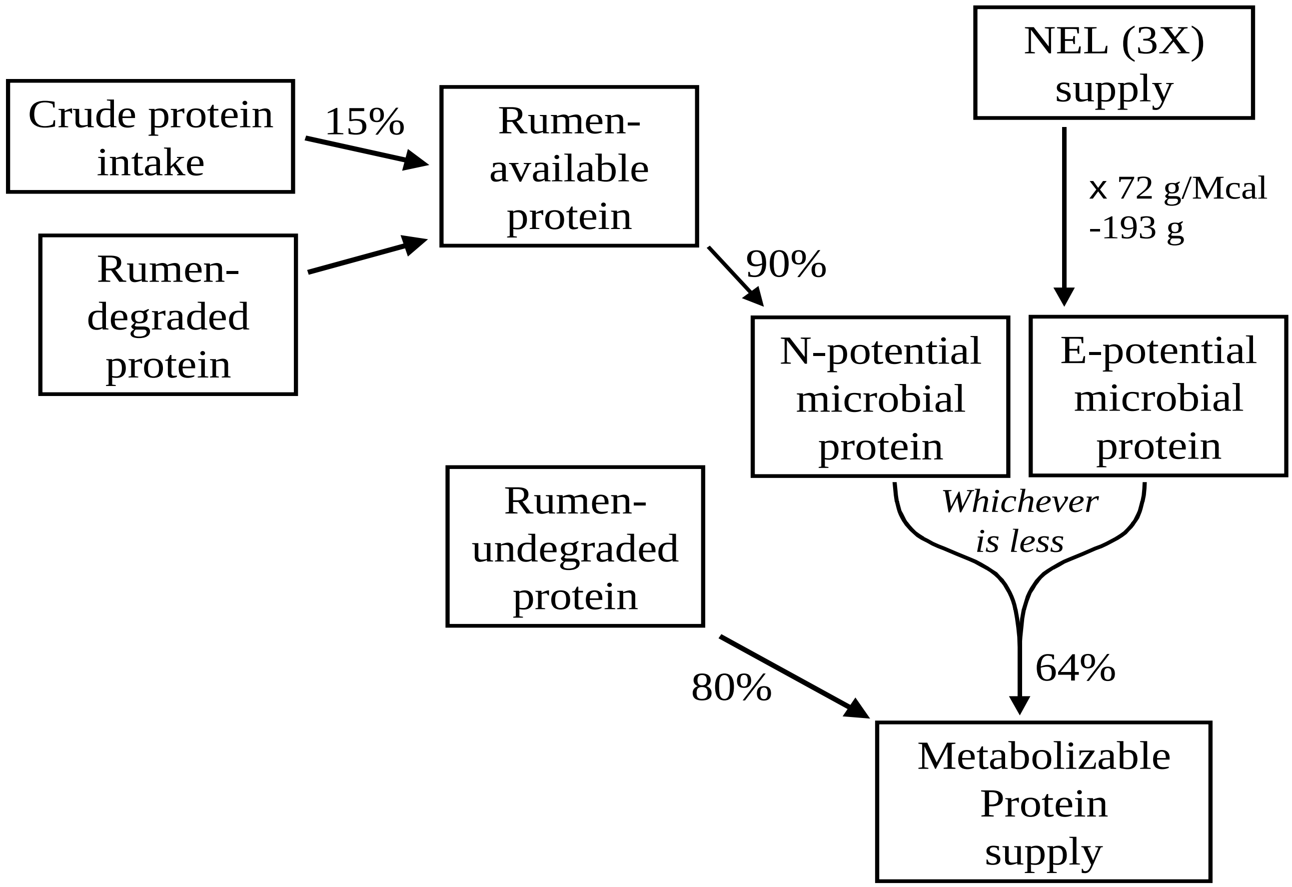

Figure 3. The metabolizable protein (MP) system in the 1989 Dairy NRC. NE_L(3X) = net energy for lactation concentration when the diet is fed at 3 times maintenance intake, N-potential microbial yield = the potential microbial crude protein yield based on the nitrogen available, and E-potential microbial yield = the potential microbial crude protein yield based on the energy available.

In the 1989 NRC, MP was called absorbed protein, rumen degraded protein (RDP) was called degraded intake protein (DIP), and rumen undegraded protein (RUP) was called undegraded intake protein (UIP).

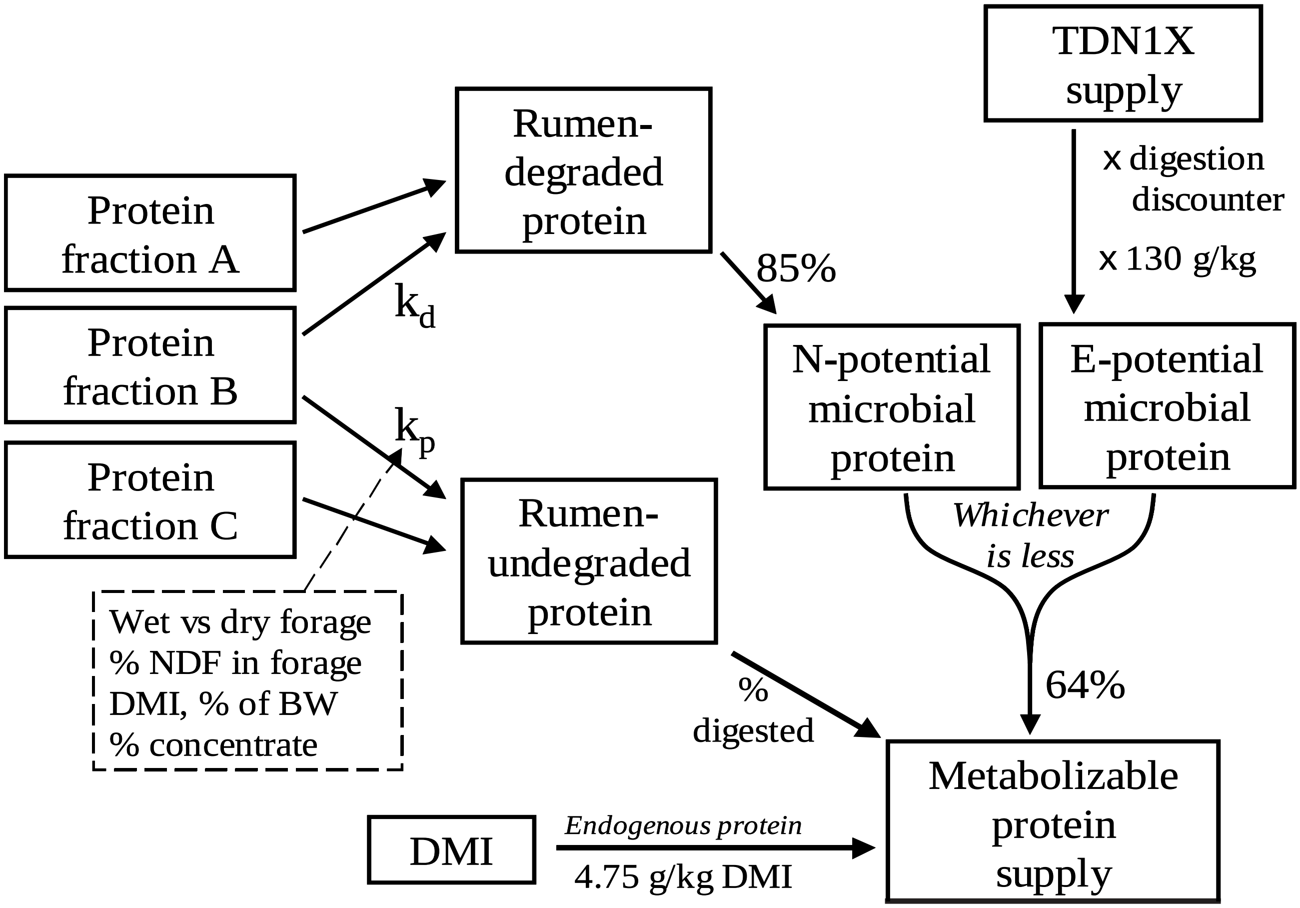

Figure 4. Metabolizable protein supply in the 2001 Dairy NRC. Fat-corrected TDN_{1X} = total digestible nutrients at maintenance intake after subtracting the TDN from fat, N-potential microbial yield = the potential microbial crude protein yield based on the nitrogen available, E-potential microbial yield = the potential microbial crude protein yield based on the energy available, NDF = neutral detergent fiber, DMI = dry matter intake, and BW = body weight.

Protein fraction A is rapidly degraded proteins, including NPN, rapidly solubilized protein, and proteins of very small particle size. Protein fraction C is protein that is not degradable in a rumen dacron bag. Protein fraction B is the remainder and the portion of B that is degraded depends on its digestion rate (k_d) and its passage rate (k_p).

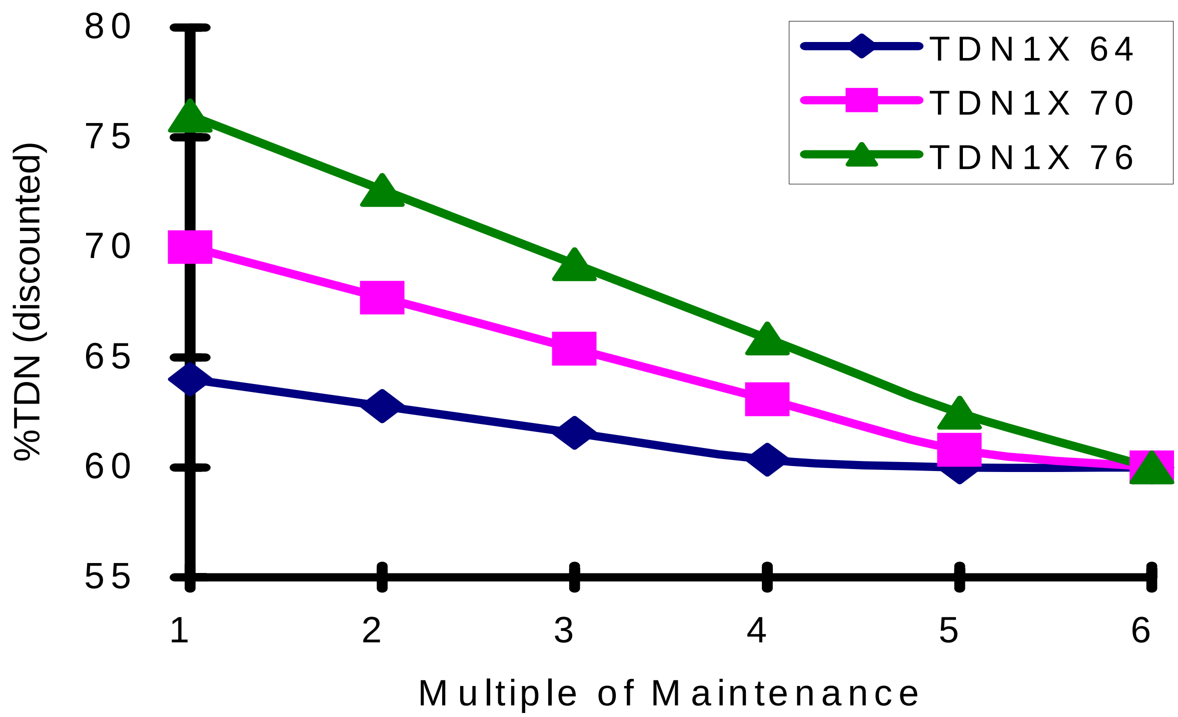

Figure 5. Changes in digestibility of diets in the 2001 NRC with increasing feed energy intake as a multiple of maintenance and different types of diets**.** As the TDN at 1X maintenance intake (TDN1X) value of a diet increases, the digestibility discount of feeds in the diet increases. In other words, a diet with a TDN1X of 76% decreases in its TDN value at a faster rate than a diet with TDN1X values of 70% or 64%. Consequently as intake of the diet increases, the energy values of the diets become more similar. At 4X maintenance intake, these diets have TDN values of 66, 63, and 60%. The TDN values cannot be discounted below 60%; so at 6X maintenance intake, all the diets provide the same amount of energy. Because most cows would never eat the TDN1X diet at the 4X maintenance energy levels, this works fine in an ration evaluation program. However, because diet characteristics do not alter predicted feed intake, this discount system can give unreasonable diets for high-producing cows. For a 1430 lb cow, these multiples of maintenance would correspond to 0 (1X), 33 (2X), 66 (3X), 99 (4X), 132 (5X), and 165 (6X) lb/day of milk with 3.5% fat.

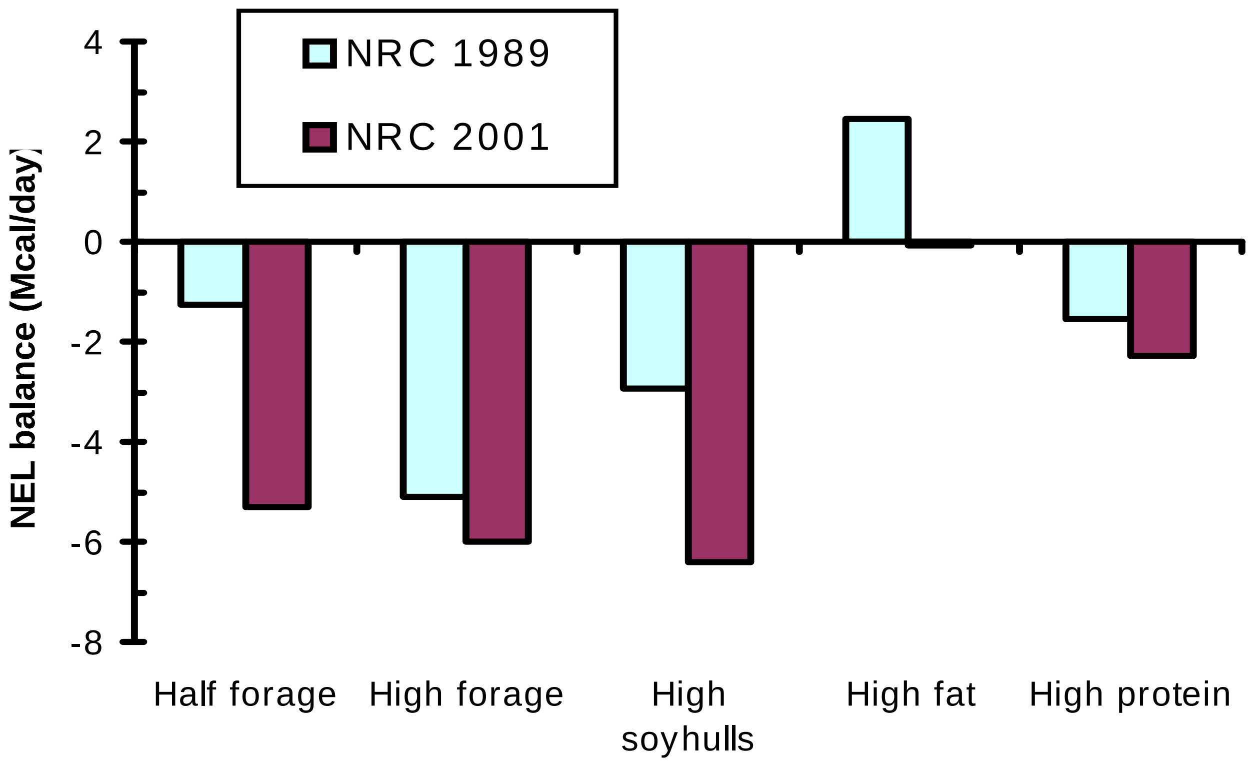

Figure 6. Changes in energy balance in response to changes in the diet balanced for a high-producing cow in the 1989 and 2001 versions of the Dairy NRC. Energy requirements were the same for all diets and are essentially the same for the 1989 and 2001 versions. The feed intake predictions from the 2001 Dairy NRC were used for both NRC versions and the predicted dry matter intake used for all diets was 29 kg (64 lb). Each bar represents the energy supply from the diet relative to the energy requirement in the respective NRC version.

The 2001 version may do a great job of evaluating diets. In this particular case, it is unlikely that any cow would actually eat the high forage diet at this level of intake. Hence, the fact that the energy supply is the same for the high forage and half forage diets is largely irrelevant when using the model as an evaluator. The 2001 model does seem to overestimate the value of the high soyhull diet, but research is lacking to prove this. While the soyhulls themselves may be much less digestible at the higher intake, perhaps the lower volatile fatty acid production with feeding soyhulls (relative to corn grain) results in increased digestibility of the forages in the diet.

When formulating diets, however, the important comparison shown in this figure is the relative change in energy balance achieved with each diet within each NRC version. Note that for the 1989 version, changing to a high forage diet from the half forage diet decreased energy supply by 4 Mcal of NE_L. With the 2001 version, the same diet change decreased energy supply only 1 Mcal. Changing to high protein did not improve energy supply with the 1989 system but increased energy supply by 3 Mcal in the 2001 system. Other information regarding these diets is given in Table 5.

New Feed Management Software

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Abstract

Computerized feed management software systems are commercially available. These software systems are added to the scales on total mixed ration **(TMR)** mixers located in the mixer's truck or tractor cab. These systems allow the feeder, farm office, or nutritionist to adjust ingredient DM and ration batch sizes on a daily basis as needed. These software programs also allow for the collection of data that can be used by the nutritionist and a farm's management team to monitor a dairy farm's entire feeding program.

Introduction

There are currently four software programs that are commercially available as tools to help manage the daily activities involved with mixing of TMR and the monitoring of a feeding program. These software programs are incorporated to a computer system that is added to the TMR mixer's scale. This system can be interfaced to the farm office by wireless radio frequency or by a type of computer disk. Some of the software programs allow for interfacing via electronic mail. Nutritionists and dairy farm managers can use these programs to help assure that all TMR will be mixed correctly and any changes to TMR mix formulations can be made quickly and accurately.

The goal for the dairy herd's feeding program is that all rations will be mixed by the feeder in the amounts or proportions formulated by the nutritionist and that the cows will then consume that ration in the proportions formulated by the nutritionist. There is little ability to control how a dairy cow will consume a TMR, because cows have the ability to sort and separate a TMR and consume only what they decide to eat. However, a nutritionist and the dairy farm's goal should be that the feeder would mix the TMR as accurately as possible following the nutritionist's formulations. These software programs are a management tool that can update TMR mixes immediately so that the feeder will always be using the most current ration mixing instructions. The programs will also monitor the entire mixing process for each batch, thus implementing a feeder-feeding quality control program. There are a number of functions these programs are capable of doing, some as standard operations and others that can be designed by the farm user.

Program Operations Useful to the Feeder on a Daily Basis

Every day a dairy farm's feeder has the challenge of mixing all the TMR batches as accurately as possible. Perhaps the most useful function these software programs have for the feeder is the updating of ingredient DM and the adjusting of TMR batch sizes to account for fluctuations in feed intake.

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If the DM of an ingredient changes, the feeder should update the pounds of that ingredient added to the mix. If that doesn't occur, the mix is not the same as formulated by the nutritionist. These software programs allow for the feeder at the mixer scale computer to enter into the computer program an ingredient's new DM and all mixes using that ingredient will be updated. Those functions can also be done via the farm office computer and transmitted to the computer at the mixer's scale by wireless radio frequency or by a type of computer disk.

Another daily challenge that a feeder encounters is increasing or decreasing the total pounds of a TMR batch. Often, this requires the feeder to do some math or rely on having batch mix sheets printed for different size batches. These software programs allow the feeder to change total batch size and have the new pounds of each ingredient displayed on the mixer's scale.

These are two very useful daily functions that add a form of quality control to the feeding program. There are other functions performed by these software programs that may also be useful to use on a daily basis for feeding the herd.

Program Operations Useful to the Nutritionist and Farm Management on a Daily Basis

In addition to up-dating ingredient DM and batch sizes, these programs can provide the nutritionist and the farm's management with daily monitoring data on: pen or group DM intakes, feed refusals, feeding times, batch mixing time, mixing errors, and feeder performance measures. The data can be displayed on a computer screen or printed and presented as a table or graph.

Other Software Program Functions

These software programs can also monitor ingredient inventory, predict inventory reordering needs, compute feed cost and income over feed cost, and other functions. Each company's software package has various functions that are unique to that particular software. These functions can be useful to the farm business.

Skill Needed to Operate the Software Programs

Like any computer software, these programs do require some learning by the users. Most of the software companies provide on-farm training. Farms considering to purchase a program probably should consider the training of the feeders who will use the program at the mixer as well as training of the farm's management personal. Most of the programs appear to be easy to learn.

Computer Needs

These programs will require a computer system at the TMR mixer (in truck or tractor cab) that interfaces with the scale system and also a computer in the farm office. Each software company provides recommendations for the computer system.

Cost

Approximate cost for the software packages are $3500 to $10,000. Costs vary depending on the type of software package purchased, and some companies have various package options. Hardware, such as new scale, scale displays, and computers, would be an additional cost.

Feed Management Software Companies

The following is a list of the companies that market the software programs.

EZfeed™
DHI Computing Service, Inc.
P.O. Box 51427
Provo, UT 84605-1427
800-453-9400, ext. 6704
801-374-5316 (Fax)
www.dhiprovo.com

Feed Supervisor®
1733 - 90th Avenue
Dresser, WI 54009
888-259-8949
715-755-3739 (Fax)
www.feedsupervisor.com

Feed Watch™
Valley Agricultural Software
442 North O Street
Tulare, CA 93274
888-225-6753
559-686-6253 (Fax)
www.vas.com

TMR Tracker®
Digi-Star
790 West Rockwell Ave.
Ft. Atkinson, WI 53538
800-225-7695
920-563-9721 (Fax)
www.digi-star.com

Fine-Tuning the Ration Mixing and Feeding of High Producing Herds

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Introduction

Feed is the single largest operating expense on dairy farms and 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 track feed quality variation, feed mixing, inventories, feed bunk delivery, shrink, and corresponding animal performance. The result is lost opportunity to improve cow performance and to better management expenses. Total mixed rations **(TMR)** have rapidly grown to be the preferred method of feeding for non-grazing herds. Although TMR caught on many years ago, the art and science of how to best manage specific mixers continues to evolve. The questions have largely moved beyond the advantages of a TMR and are now more focused on "How can my TMR mixing and feeding be improved?"

Feedbunk management is more than just feed delivery and removal of refusals. It also involves ingredient characteristics and feedstuff quality control, feed processing and mixing, and factors related to feed presentation. On many dairy farms, the manager or employees responsible for feeding don't fully appreciate the impact their role has on the overall profitability and success of the dairy farm. In reality, the feeding management practices from forage harvest and storage to feedbunk delivery provide a large window of opportunity for improvement in cow performance and expense management on most dairy farms. The feed manager is responsible for handling over 50% of the variable costs of the dairy farm, and often the equipment that is worth several thousands of dollars.

In this paper, I want to focus on some key areas I see on high performing dairy farms that allow them to better monitor and manage the variability and shrink that occurs with feeding TMR's, specifically looking at the large financial opportunities gained by establishing better process controls as part of their daily feeding and bunk management. Specifically, lets address 1) forage variation and feed-out management, 2) the actual TMR mixer and mixing, and 3) feed delivery and bunk management. Many of the management items discussed in this paper were described for nine Wisconsin dairy herds surveyed in January 2002 (Appendix I).

Feed will vary as it's pulled from storage for mixing and feeding, while human mixing errors will also occur. Both are sources of variation in the actual rations delivered and consumed by cows. In turn, ration variation places production, cow health and feed efficiency at risk. Cameron et al. (1998) implicated that feed bunk management is a risk factor for left-displaced abomasums **(LDA)** through the variations associated with day-to-day feeding and bunk management, and thus the actual nutrients

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consumed by the cows. An excellent discussion of how feeding and bunk management can impact cow health, and specifically LDA, was recently presented (Shaver, 2001b).

Fine-Tuning Goals

The overall purpose of this paper is to address these key goals of fine-tuning the ration mixing and feeding of high-producing herds:

1. Minimize the within batch and between batch variation in the DM, energy, and effective fiber for all ingredients, but in particular forages.

2. Minimize any effective fiber reduction during handling, mixing, or feeding, while assuring uniform mixing and a consistent ration in terms of physical attributes.

3. Provide a fresh, high-quality, non-sorted ration at all times. Cows should be able to get feed when they want, in unlimited quantities, without competition from other cows. Both feed and water must be available in a comfortable environment.

4. On-going monitoring, record systems, and training of key employees will allow proactive evaluation and review of the mixing and feeding, which in turn limits unexpected events and risk and allows better measurement of management changes.

Managing Risk

The success of any team or dairy farm depends on its ability to consistently execute the basic fundamentals, or as some say the "blocking & tackling". For the dairy farm, the financial fundamentals of success are maximizing revenues and controlling costs. Financially speaking, a large order of magnitude for a dairy is to have better management of feed inventories, feed mixing and delivery, feed shrink, and other expenses associated with feeding. One might consider this "blocking and tackling" of feeding. It's important to note that controlling costs within defined production parameters, while minimizing wide variations in expenses, does not necessarily equate to "cutting costs" (Fetrow, 2001).

Many dairy farms forego very significant profit opportunities in the false pursuit of cost-cutting and reducing inputs. By focusing largely on the costs of inputs, rather than the inputs' marginal impact on revenue (typically more milk or better herd health), many dairy farms place a ceiling on profits. Better management of the feeding program should not be simply positioned as a cost-cutting strategy versus opportunities associated with minimizing variation and improved feeding and nutrition largely created through better day-to-day consistency and quality of the feed consumed.

One of the first steps to maximizing revenue involves identifying and managing areas of risk and developing appropriate management plans to limit unexpected expenses, controlling the income stream, and reducing the exposure and impact of animal health or catastrophic events that may occur on a dairy. An example of this would be having a relatively simple yet very well implemented plan in place for the feed mixing, feed delivery, and bunk management.

Suffice it to say, things don't always turn out as planned. To some degree, every dairy farmer tries to minimize risks and variability as part of day-to-day management, but breakdowns are common and opportunities abound in the area of mixing, feeding, and bunk management. There are different types and levels of risks that occur on a dairy farm, which can be managed in three fundamental ways (Fetrow, 2001):

1. Reducing the chance of an undesirable event or outcome (e.g. mixing and delivery monitoring systems for early signs of breakdowns or losses),

2. Reducing the impact of an event if and when it does occur (e.g. having treatment protocols in place for health challenges caused by breakdowns), and

3. Transferring risk to others (e.g. contracting for a blend of proteins and minerals).

Reduce Variation, Improve Consistency

Variability, or *lack of consistency*, is a dimension of risk and involves feeding management on dairy farms (Fetrow, 2001). There inherently always will be some variation in outcomes on a dairy farm 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; even the same cow varies in production from day to day. Variation makes operating a dairy farm 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 planning of future outcomes more difficult. For example, not knowing the packing density and moisture of silage can make planning for future rations somewhat difficult. Another example would be not having any mixing or feed intake records, making the monitoring of the impact of nutrition on cow health and production very difficult. In both cases, variation or deviation from the target points or goals impacts the outcome. Without records, or a monitoring system, the variation cannot practically be measured or managed. In this case, the old adage "if you can't measure it, you can't manage it" is quite true. Figure 1 can be used to depict how distribution of variation might change and improve before and after a mixing and feeding monitoring process and system are implemented.

Lack of consistency in the day-to-day feeding and bunk management creates challenges associated with normal 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 aren'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.

Variation makes it more difficult to monitor the effects of any management intervention or action (e.g. producer decides to feed sodium bicarbonate), since the actual effects of the action may be obscured by normal variation. To verify this point, consider how much the bulk milk tank will vary daily due to every day influences, such as weather. If the hypothetical dairy farm that added sodium bicarbonate has wide daily swings in milk production due to variable forage quality, inconsistent mixing practices, and variable forage moisture content, then it will be difficult or impossible to tell if adding the sodium bicarbonate to the ration actually improves production or health. The effect of sodium bicarbonate might be positive and cost-effective but hidden under the daily swings and accepted variation. Management in this case is significantly limited in being able to make accurate and solid business decisions due to the high level of variation (Fetrow, 2001).

The best-managed and typically most profitable dairy farms seek ways to reduce variation in daily processes. Dairy farms that can create consistency through protocols and routines will improve their ability to plan and improve management. While breakdowns will still occur, these dairy farms will be quicker to modify systems and make needed adjustments. In the long-term, dairy farms that are able to minimize variation and create better day-to-day consistency within the feeding program will likely be more successful. The answer to getting started with improving variation in the feeding, lies in better implementation of good plans with supporting monitoring systems. **Day-to-day consistency in the mixing and feeding is a key driver of profitability on well-run dairy farms!**

Mixing & Feeding Risk Exposure – Self-Assessment

A dairy farm that has a sound mixing and feeding management plan that minimizes variation, and thus limits risk exposure, should be able to answer these questions:

- What criteria and benchmarks are used to measure and determine if the feeding management is on track? Do the feed manager, owners, nutritionist, and veterinarian agree on what type of assessment criteria are collected and evaluated?

- How are cow head counts for pens or barns recorded and available to the feeder daily? How does the feeder determine the proper batch size based on cow numbers?

- At what maximum percentage of "struck full" capacity is the mixer still fully effective?

- What is the recommended mixer fill order sequencing of ingredients? Do the TMR manufacturer and the nutritionist agree on the sequencing order?

- What is the target level of daily TMR refusals, and how much does this vary from day-to-day? How much can the actual intake vary from projected, for a given number of cows, before a new ration should be balanced?

- How will TMR refusals be utilized or discarded? What is the maximum level of refusals that can be re-fed?

- Are refusals monitored for particle size relative to the fresh TMR by the feeder?

- When should haylage moisture be measured and why? What is the procedure for taking a haylage sample for moisture testing, and what is the agreed upon DM determination method that will provide consistent results?

- How reliable and consistent is the forage moisture determination method on the dairy farm?

- What is the recommended mixing time for the specific mixer on the dairy farm?

- Who's responsible for TMR mixer maintenance; what and when does this constitute?

Forage Variation and Feed-Out

One of the greatest areas of feed quality variation is with forages (Buckmaster and Muller, 1994). Variation in forage quality, moisture, and shrink occurs by two modes: 1) forage loss as it moves through different handling and storage processes, and 2) microbial deterioration and fermentation DM losses. The obscurity of microbial deterioration has led many to believe that they have relatively modest forage losses and quality issues. In fact, DM losses of 5 to 20% may be occurring before one actually sees visual evidence of molds on forage (Holmes and Muck, 2000). Actual forage losses and shrink are highly dependent on harvest and storage structures. Data adapted from Holmes and Muck (2000) indicate total forage DM losses can range from about 10 to 50%, including the losses associated with filling, seepage, fermentation gasses, surface spoilage, and feed-out losses.

There are several factors that impact the forage quality delivered to the bunk. Following accepted recommendations for harvest maturity, filling, packing, storing, and unloading minimizes quality losses and shrink. Feed managers must understand and manage the process of ensiling and fermentation in order to have high quality forages.

Have we as consulting nutritionists and veterinarians truly invested in training the proper people that have a key role in the feeding management? 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.

Several common breakdowns related to forage quality variation that limits cow performance, include: 1) variable packing density of ensiled forages, 2) removal rate and uniformity of ensiled forages, 3) feeding of moldy or spoiled forages, and 4) lack of accurate moisture determination of the forages. In many respects, each of these are closely related.

Packing Density – Quality Forage

Achieving a high packing density of ensiled forage is an important goal for dairy farms. Density and DM content determines the porosity of the silage, which affects the rate at which air can penetrate the silage mass at the feed-out face. Often packing density of bunker silos and even bagged silage are not sufficient to prevent high DM losses or to ensure consistent high-quality silage. Moisture variation and low packing density within a forage storage unit creates challenges for the feeder from the moldy and spoiled feed that occurs, and difficulty in trying to determine at what moisture should the forages be balanced in the ration. While it's recommended that the minimum DM density for both haylage and corn silage be 14.0 lb/cu.ft. or greater (Bolsen, 2001a), there continues to be a huge range of silage densities seen in bunkers, piles, and bags. Holmes and Muck (1999) found that significant variation existed in the packing density of both haylage and corn silage when 168 bunker silos were surveyed in Wisconsin (Table 1). Subsequent research by Holmes and Muck, 2001 (personal communication) showed that significant variation in packing density can also occur in silo bags.

Packing bunker silage in layers no greater than 6 to 10 inches in depth is key to achieving recommended packing densities and good fermentation. Often the ability to deliver large quantities of forage to the bunker has outstripped the packing tractors' ability to adequately pack the silage. Calculating the recommended packing tractor weight relative to the mass of silage being delivered per hour is an important step that should be reviewed (Batchelder, 1998; Holmes and Muck, 1999). Adding additional packing tractor weight; or an additional packing tractor may be an option. Because it requires no additional capital, strongly consider reducing the packing layer thickness while continuing to use the existing packing tractor. Although often achievable, the challenge is to manage or moderate the delivery rate of freshly chopped silage to the silo so the packing layer thickness can be decreased. With the growing popularity of custom harvesting and more tonnage per hour of harvested material with bigger equipment, adding an additional packing tractor may be required.

Silage Feed-Out

Silo bags offer flexibility for segregating forages by type and quality so inventory can be better managed. Bunker silos need to be sized appropriately and kept narrow enough so adequate silage can be removed from the silage-face to ensure fresh forage and minimize heating. Corn silage should be fed at a rate to allow at least 12 inches or more of silage to be removed during warmer months, and 8 to 10 inches during cooler temperatures. Splitting bunker silos to reduce the width of the silage-face can be an effective way to achieve an adequate removal rate of the silage, while minimizing the amount of DM loss and shrink due to air exposure. Always avoid knocking down more silage than is needed for immediate mixing and feeding; this should also apply during cooler weather where secondary fermentation can still occur. Some dairy farms have gone to putting corn silage in bunker silos and hay silage into bags, with the idea that corn silage is an easier crop to handle in bunker storage. Silo bags must be packed with adequate tension on the bagger, kept on a solid surface (not dirt or mud), and located to minimize punctures to the plastic from animals, equipment, or kids. Carefully monitor and manage any moisture changes that can occur abruptly with bagged haylage due to field differences.

Silage De-facers

Silage “de-facers” are currently getting lots of attention, with several dairy farms purchasing one in the last 1 to 2 years. Different commercial de-facers are available as attachments to telehanders or skid-loaders. More expensive stand-alone units are also available which allow direct loading to the mixer after silage face removal. Essentially, de-facers are a mechanical means of loosening and removing silage from the bunker-face without disrupting the overall silage-face, otherwise caused by the lifting with a loader-bucket. It’s the lifting of the silage mass with the loader that tends to expose more silage to oxygen and creates secondary silage fermentation, heating, shorten bunk-life, and spoiled feed. Feedback from dairuy farms utilizing de-facers has generally been very good, with the primary reason for satisfaction being the better consistency of silage being fed. Safety has also been mentioned as a benefit of the de-facer by allowing the bunker or silage pile to be higher while not risking the silage “cave-ins” that can occur when removing silage with a loader. Equipment cost and “wear and tear” on the de-facer and associated equipment must be considered, along with possibly additional time required to load forage.

Questions on whether the effective fiber and particle size of forage would be reduced from the grinding action of the de-facers were recently addressed in a controlled field study (Sutter and Shaver, 2001). In this study, three commercial de-facers (Valmetal, Bunker Claw, and Bunker Buster) were compared to bucket removal (positive control) and hand-removal (negative control), looking at any differences in particle size reduction due to the type of removal method. No reduction in effective fiber occurred with either hay silage or corn silage with any of the three different commercially available de-facers when compared to either hand-removal or unloader-bucket removal (Table 2).

Moldy Feed

Rations should be fresh, palatable, and contain only quality forages. Spoiled and/or moldy forage should be discarded. Unfortunately, discarding spoiled forages is not always a common practice. In a recent study at Kansas State University, growing steers were fed high silage rations, which contained 90% well-preserved corn silage or a blend of the well-preserved corn silage, and some spoiled corn silage (from the top of the unsealed bunker silo) (Whitlock, 1999). Steers receiving the ration with spoiled silage had significantly lower DM intake and lower organic matter, protein, and fiber digestibilities. Preventing the formation of moldy silage and having a well-communicated plan on how to handle and toss any moldy silage is key to achieving high performance. A common practice amongst the highest performing dairy farms is their commitment to avoid feeding moldy or spoiled forages or feeds, albeit this can require that feed be discarded and hauled. The prevailing attitude should be "lost feed is better than lost milk and/or cow health that is caused by moldy spoiled feeds".

Moisture Monitoring

Successful feeding management is highly dependent on delivering the proper amount of each ingredient, which in turn is highly dependent on accurate measurement of DM of the feed. Errors commonly occur in delivering an accurate ration that doesn't match well with the formulated ration because of the failure to either routinely or accurately measure the DM content of wet ingredients, and then adjust the rations accordingly to maintain the proper proportions of ingredients. This is especially true for the DM proportion of effective fiber and forage to concentrate levels.

There are a couple of primary reasons behind when delivered rations are not well balanced (although often well-formulated by the person doing the nutrition work) due to DM variation and inaccurate DM values on the feeds (typically forages). **Reason #1 – lack of a specific agreed upon plan for testing forages.** Rather than some type of random DM testing, or testing forages after a production drop or negative situation has occurred, a specific plan should be in place for testing forages based on type of forage, storage structure, weather, and/or the interval between testing. The mind-set needs to be that regular forage DM testing is an "investment" rather than a cost. Have a plan!

Reason #2 – lack of the right equipment and a procedure that's well understood to measure and determine DM in forages. Using either a microwave or Koster-tester with accurate scales (+/- 1 gram) has been shown to be an effective method of consistent and reliable on-farm DM determination. Although a specific method must be followed with care, either system is capable of generating reliable results. Neither the microwave nor Koster-tester are particularly difficult to operate nor are expensive. Breakdowns in the accuracy or reliability of the DM measurements on-farm typically come from corners being cut in the methodology (either rushing or over-drying and burning the sample) or poor scale accuracy. Variation in chop length of the silage (particularly corn silage) will affect accuracy. The finer the chop, the more accurate the DM measurement can be. It's in the best interest of every nutritionist to take time to have a written DM determination procedure that is well understood by the feeder and is posted at the farm in a convenient location for review. Take time to make sure the math in the calculations is understood .

On-Farm Versus Laboratory Moisture

There continues to be some frustration over the "residual moisture" that isn't accounted for with on-farm moisture testing. Often, a silage sample is tested carefully on the dairy farm, only to have the same silage DM come back from a commercial laboratory at 2 to 3% units lower (Peters, 2000). Approximately 2 to 3% residual moisture is typically measured in samples submitted to commercial laboratories over and above the moisture content measured on-farm using a microwave or Koster-tester. In other words, an identical sample of silage could have a DM content of 34% as measured on-farm, while the same sample tested in a commercial laboratory might indicate the silage contained 32% DM. Lab tested results will typically be higher moisture, or lower DM content, due to residual moisture. The residual moisture figure can range from 1 to 6%, depending on operator accuracy at the farm, and the type of silage sample being tested. Although both microwave and Koster-testers have similar accuracy when operated under sound methodology, the results with a microwave will tend to be more variable on-farm due to more frequent incomplete drying or burning.

Figure 2 shows the results of different methods widely accepted and used to measure DM content. The unpublished results (Barmore, 1997) were completed through a research project team, including the Dairy Science Department at the University of WI-Madison , School of Veterinary Medicine at the University of WI, Rock River Laboratory (Watertown, WI), and Vita Plus Corporation (Madison, WI). These results on both corn silage and haylage clearly showed that the widely accepted oven-methods of drying forages, namely forced-air and convection oven-drying, resulted in lower moisture and higher DM content than the procedure (Karl Fischer) utilized to measure total moisture, including what many consider the residual moisture. During the time of the research, the laboratory industry did not have a standardized procedure for testing moisture. Now as of January 1, 2002, the National Forage Testing Association has implemented a standardized moisture test, where all certified forage testing labs will use an oven-dry at 105° C for exactly 3 hours. Having all certified forage testing labs using a standardized moisture testing procedure should help bring some consistency and answers to the often asked question of why moisture testing results are quite variable.

So if residual moisture is real, does it really make sense to take the time to measure forage moisture on-farm? **Absolutely!** Even though a commercial laboratory DM content should be used to balance rations, regularly measuring forage moisture on-farm allows the DM content to be watched and monitored closely. On-farm moisture determination can be accurate and repeatable with excellent operator procedure; however, the results will be biased towards the moisture being lower than commercial laboratory values on moisture. Having current DM values on the forages at the dairy farm allows relatively simple ration adjustments in the forage levels to be made immediately, without having to wait for an entirely new ration to be rebalanced and implemented, often with a lag of several days. Of course, significant DM changes in the forages should signal that new rations be balanced to make sure other nutrients, such as fiber and protein, haven't changed. With regular DM monitoring on-farm, a relationship of the on-farm DM percentage and the corresponding lab DM content will develop quickly. Having on-farm DM content is invaluable during corn silage harvest when dry-down occurs rapidly, and the harvest window must be closely managed to prevent corn silage from getting too dry.

TMR Mixers

According to Kammel (1999), there are over 20 different mixer manufacturers in the industry, and in general, the different types of mixers seem to be doing an adequate job of mixing TMR. Types of mobile TMR mixers include auger (1,2,3, and 4 auger models), reel auger, and vertical screw mixers. Mixers vary considerably in their ability to handle and mix long hay, with vertical screw mixers having the greatest capacity for handling hay. Over only a few years, the market demand has produced mixers that can process and mix a high level of hay, to the other extreme of mixers that fail at uniformly mixing hay. The design change to allow processing and mixing of hay has created another potential problem with misuse of the mixers designed for hay (really a processor), causing particle size reduction when excessive mixing times occur. Kammel (1999) has a complete discussion of TMR mixer design, selection, and operating guidelines that should be reviewed.

Huffman (cited by Hutjens, 2001c) found five different TMR mixers (two auger mixers, two different reel mixers, and one vertical) to be similar in their mixing characteristics of a TMR that included 5.4% hay (of the DM). The particle size distribution and evaluation was done using the Penn State Separator box (Lammers et al., 1996). A key cited by the author was that the mixing sequence of ingredients was determined by factory representatives for their respective TMR mixer and that recommended mixing times might vary by type of mixer. Similar work comparing horizontal and vertical mixers found little difference in particle size distribution when mixing times were followed (Rippel et. al., 1998).

Proper blending and uniform mixing requires that there be no dead spots or non-mixed feed in the mixer. While most mixers are designed with this in mind, some do not have sufficient ingredient flow to adequately blend liquids or minerals that are rapidly added to the mixer. Some mixers do not have proper ingredient flow and movement when the batch size is too small for the mixer capacity potentially creating a real challenge with transition rations often mixed in smaller batch sizes. A TMR mixing accuracy check should be done with all rations but in particular smaller batch size mixes, such as transition cow TMR. As discussed by Buckmaster (1998), mixer capacity is key to designing and selecting a TMR mixer feeding system.

Mixing Hay

Dry baled hay is one of the biggest challenges to proper TMR mixing and feeding. Without grinding or processing the hay prior to mixing, it is almost impossible to use an auger or reel type mixer and consistently get a good TMR mix of hay where the hay won't be sorted by the cows. This becomes even a bigger challenge when feeding Midwest grown hay versus western or Canadian hay that tends to mix better with smaller stem size and typically being of higher quality. Although very palatable, high quality grass type hays usually cause problems for most mixers because it wraps around the augers and is difficult to incorporate into the mix.

The amount of hay that can be incorporated and properly fed is a function of the type of mixer (Salfer, 2001). Most auger type mixers on the market can handle a small amount of hay (less than 5 to 8% of DM). Larger amounts of hay can be incorporated in more aggressive auger type mixers and virtually all vertical mixers. Clearly, the vertical mixer design is the best overall at processing either long-stem hay or wrapped balage, and thus this has led to their growing popularity. It's key with any type of mixer, and particularly with vertical mixers or mixers with a "hay unit or saw tooth augers", that the mixing time, sequencing of ingredients, and evaluation of forage particle size in the fresh TMR and the feed refusals be followed and monitored continuously.

Mixer Capacity

Shaver (1998) listed six areas of mixing error that can occur, including: 1) batch size too small, 2) batch size greater than mixer capacity, 3) trying to mix too much hay, 4) improper sequencing of ingredients, 5) under-mixing or inadequate uniformity in the mix, and 6) over-mixing causing reduction of forage particle size. Most mixers are not very effective at uniformly mixing a ration when too full. Mixer manufacturers typically refer to the maximum fill capacity as a percentage of "struck full" or level-full capacity. Fill capacities given by manufacturers range from about 60 to 90% of struck full capacity in order to achieve optimum mixing efficiency.

To determine the optimal size of a TMR mixer, figure that a typical ration will range between 15 to 20 lb per cubic ft, with an average Midwest ration having a TMR density around

17 lb per cubic ft. Feed intake varies due to many factors, but a large breed lactating cow will typically consume between 5 and 7 cubic ft/day of TMR . As hay content increases, the cubic feet consumed daily also increases. In order to estimate an approximate TMR mixer size, take the maximum number of cows in a group, multiplied by 6 to 6.5 cubic ft per cow, and then divide by the number of feedings per day (Kammel, 1999). This figure in turn should be divided by the maximum fill capacity (60-90%) to determine the overall TMR mixer size.

Mixing Time

The goal and reason behind adhering to a constant mixing time is to obtain a uniform mix, while maintaining the desirable forage particle length…each and every day! Over-mixing is clearly a problem as far as reducing particle size of long forage (Rippel et al., 1998). Different mixer types and sizes carry different recommendations regarding mixing times and protocol. Typically, the manufacturer's recommended mixing times range from 3 to 6 minutes (Kammel, 1999). Over-mixing continues to be a problem, but maybe even more common, is the problem with inconsistent mixing times.

If insufficient mixing time occurs, the ration composition can be altered considerably. If the load is split between two groups, this can become a big issue. Even if the incompletely mixed ration is delivered to just one pen, consider the impact of the altered ration composition on individual cows. The question becomes…"Is the recommended mixing time while loading all ingredients or is it after all ingredients are added?" With rations heavily dependent on commodities, it is common for loading times to exceed 15 to 20 minutes. Should the mixer be running during the entire loading period? When determining the optimum mixing time, the goal is to consistently achieve a well-mixed uniform ration while maintaining the effective fiber and forage length. Depending on the mixer type, this often means that the grain, protein, and small particle feeds are loaded first, mixed, and then the long particle forage is added last, with a mixing time of 3 to 6 minutes followed after the forage is added. There are many situations where the recommended mixing times and sequencing of ingredients is not followed due to the load sheet format, the storage location of ingredients and forages, location of the feed bunks, use of bulk bins, etc…

Ingredient Sequencing

The physical properties of different ingredients can influence the mixing, particle size, density, adhesiveness, and dustiness of the TMR. Particle size, particle shape, and density are believed to have the greatest impact on ration mixing and uniformity. Particle retention on the top screen was manipulated as much as 30% by altering the inclusion of hay from the first to the third order in loading sequence (Rippel et al., 1998). The bulk density differences of grain compared to forage, and mineral being two to three times more dense than grain or protein, creates mixing challenges. Generally, the lighter and larger particles tend to move upward in the mixing process, while the smaller more dense particles gravitate downward in the mixer. Because of this, some recommend that the larger particle sized forages be added first, with grains, proteins, and minerals last. However, any reduction in forage particle size from this method of mixing would have to be questioned. The best compromise may be to utilize a "pre-blend" where the smaller and more dense ingredients (protein, grain, minerals, fats, additives, etc…) are pre-blended prior to adding to the mixer, and then added as "one ingredient" to the TMR mixer. This allows forages to be added towards the end of the mixing process, while ensuring a uniform mix on the other ingredients. Buckmaster (1998) discussed how mixing can be evaluated and modified on the dairy farm.

Utilize Pre-blends

Whether multiple ingredients are blended together on-farm or as a service provided by a feed company or local mill, the merits of pre-blending to minimize mixing errors and to reduce shrink should be strongly considered. Mixing ingredients together, such as proteins, minerals, vitamins, feed additives, and energy sources, in a large quantity as a pre-blend or "surge mix" improves the odds of a more consistent ration, while reducing shrink caused by mixing error.

Consider a situation where a ration calls for five different ingredients, other than forages, that are added to the mixer individually. If a feeder overfeeds (usually over-fed versus under-fed) each ingredient by an average of 20 lb per load (just an extra shake of the loader bucket), then by adding five ingredients separately, the feeder would be wasting 100 lb of feed per load. If six loads of TMR were being fed each day for all milking pens, then a total of 600 lb/day of extra feed would be mixed. With an assumed average value of $0.065 per pound for all five ingredients, this would amount to $1170 per month of "feed shrink".

Compare this to using a pre-blend of the five ingredients, where instead of adding five different ingredients to all six TMR loads, only the one pre-blend is mixed. With the same over-feeding rate of 20 lb for the pre-blend, multiplied by the six TMR loads daily, the amount of pre-blend over-fed per month would be 3,600 versus 18,000 lb for the five separate ingredients. Assuming a mixing or labor charge of about $15 per ton, the pre-blend average cost becomes $0.0725/lb or a total of $261 per month compared to the $1170 charge when the ingredients were fed separately. On an annual basis, this would amount to a feed cost savings of $10,908 using the pre-blend versus individual ingredients. Although, variation in mixing errors would be expected from dairy farm to dairy farm, experience has shown that mixing errors (over-fed) less than 20 lb per ingredient would be the exception rather than the rule. It's only natural that low inclusion rate ingredients are more susceptible to mixing errors, as are ingredients that tend to be sticky or are more difficult to handle.

Pre-blends also will minimize the amount of over-mixing and potential forage particle size reduction that could occur. Shaver (2001a) has discussed mixing errors and effective fiber evaluation.

Advantages of a Pre-blend:

- Reduces carrying cost of ingredient inventory,
- Improves ingredient quality control,
- Just-in-time inventory, potentially fresher feed available,
- Risk exposure reduced and shared with third party,
- Minimal cost differences for blending,
- Additional services possibly provided in conjunction with pre-blend, and
- Labor savings and more cost-effective deployment of on-farm labor.

Accuracy of Loading

Knowing the accuracy of how ingredients are loaded into a mixer is important to minimize mixing errors which will limit milk production and likely compromise cow health. 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 to high producing and special needs cows. 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 farm that experienced a significant health challenge with fresh cows, or a dairy farm 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 determine specific causes or to allow implementation of a better management plan.

There are several methods for monitoring and tracking the actual loading, mixing, and feeding process. No one system will fit all dairy farms, and no system is 100% accurate. Essentially, there are three ways to approach setting up a monitoring system, including: 1) using a simple “pencil & paper” system of recording, 2) using spreadsheets, or 3) using a computerized software program specifically developed for tracking and monitoring feeding and inventories. 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. A detailed discussion of monitoring systems can be reviewed in the paper by Barmore (2001) or as presented by Bucholtz at this 2002 Tri-State Conference.

Feed Delivery & Bunk Management

Feed 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 refusal management, and the bunk environment, including stocking density and manger design. The goal is 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. Bunk management practices that cause cows to eat fewer and larger meals more quickly may be associated with an increased incidence of ruminal acidosis and laminitis (Shaver, 2001a). Ruminal pH declines following meals, with the rate of decline increasing as meal size increases and as dietary NDF concentration decreases (Allen, 1997). Several reasons that cause slug feeding, or larger meals, were cited by Shaver (2001a), including: 1) limited bunk space, 2) limited feed access time, 3) restricted feeding, 4) inconsistent feeding schedule, 5) infrequent TMR push-up, and 6) bunk competition.

Frequency of Feeding

Feeding the TMR once per day has been successful in research trials and on high-producing dairy farms. The advantage is the lower labor required for feeding and that the feed mixing is typically controlled by one person or a single labor shift. Providing abundant feed to the full length of the bunk, with extra TMR in the areas closest to the waterers, is required, along with frequent TMR push-up to make once per day feeding work well. The TMR push-up of at least four to six times daily is common, with constant availability of non-sorted fresh feed being the key rather than a specific number of push-ups. Minimizing sorting of the TMR is very important, with a goal of the top screen of the Penn State Shaker box not changing more than 5% units over the 24 hour feeding period (ie. fresh TMR on top screen = 8%, refusals at 23 hours on top screen <13%). If excessive sorting occurs, ration conditioners such as water, liquid molasses, and wet by-products can be effective in reducing the amount of sorting that occurs. Shaver (2001a) identified several practical management practices that can be implemented to minimize and address sorting issues. The frequency of mixing and feeding fresh TMR should be increased anytime the TMR is heating in the bunk due to warm conditions or unstable silages. Often herds that practice once per day feeding in the winter will shift to twice a day mixing and feeding in the spring as temperatures begin to rise. Those feeding at outside bunks may need to increase feeding frequency during periods of inclement weather.

Bunk Space & Access Time

The combination of limited bunk space (<16 to 18 inches per cow) space and limited feed access time (<18 to 20 hours per day) is worse than either alone. Overcrowding of a pen or pens with a feed alley less than 12.5 to 13 ft in width can also limit the access time to the bunk. Six-row barns with feed alleys less than 12.5 to 13 ft in width should not be overstocked beyond 100% since the square footage per cow is already reduced due to the barn design; overstocking can significantly compromise the bunk access time and potentially feed intake and efficiency. Currently, my recommendation for lactating cows is that bunk space always be greater than 16 to 18 inches per cow, with 2 ft per cow preferred. Special needs cows or transition cows should have a minimum of 2 ft per cow, with 3 ft per cow preferred. Michigan State data (Dado and Allen, 1994) would suggest that the meal behavior of first-lactation heifers is different from older cows, and work from Krohn and Krongaard (1979) indicated advantages to having first-lactation heifers eating separate from older cows. My field experience strongly supports these data, particularly where stocking density or crowding are an issue. First lactation heifers should be allowed to access a bunk separate from older cows if possible; this seems to promote better bunk access time for them.

Bunk-Life and Stability

Bunk stability refers to the freshness and stability of the TMR over time. Problems arise with warm or hot feed, moldy or musty smelling feed, and slimy or stinky feed particles (Hutjens, 2001b). In general, high producing cows will not eat as much DM with even moderate levels of heating of the ration occurring, with transition cows being even more selective. Feed digestibility can decline due to warm or heating rations, while the risk of mold spores growing and multiplying increases significantly. Adding mold inhibitors can slow ration deterioration caused by heating, often stretching the time necessary between feedings. Products containing a blend of organic acids often will provide better bunk-life and stability, but typically these products are more expensive than using only proprionic acid. Safety with any liquid mold inhibitor should always be a priority.

Timing of Feeding

Cows have major TMR meal patterns after milking (Menzi and Chase, 1994; Shaver, 1998), thus fresh TMR should be available to cows after they come back to the bunk from milking. This also serves the purpose of encouraging cows to remain standing to allow more compete teat-end closer before lying down. Pens with higher stocking density or limited bunk space will typically respond positively to having fresh feed available as the first cows return from milking. As these cows finish eating and begin to return to the freestalls, the last of the cows from that pen are returning from milking and are able to find open space at the bunk. During warmer weather, cows will shift a higher portion of their total feed intake to the late evening and early morning, thus fresh feed should always be provided in the evening.

Feed Refusals

Feeding for 4 to 5% refusals is a common recommendation. This is particularly important with pens where cow numbers fluctuate widely or frequently or for pens of early lactation cows where feed intake is ascending rapidly. Typically, refusals are pushed out and fed to steers, low group cows, dry cows, or replacement heifers. With stronger emphasis on biosecurity and Johnes disease, the recommendation is often made not to feed any refusals to replacement heifers or younger animals. Having steers available really doesn't provide a viable option for many dairy farms, thus leaving the question of how to best manage the refeeding and use of refusals to dry cows and/orgroups of low producing cows. Lets clarify an important point…there are good quality refusals and then there at times "garbage" refusals where the feed is hot, slimy, and stinky. Real simple…garbage refusals should be discarded and not fed to any animals. Refusals that still have good feed quality can be remixed and fed, preferably to the low group cows at a fixed rate and small percentage of the overall ration. Although feeding refusals to dry cows can work, the amount of refusals available often varies considerably along with having limited numbers of dry cows. This in turn results in dry cows getting too much good feed and becoming over-conditioned. This is a real watch-out with feeding refusals to dry cows.

Slick Bunk Management?

So what about the idea of feeding lactating cows to an empty bunk? Loerch (2001) suggested that the dairy industry should investigate the application of "slick bunk" management for lactating cows, based on the experiences of many in the beef feedlot industry. He suggests that having feed always available isn't bunk management but rather a "high labor, high cost, self-feeder". He brings forward several good points that the dairy industry should consider further. Several research studies with beef cattle have shown better feed efficiency, similar animal performance, less digestive disorders, and more consistent feed intakes when fed to a slick bunk (Pritchard, 1998).

In fact, a few dairy farms have successfully implemented a slick bunk management scheme and are quite satisfied with the cow performance and are very pleased with the reduced level of feed refusals. So for the dairy industry, a question may be "If slick bunk mangement is being considered, is it to reduce the level of feed refusals or to improve cow performance?". Because lactating cows eat much greater quantities of feed than beef cattle and because it is widely accepted that milk production is largely driven by feed intake, I feel quite comfortable saying that slick bunk management will not improve lactating cow performance over feeding for a 4 to 5% refusal level. Milton (1998) reported that feedlot cattle fed to a slick bunk had reduced frequency of meals (4.5 versus 8.2 meals per day) and had greater average meal size (7.7 versus 3.5 lb per meal) than cattle fed ad-libitum. As stated earlier, Allen (1997) has shown that increasing the meal size of lactating cows will cause a decline in ruminal pH. Milton (1998) also reported that deviations of 2 to 4 hours from a normal feeding schedule greatly increased the risk of acidosis in feedlot cattle.

From my perspective, a logical discussion around slick bunk management deals with the growing costs associated with the large quantities of feed refusals larger dairies are experiencing. With 1000 milking cows on a dairy farm, feeding TMR for a 5% feed refusal often amounts to over $50,000 worth of feed being at best devalued and at worst discarded over one year. If refusals could be managed closer to 2 to 3% across the milking herd, this would account for $25,000 to 30,000 in feed savings annually.

Realistically, I don't see most dairy farms capable of managing for a slick bunk given the large amount of variation that occurs in forage moisture, cow movement between pens, feeding times varied, limited controls, and monitoring of the feeding process. I do think an achievable goal for very well managed dairy farms is to reduce the level of feed refusals to 2 to 3% versus the more common 4 to 6% levels, allowing significant feed savings to occur without compromising cow performance. This requires excellent forage quality, mixing and feeding, and overall management. For even the well managed dairy farm, my quick answer to the feasibility of slick bunk management is "It's possible, but not very practical or realistic for the vast majority of dairy farms given the challenges with labor and day to day inconsistencies that typically occur". From a research perspective, the concept proposed by Loerch (2001) on slick bunk management for the dairy industry probably warrants more investigation.

Water Delivery

Although not technically part of the feeding, water delivery needs to be mentioned in this paper to help bring awareness to what I believe is a water delivery problem on many dairy farms. Historically, the most common problem seen on dairy farms with water was the filth and quality of the water due to dirty waterers and the difficulty to keep them clean. Although it is a constant challenge to keep fresh quality water available to cows, the issue of keeping waterers clean has improved considerably in the industry. A more common water delivery challenge seen in my on-farm work involves giving the cows adequate space around the waterers so more than 1 to 2 cows can drink at any given time. This was discussed in an article by Roenfeldt (2000), while an excellent paper on water delivery was done by McFarland (1998).

Monitoring and Tracking Success

Understanding and implementing a comprehensive monitoring program for the mixing, feeding, and bunk management needs to incorporate a number of observations and recordings, many of which have been mentioned in this paper. Further discussion on how to fully monitor the success of the feeding management is really outside the scope of this paper. Recent papers and articles by Barmore (2000),Batchelder (1998), Bethard and Stokes (1999), Dickrell (2001), Hall (2001), Hutjens (2001a), and Shaver (2001a) fully cover the topic and can be reviewed.

Implementation & 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, they are under-utilized. Collecting feed quality and variation information, feed disappearance, and feed inventory information allows one 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 to address reducing risk exposure.

Begin by making a commitment to improving the mixing and feeding management and managing the feeding process on a daily basis; speak to this commitment with employees and other professionals supporting the dairy farm. Understand the areas which contribute to the greatest variation, while better understanding how to best manage specific types of mixers. 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 occur 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, mixers, storage facilities, and bins and 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.

Now get busy, and celebrate the success and improvements along the way!

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Table 1. Bunker silo densities from 168 Wisconsin bunkers[1].

Characteristic	Hay Crop Silage (87 silos)			Corn Silage (81 silos)		
	Average	Range	SD*	Average	Range	SD*
Dry matter, %	42	24-67	9.50	34	25-46	4.80
Wet density, lb/ft^3	37	13-61	10.90	43	23-60	8.30
Dry density, lb/ft^3	14.8	6.6-27.1	3.80	14.5	7.8-23.6	2.90
Particle size, inches	0.46	0.27-1.23	0.15	0.43	0.28-0.68	0.08

[1]Data taken frm Holmes and Muck (1999).
* SD = standard deviation.

Table 2. Particle size evaluation of silage removed with a de-facer.[1,2]

Farm	Forage	Bunker-Facer	Top or Coarse Fraction, %	Middle Fraction, %	Bottom or Fine Fraction, %
A	Alfalfa Silage	Valmetal	39.7	45.0	15.3
A	Alfalfa Silage	Hand	40.1	44.7	15.4
B	Corn Silage	Valmetal	10.6	74.2	15.2
B	Corn Silage	Hand	11.6	75.0	13.4
C	Alfalfa Silage	Valmetal	27.0	46.3	26.7
	Alfalfa Silage	Bunker Buster	31.8	41.9	26.2
	Alfalfa Silage	Bunker Claw	30.5	44.8	24.8
	Alfalfa Silage	Hand	30.9	45.1	24.0
D	Alfalfa Silage	Bunker Buster	43.2	40.3	16.6
	Alfalfa Silage	Bucket	48.2	42.6	9.3
	Alfalfa Silage	Hand	45.7	33.7	20.6
	Corn Silage	Bunker Buster	6.0	78.3	15.7
	Corn Silage	Bucket	11.2	74.3	14.5
	Corn Silage	Hand	7.6	77.4	15.0
SEM			1.6	1.3	1.1
Effects					
Farm			$P < 0.01$	NS	$P < 0.001$
Forage Type			$P < 0.001$	$P < 0.001$	NS
Sample Day			NS[1]	NS	NS
Facer System			NS	NS	NS
Interactions			NS	NS	NS

[1]Data taken from Sutter and Shaver (2001).
[2] NS = not significant and SEM = standard error of mean.

Figure 1. Relative accuracy of a delivered ration expressed as a percentage of formulated accuracy (assumed to be 100%).

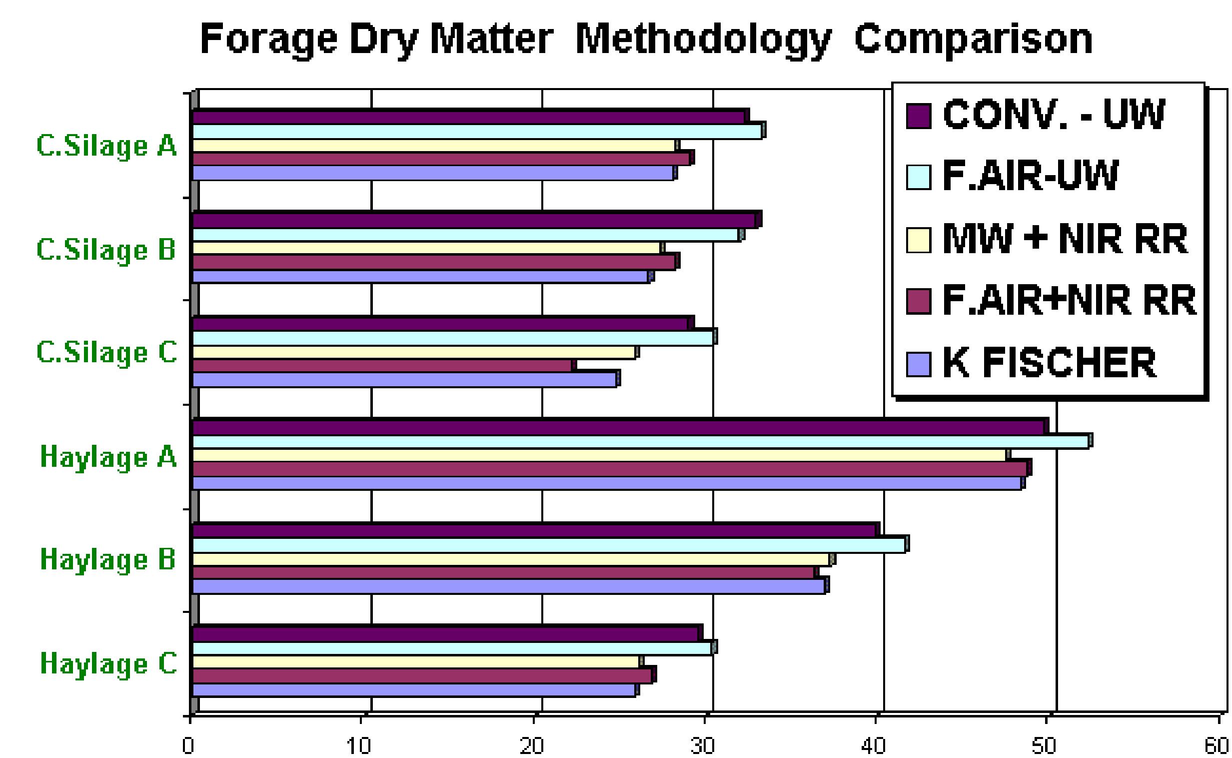

Figure 2. Comparison of different methods for determining forage DM (Barmore, 1997, unpublished). All values represent percentage of DM in forages; Conv-UW = Convection oven at 100°C for 8 hours, g. Oetzel, Univ. of Wisconsin, Madison; K. Fischer = Karl Fischer procedure, W. R. Windham, USDA Athens GA; F.Air-UW = forced-air oven (50°C for 24 hours) + near infrared reflectance (NIR), Rock River Laboratory, Watertown, WI; MW+NIR RR = microwave plus residual moisture by NIR (calibrated on Karl Fischer), Rocker River Laboratory, Watertown, WI; and F. Air + NIR RR = forced-air oven, 60°C for 48 hours, D. Combs, Univ. of Wisconsin-Madison.

Appendix I. Profile of nine Wisconsin, high producing herds during January 2002 (J. A. Barmore, unpublished).

Parameter	Herd 1	Herd 2	Herd 3	Herd 4	Herd 5
Breed	Holstein	Holstein	Holstein	Holstein	Holstein
Milking Cows	550	1532	240	375	830
Milking Frequency	3X	3X	3X	3X	3X
Milk, lb/cow/day	**97**	**87**	**102**	**88**	**90**
% First-Calf Heifers	36	25	33	?	?
% Holstein Cows	100	100	100	100	100
% Milk Fat	3.45	3.8	3.66	3.5	3.77
% Milk True Protein	3.03	3	2.98	2.9	2.95
Posilac Used	Yes	Yes	Yes	Yes	Yes
Posilac Start, DIM	85	65	70	75	>70
# Cows 1994	350	?	170	265	380
# Cows 1998	581	?	190	268	650
# FT Employees	14	30	4	7	8
# PT Employees	2	10	2	3	4
Facilities - Milking Cows					
Freestall Design	4-Row	6-Row	4-Row	4 & 6-Row	4 & 5-Row
Bedding Type	Deep Rice Hulls	Sand	Mattress	Mattress	Sand
Manger Design	Lock-ups	Post-n-Rail	Lock-ups	Lock-ups	Lock-ups
Lock-Up Time	3 hr/wk	?	0	1 hr/day	?
Fans	Holding Pen	Holding Pen	Holding Pen	Holding Pen	Holding Pen
	Freestalls	Freestalls	Freestalls	Freestalls	No
	Manger	No	Manger	Manger	Manger
Sprinklers	Yes	No	Yes	Yes	Yes
Waterers, #/pen	3	2	2	3	3 or 4
Waterer, inch/cow	3	?	?	1.75 - 2.9	2.7
Breezeway water	No	Yes	No	Yes	Yes
Bunk Space/cow	2 ft.	?	2 ft.	22.6 inches	22 inches
Bunk Access, hr/day	21.5	20	20	21	20
% High Pen Density	104	114	116	100	115
1st Calf Separate	Yes	Yes	Yes	Yes	Yes
% 1st Calf Density	104	114	116	109	117
Feed Storage & Ingredients					
Bagged Silage	Alfalfa, Cereals	No	No	Oats, Alf, Corn	Alf, Corn, Cereal
Bunkers	Corn Silage	Alf & Corn Silage	Alf & Corn Silage	Alf & Corn Silage	Alf & Corn Silage
Piles	No	No	Corn Silage	No	No
Upright Silo	HM Shell Corn	No	HM Shell Corn	Oatlage, HMSC	HMSC, Stalklage
Commodity Bays	Ingred. Blend	Chp Hay, SBM	Cottonseed	No	Mineral
		WCS, Gluten Fd			WCS, Gluten Fd
Upright Bins	No	Protein, Mineral	Protein Blend	Protein, Corn	SBM, Distillers
		Dry Corn		Gluten Fd, Bt Plp	
Liquid Fat/Molass.	No	Yes-Fat	No	No	Yes-Molasses
Water Added	No	No	No	No	No

Appendix I (continued).

Parameter	Herd 1	Herd 2	Herd 3	Herd 4	Herd 5
Milking Cows	550	1532	240	375	830
Milk, lb/cow/day	**97**	**87**	**102**	**88**	**90**
DM intake, lb/cow/day	54-56	60	63	53	58
Forage & Feeding Management					
Preblend (PB) Used	Yes	No	Yes	No	Yes
# Ingred. Preblend	6	0	?	0	5
Freq. Mixing PB	3x/week	0	1x/day	0	2x/week
Silage Removal	8"/day	12-16"/day	4-6"/day	4-6"/day	?
Silage De-facer	No	Yes	No	No	Yes
Purchased When	Considering	Fall 2001	None	None	Built 2000
Satisfaction, 1 to 5	None	4	None	None	5
Silage De-facer Satisfaction Rating: High = 5, Low = 1.					
Moisture Tester	Lab	Koster	Lab	Koster	Koster
Haylage	Weekly	Daily	with Changes	2x/week	1-2x/week
Corn Silage	Weekly	Daily	with Changes	2x/week	1x/week
TMR Rain Adjusted	Yes	Minimal	Feeder Est.	Yes	Yes
Monitoring/Record	EZ-feed	EZ-feed	Intake	Daily DMI/Refusal	EZ-feed
Bought/Satisfied	~3 yr/Good	~6 yr/Excellent	None	None	3 yr/Fair
Mixer & Mixing					
Mixer Type	4-auger	4-auger	vertical	4-auger	4-auger
Mixer Age	5 yr	2 yr	5 yr	6 yr	3 yr
# Batches/Day	5	15	6	10	8
Mixer Size, cu ft.	750	?	?	540	~900
Fill Level, % Struck	90	?	?	90	85
Hay in TMR, lb/cow/day	2-Fresh Cows	2-Transition Cows	2	0.75	No
Hay Source	Canada	WI	WI	WI	None
Hay Processed	No	Slicer	Vertical Mixer	Chopped	None
Target Refusal, %	5	2	1-2	Zero	3-5
Refusals Fed	Yes-Heifers	Yes-Low,Heifers	No	Yes-Heifers	Yes-Heifers
Fed When	9 months	Year-round	None	Year-round	~10 months
Refusal Recorded	Yes	Yes	No	Yes	Yes
Bunk Clean-Warm	Daily	Daily	2x	Daily	Daily
# Push-up/Day	4	6 to 8	None	7	5
Mix Time>Last Ing	5 min	3 min	5 min	40 revolutions	3.5 min
Load Time/Batch	20 min	15 min	45 min	30 min	20-25 min
Hay Sequence	1st out of 7	7th out of 11	3rd out of 5	8th out of 11	None
Haylage Sequence	2nd out of 7	8th out of 11	5th out of 5	9th out of 11	2nd out of 4
Corn Silage Seq.	7th out of 7	9th out of 11	4th out of 5	11th out of 11	4th out of 4
Feeding Frequency					
Summer Freq.	2x - every 12 hr	1x	1x	4x	2x
Winter Frequency	twice in 2 hrs	1x	1x	4x	2x

Appendix I (continued).

Parameter	Herd 6	Herd 7	Herd 8	Herd 9
Breed	Holstein	Holstein	Holstein	Holstein
Milking Cows	565	360	335	575
Milking Frequency	3X	3X	3X	3X
Milk, lb/cow/day	**95**	**98**	**93**	**90**
% First-Calf Heifers	36	28	29	38
% Holstein cows	100	100	98	100
% Milk Fat	3.6	3.71	3.62	3.9
% Milk True Protein	2.9	2.95	3.07	2.94
Posilac Used	Yes	Yes	Yes	Yes
Posilac Start, DIM	57	63	65	60
# Cows 1994	110	112	125	550
# Cows 1998	565	137	175	575
# FT Employees	10	7	5	14
# PT Employees	5	2	0	2
Facilities - Milking Cows				
Freestall Design	3 & 6-Row	6-Row	4-Row	3-Row
Bedding Type	Sand	Sand	Sand	Sand
Manger Design	Post-n-Rail	Lock-ups	Lock-ups	Post-n-Rail
Lock-Up Time	0	1	2	0
Fans	Holding Pen	Holding Pen	Holding Pen	Holding Pen
	Freestalls	Freestalls	Freestalls	Freestalls
	Manger	Manger	Manger	Manger
Sprinklers	No	Yes	Yes	Yes
Waterers, #/pen	2	3	2	2
Waterer, inch/cow	<2	4.3	?	1.3
Breezeway water	No	Yes	Yes	Yes
Bunk Space/cow	~15 in.	17.3 in.	20 in.	14.3 in.
Bunk Access hr/day	21	21	20	21
% High Pen Density	108	106	110	120
1st Calf Separate	Yes	Yes + 2nd Calf	Yes	Yes
% 1st Calf Density	123	106	110	123
Feed Storage & Ingredients				
Bagged Silage	Alfalfa, Corn Sil.	Alfalfa, Corn Sil.	Alfalfa, Corn Sil.	No
Bunkers	Corn Silage	No	No	Alf & Corn Silage
Piles	No	No	No	No
Upright Silo	HM Shell Corn	HM Shell Corn	HM Shell Corn	No
Commodity Bays	No	No	Cottonseed	WCS, Barley
			Beet Pulp, SBM	Protein, Hay
Upright Bins	Corn, Protein	Corn, Protein	No	EnerGII, Mineral
	Minerals	Minerals		
Liquid Fat/Molass.	Yes-Molasses	No	Yes-Molasses	Yes-Molasses
Water Added	No	No	No	No-Wet Brewers

Appendix I (continued).

Parameter	Herd 6	Herd 7	Herd 8	Herd 9
Milking Cows	565	360	335	575
Milk, lb/cow/day	**95**	**98**	**93**	**90**
DM intake, lb/cow/day	61-64	64	56	54
Forage & Feeding Management				
Preblend (PB)Used	No	No	Yes	No
# Ingred. Preblend	0	0	5	0
Freq. Mixing PB	0	0	1-2x/day	0
Silage Removal	6"/day	?	?	~3"/day
Silage De-facer	No	No	No	No
Purchased When	None	None	None	None
Satisfaction, 1 to 5	None	None	None	None
Silage De-facer Satisfaction Ratin: High = 5, Low = 1.				
Moisture Tester	Lab	Koster	Microwave	None
Haylage	bi-weekly	Weekly+	Weekly	6x/year
Corn Silage	bi-weekly	Weekly	bi-weekly	2x/year
TMR Rain Adjusted	None	No-Bags	Feeder Est.	Feeder Est.
Monitoring/Record	TMR-Tracker	TMR-Tracker	Intake	Daily DMI/Refusal
Bought/Satisfied	1.5 yr/Poor	~2 yr/Fair	None	None
Mixer & Mixing				
Mixer Type	Reel	4-auger	Reel	4-auger
Mixer Age	2 yr	4 yr	New	New
# Batches/Day	7	10	4	9
Mixer Size, cu ft.	?	630	450	630
Fill Level,% Struck	100	?	75	90
Hay in TMR, lb/cow/day	No-T.D. Fresh	Yes	No	Transition
Hay Source	WI	Western	None	WI
Hay Processed	No	Tub Gr-Consider	None	Tub Grinder
Target Refusal, %	4	3-5	5	1-3
Refusals Fed	Yes-Dry Cows	Yes-Heif/Steer	Yes-Heifers	Yes-Dry Cows
Fed When	Fresh Yr-round	Year-round	Year-round	Year-round
Refusal Recorded	No	Yes	No	Yes
Bunk Clean-Warm	Daily	Daily	Daily	Daily
# Push-up/Day	3	~6	6	5
Mix Time>Last Ing	3 min	5 min	3 min	6 min
Load Time/Batch	17 min	35 min	45 min	30 min
Hay Sequence	None	6th out of 9	None	None
Haylage Sequence	7th out of 8	8th out of 9	5th out of 5	2nd out of 6
Corn Silage Seq.	8th out of 8	9th out of 9	4th out of 5	6th out of 6
Feeding Frequency				
Summer Freq.	1x	1x	2x	1x
Winter Frequency	1x	1x	1x	1x

Relative Feed Value of Forages and Dairy Cows: A Critical Appraisal

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Abstract

Hay crop forages, especially alfalfa hay, is often evaluated using relative feed value **(RFV)**. Relative feed value was developed to be an index of forage quality based on potential intake of digestible energy (i.e., a forage with a high RFV is better than a forage with a lower RFV). The RFV is calculated as [(120/NDF)*(88.9 - 0.779*ADF)]/1.29 (an RFV of 100 is equivalent to full bloom alfalfa), where NDF and ADF are expressed as percentages of DM. Because NDF and ADF concentrations are extremely highly correlated within a forage class (legumes, grasses, and mixtures), one can estimate ADF accurately using NDF. Therefore, the RFV equation can be condensed into a function based solely on NDF. Because RFV can be estimated accurately using only NDF, RFV is really not an index but rather a different way to express NDF concentration. Production data from lactating cows were used to determine whether RFV was a more accurate indicator of cow performance than NDF. Yield of fat-corrected milk **(FCM)** yield decreased, on average, 0.34 lb/day per percentage unit increase in NDF concentration of alfalfa, and FCM yield decreased 0.08 lb/day per one unit decrease in RFV. Relative feed value was no better (or no worse) at predicting milk yield response to forage quality than NDF concentration.

Introduction

In the early 1970's, the American Forage and Grasslands Council established a task force charged "with establishing a system for pricing hay based on some realistic measurements of feed value" (Rohweder et al., 1978). The RFV concept was a major outcome of the task force. Relative feed value was developed to be an index that could be used to rank hay crop forages based on their ability to promote intake of digestible DM. However, RFV came with an important caveat clearly stated by Rohweder et al. (1978), "It [RFV] is an expression of overall forage quality and estimates the relative intake of digestible energy when forage is the only source of dietary energy and protein" (italics added for emphasis). Lactating dairy cows in the U.S., which are perhaps the biggest market for tested hay, are not fed diets in which forage is the only source of energy and protein. Although RFV has become widely accepted as the standard to evaluate and price hay crop forages in many areas of the U.S., it has undergone surprisingly little scientific evaluation as to its ability to determine relative nutrient value of forages when fed to dairy cows.

The purpose of this paper is to critically evaluate the following aspects of RFV: 1) its value as an index (i.e., a single number incorporating different components of forage quality) to rank hay crop forages; 2) its ability

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to predict differences in animal production (i.e., milk production) when different forages are fed to dairy cows; and 3) its ability to accurately reflect relative economic value of alfalfa when fed to dairy cows. This paper will not discuss the applicability and utility of RFV for other ruminants. Moore et al. (1999) and Moore and Undersander (2002) provide a good overview of RFV for sheep and nonlactating cattle.

History

In theory, RFV is a relative measure of potential intake of digestible DM of forages by ruminants. The original equations used to calculate RFV were developed from data obtained from sheep fed all-forage diets. Of the variables measured, the concentration of ADF had the highest correlation to in vivo DM digestibility. Quadratic equations to estimate in vivo DM digestibility were derived by regressing in vivo DM digestibility on ADF concentration. One equation was developed for grass and predominantly grass forages and another equation was derived for legume and predominantly legume forages (Rohweder et al., 1978). Concentration of NDF had the highest correlation with DM intake and quadratic equations were developed by regressing intake (original equations were based on intake per unit of metabolic body weight **(BW)**) on NDF concentration (separate equations for grasses and legumes). Estimated DM digestibility was multiplied by estimated DM intake and the product was multiplied by 0.025. The 0.025 was used to scale the results so that average full bloom legume hay would have an RFV of 100. The original equations for RFV (Rohweder et al., 1978) were:

Grasses:

[1] $$\text{RFV (original)} = (34.8 + 2.56*\text{ADF} - 0.0491*\text{ADF}^2) \times (54.8 + 1.22*\text{NDF} - 0.0176*\text{NDF}^2)* 0.025$$

Legumes:

[2] $$\text{RFV (original)} = (65.5 + 0.975*\text{ADF} - 0.0277*\text{ADF}^2) \times (39 + 2.68*\text{NDF} - 0.041*\text{NDF}^2) * 0.025$$

where ADF and NDF are expressed as percentages of DM.

Some time after the original equations were published (I could not find the exact year the modification occurred), the National Forage Testing Association (Undersander et al., 1993) modified the RFV equation. I was unable to determine why the equations were changed or the rationale of the new equation. A single equation is now used for RFV (instead of separate equations for grasses and legumes). Dry matter digestibility is estimated using a linear equation based on ADF and intake (expressed on a BW basis rather than metabolic body size) is estimated using NDF. The current equation to calculate RFV is:

[3] $$\text{RFV} = [(120/\text{NDF}) * (88.9 - 0.779*\text{ADF})]/1.29$$

where NDF and ADF are expressed as percentages of DM.

The intake term (120/NDF) presumably is based on data from Mertens, suggesting that maximum gut fill occurs when cows consume about 1.2% of BW as NDF (see review by Mertens, 1994). The 1.29 term is a scaling factor so that average full bloom legume hay has an RFV of 100.

Methods

For the remainder of the paper, RFV will refer to the value calculated using equation [3]. To evaluate RFV, a large database of analytical data was obtained from commercial feed testing labs. Samples were from across the entire country and were from at least two growing seasons. The data were divided into alfalfa (N = 2596), cool season grasses (N = 3056), and grass-legume mixtures (N=5434). These data were used to quantify relationships among nutrients and RFV. Data from published studies that compared the feeding value of legumes (i.e., alfalfa) with grasses and studies that compared the feeding value of alfalfa that differed in fiber concentrations and RFV were compiled to test whether RFV could predict differences in milk production.

Is RFV an Index of Forage Quality?

An index can be defined as a number calculated from a set of data that can be used to characterize something. For example, the consumer price index reflects the overall change in cost of living not just the change in the price of gasoline. A forage quality index should reflect differences in overall nutrient value; it should not simply reflect changes in a single nutrient or component. Relative feed value is calculated from NDF and ADF concentrations. Therefore, if RFV is an index of forage quality, it should rank or differentiate forages better than either ADF or NDF singularly.

RFV as a Quality Ranking Tool

The NDF fraction is comprised mostly of cellulose, hemicellulose, and lignin, and ADF is mostly cellulose and lignin. Since almost all of the ADF fraction is found in the NDF fraction, one would expect the two fractions to be highly correlated. When the entire database was used, NDF and ADF were significantly ($P < 0.001$), but only moderately, correlated ($r^2 = 0.53$). The correlation is relatively low because grasses have more hemicellulose than do legumes. Therefore at the same ADF concentration, a grass will have more NDF than a legume. When the data were separated by forage class (alfalfa, grass, and mixtures), correlations between NDF and ADF were much higher and NDF could be used to accurately estimate ADF (Table 1). When ADF was estimated using NDF (Table 1), 97% of the estimated values were within 3 percentage units of the observed values (83% were within 2 percentage units) for alfalfa samples. This means that if NDF concentration of an alfalfa sample is known, ADF can be estimated with a high degree of certainty. The relationship between ADF and NDF for grasses was not quite as strong as for alfalfa but estimated ADF was within 3 percentage units of observed ADF for 86% of the samples (69% were within 2 units). For mixtures, estimated ADF was within 3 units of measured ADF in 74% of the samples (57% of the samples were within 2 units).

The expected conclusion derived from these data are that ADF and NDF are highly correlated and not independent of each other. If one is known, the other can be estimated accurately. Therefore, the equations shown in Table 1 can be substituted into the RFV equations. For alfalfa, ADF = (0.825 x NDF) - 1.52 and RFV = [(120/NDF) x (88.9 - 0.779 x ADF)]/1.29. After substitution and rearrangement, the RFV equation can be written as:

[4] RFV = 8380/NDF - 59.8 (Figure 1).

The RFV calculated using only measured NDF was regressed on RFV calculated using measured NDF and ADF (Figure 2). The resulting equation had an intercept of 1.86 (different from 0, $P < 0.05$) and a slope of 0.986 (not different from 1). The RFV calculated only from NDF were within +/- 4 units of RFV calculated using equation [3] for 89% of the samples (99% of the samples were within +/- 6 units). A range of +/- 4 RFV units would be expected based on normal variation in ADF and NDF assays. The same exercise was performed for the grass and grass-legume database. The resulting RFV equations based on NDF were:

[5] Grasses: RFV = 8762/NDF - 50.8 (Figure 3)

[6] Mixtures: RFV = 8279/NDF - 48.1 (Figure 4)

When RFV was estimated using only NDF and was regressed on RFV calculated using equation [3], the slopes for both grasses and mixtures were equal to 1.00 but the intercepts (3.02 for grasses and 4.69 for mixtures) were statistically ($P < 0.01$) greater than 0 (data not shown). For the mixed samples, 79% of the estimated RFV were within +/- 4 units of observed RFV (99% were within +/-9 units). For the grasses, 93% of the estimated values were within +/- 4 units of observed RFV (99% were within +/- 7 units).

What this means is that RFV is essentially a function of NDF (or ADF). Ranking forages within a species class by NDF (or ADF) will be virtually identical to ranking the forages by RFV. In this aspect, RFV does not meet the definition of an index and provides no additional information not provided by NDF or ADF singularly.

Crude Protein Concentrations

The goal of the task force that developed RFV was to rank forages based on energy and therefore RFV does not include crude protein **(CP)** concentration as a criteria for ranking forages. However, CP has economic value and should be considered when making forage purchasing decisions. As forages mature, concentrations of NDF increase (meaning RFV decreases) and concentrations of CP decrease; therefore, CP and NDF are correlated. The correlations between NDF (or RFV) and CP within forage classes (legumes, grasses, and mixtures) are significant but not extremely strong (Table 2). Figure 5 shows that for alfalfa (other forages classes are similar, data not shown), CP concentration can vary by +/- 5 percentage units within a given RFV (the same range occurs within a given NDF concentration). Assuming an average value for rumen undegradable protein of $0.32/lb and $0/lb for degradable protein (N. St. Pierre, personal communication) and that on average alfalfa hay protein is 80% degradable (NRC, 2001), a one percentage unit change in CP would change the value of alfalfa hay (85% DM) by about $1/ton. Alfalfa hay with an RFV of 150 averages 20% CP but could easily range from 16 to 24% CP (equivalent to about +/- 4 $/ton). Pricing hay solely on NDF or RFV ignores important variation in economic value caused by variation in CP concentrations.

Forage Quality and Cow Response

Published papers in which treatments involved feeding alfalfa with different NDF concentrations to dairy cows were used to generate a database (Alhadhrami and Huber, 1992; Beauchemin, 1991; DePeters and Smith, 1986; Kaiser and Combs, 1989; Kawas et al., 1991; Nelson and Satter, 1990, 1992; Turnbull et al., 1982). Data comparing grasses or mixtures with different NDF concentrations are not available. Alfalfa was the sole forage in the diet. In most studies, the proportion of alfalfa in the diet was constant so that dietary NDF increased when alfalfa that had higher NDF concentrations was fed. In a few studies, the proportion of alfalfa in the diet increased as the concentration of NDF in the alfalfa decreased. Measured ADF and NDF concentrations of the alfalfa were used to calculate RFV using equation [3]. The data set had 52 observations for FCM yield from 8 different papers and 48 observations from 7 different papers for DM intake (one paper did not report intakes). Descriptive statistics of the data set are in Table 3.

Milk Production

As expected, an improvement in alfalfa quality, whether expressed as a decrease in NDF or an increase in RFV, was related to an increase in 4% FCM yield. To quantify the response in FCM yield to changes in quality of alfalfa, mixed model regression that included trial as a random variable (St. Pierre, 2001) and either NDF concentration or RFV were conducted. Trial was a significant variable in all regressions and accounted for the majority of variation. However, NDF and RFV also were significantly related to FCM yield. The regression equations were (trial effect is incorporated into the intercept):

4% FCM (lb/day) = 75.0 - 0.34*NDF (%)
($P < 0.01$; SE slope = 0.098) (Figure 6)

4% FCM (lb/day) = 49.5 + 0.080*RFV
($P < 0.01$; SE slope = 0.024) (Figure 7)

Overall fit and prediction error were similar for both equations. These equations mean, that on average, a 1 lb/day increase in FCM would be expected if the concentration of NDF in the alfalfa decreased about 3 percentage units or RFV increased about 13 units. No indication of nonlinearly was observed for the NDF or RFV equations.

Because the relationship between NDF and RFV is a reciprocal function (Figure 1), linear functions between both FCM and NDF and FCM and RFV would not be expected. If the relationship between FCM and NDF was in fact linear, then one would expect that a linear regression of FCM on RFV would over predict FCM at high RFV. The reason for this contradiction is most likely caused by the lack of production data with forages with very low NDF concentrations (i.e., very high RFV). The minimum NDF concentration in this data set was 35% (maximum RFV was 178).

Intake

The same data set and statistical analysis used for milk production was used to evaluate relationships between alfalfa quality and intake, except that one study (four treatments) did not report intake data. With trial adjusted regressions, neither NDF nor RFV were significantly related to DM intake ($P > 0.40$). Given the small response in FCM yield to forage quality (e.g., a change of 10 percentage units in NDF would be expected to change FCM yield by 3.4 lb), the lack of a statistically significant relationship of intake with forage quality is not surprising. On average, a 1 lb increase in milk yield is associated with a 0.5 to 0.67 lb increase in DM intake. The effect of forage quality on intake, if any, may have been too small to statistically detect with the available data set.

Interpretation Precautions

The expected response in FCM yield to changes in alfalfa quality (measured as NDF or RFV) are based on data from cows fed diets with alfalfa as the sole forage. Mean intake of alfalfa DM in these studies was 24.9 lb (average of 52.5% of dietary DM). A reasonable expectation would be for a smaller response in FCM yield to changes in alfalfa quality when alfalfa was not the sole forage and comprised less of the total diet. Cows in this data set also were not in early lactation. Forage quality would probably have a greater influence on intake and FCM yield with early lactation cows.

Conclusions - Cow Data

For alfalfa with 35 to 55% NDF (this range will include most of the alfalfa fed), RFV offers no advantage over NDF in ranking of alfalfa quality when fed to lactating dairy cows.

Economics

In the lactation studies used to derive the regressions, average DM intake was 47.5 lb/day and the average diet was 52.6% alfalfa DM (about 25 lb/day of alfalfa DM). On a dry hay equivalent basis, the average cow consumed about 30 lb of hay (as-fed) which means that 1 ton of hay (2000 lb) would feed about 67 cows for one day. Economic value of a change in forage quality (measured using NDF or RFV) was determined by calculating the expected change in milk yield and was expressed on a per ton of hay basis. Based on the lack of a significant effect of NDF or RFV on intake, feed costs were assumed not to change.

Example

Alfalfa A has 42% NDF and 140 RFV and alfalfa B had 44% NDF and 131 RFV. If alfalfa A was substituted for alfalfa B, one would expect an average increase in FCM yield of about 0.7 lb/day based on changes in NDF or RFV. Based on the averages from this data set, 1 ton of hay would feed 67 cows; therefore, 1 ton of the better hay would be expected to increase FCM yield by 0.7 x 67 = 47 lb. If FCM was worth $0.14/lb, the value of the increased FCM yield would be about $6.60/ton of hay. Other costs (excluding feed) are associated with increased production and were assumed to equal10% of gross receipts. Therefore, the net value of the increased production would equal 6.6 x 0.9 = $5.9/ton of alfalfa. In other words, based on changes in net milk income, alfalfa A would be worth no more than $5.9/ton more than alfalfa B to a dairy producer. If the milk (FCM) price was $0.12/lb, then alfalfa A would be worth no more than about $5.0/ton and if the milk (FCM) price was $0.16/lb, alfalfa A would be worth no more than about $6.8/ton. Based on Wisconsin hay auction data (Silveira, 2002), a 9 unit increase in RFV is associated with about a $6.7/ton increase in price. That value is reasonably close to the expected change in net milk income assuming a normal range in milk prices.

The economic value calculated above is based on data in which alfalfa was the sole forage fed. The milk yield response to changes in RFV or NDF is likely smaller when less alfalfa is fed. If this is true, then a change in RFV or NDF is worth less than discussed above.

Grasses Versus Legumes

Grasses usually have higher concentrations of NDF than legumes at equal plant maturity; therefore, if NDF is used to rank quality of forages, grasses and grass-legume mixtures will generally rank lower than legumes. Because the relationship between NDF and ADF differs for grasses and legumes, RFV could theoretically offer an advantage when ranking forages across species classifications. At equal NDF concentrations, a grass will usually have a higher RFV than a legume (average difference is about 10 units). A data set from studies (Hansen et al., 1991; Hoffman et al., 1998; Weiss and Shockey, 1991; Weiss, 1995) in which diets with cool season grasses or alfalfa were fed to lactating cows was compiled. Only four studies were found (simple statistics are shown in Table 4). The same type of statistical analysis was performed on these data as for the alfalfa data except that forage class (legume or grass) was included as a discrete fixed variable. With this set of data, NDF concentration and RFV were not related to FCM yield. The NDF concentrations averaged 55% and 45% and RFV averaged 106 and 129 for the grasses and legumes, respectively. This very limited data set indicates that, on average, grasses with about 55% NDF and 110 RFV are nutritionally equal to alfalfa with 45% NDF and 126 RFV when fed to lactating dairy cows. This limited data set also implies that RFV will not rank grasses appropriately when compared with legumes (i.e., the same problem as when NDF is used to compare grasses and legumes).

The Future

The development of a true index of forage quality is clearly a worthy goal. With a valid index, a forage buyer (or feeder) could compare the 'nutritional value' of different forages using a single number. A valid index should be based on expected net dollar returns when the forage is fed to a dairy cow (or whatever target animal is of interest). This means that the index should incorporate the dollar value of all the major nutrients provided by the forage and any animal response not accounted for by changes in measured nutrients. The economic value of nutrients can be determined using available software (SESAME, 2000), and the equations shown in this paper relating changes in NDF to milk yield can be used to estimate potential change in milk income caused by forage quality.

Conclusions

1. Because ADF and NDF are so highly correlated within a forage species class, ranking forages by RFV is virtually identical to the ranking obtained using NDF. In other words, RFV is not an index, but simply a different expression of NDF.

2. A substantial amount of variation in CP concentration is not accounted for by variation in RFV or NDF. Forage evaluation should include a complete measure of nutrient composition, including NDF and CP.

3. Yield of FCM was related to forage quality (as expressed by NDF or RFV) but DM intake was not. A 1 lb/day increase in FCM would be expected if the NDF concentration in alfalfa decreased by about 3 percentage units or RFV increased by about 13 units when alfalfa was the sole forage fed. Change in RFV was no better or worse than change in NDF at estimating change in FCM yield.

4. Comparing grasses with legumes using RFV or NDF underestimates the nutritional value of high quality grasses relative to legumes.

Acknowledgements

The forage composition data provided by Mr. Dave Taysom (Dairyland Labs Inc., Arcadia, WI) and Mr. Ralph Ward (Cumberland Valley Analytical Services, Hagerstown, MD) is gratefully acknowledged.

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Table 1. Regression equations relating neutral detergent fiber **(NDF)** and acid detergent fiber **(ADF)** concentrations for different classes of hay crop forages.[1]

Forage Class	Equation	N	RMSE	r^2
Legumes	ADF = (0.825 x NDF) - 1.52	2596	1.55	0.87
Grasses	ADF = (0.701 x NDF) - 6.85	3056	2.34	0.76
Grass-legume mixes	ADF = (0.664 x NDF) + 0.082	5434	2.77	0.71

[1]NDF and ADF are expressed as percentages of DM; RMSE = root mean square error.

Table 2. Correlations **(r)** between crude protein **(CP)**, neutral detergent fiber **(NDF)**, and relative feed value **(RFV)** calculated using equation [3] for different classes of hay crop forages. All correlations were significant (P < 0.001).

	CP	NDF	RFV
All (N= 10,993)			
NDF	-0.78	. . .	-0.96
RFV	0.73	-0.96	. . .
Legumes (N = 2504)			
NDF	-0.50	. . .	-0.97
RFV	0.45	-0.97	. . .
Grasses (N = 3056)			
NDF	-0.46	. . .	-0.97
RFV	0.48	-0.97	. . .
Mixtures (N = 5433)			
NDF	-0.67	. . .	0.97
RFV	0.62	-0.97	. . .

Table 3. Simple statistics for the data set used to determine the relationships between alfalfa quality and milk production.[1]

	Mean	SD	Minimum	Maximum
Milk production data set (N = 52)				
4% FCM, lb/day	60.5	8.8	44.0	81.8
Forage, % of DM	52.5	10.3	25.0	76.0
Alfalfa NDF, % of DM	44.3	5.8	35.9	59.5
Alfalfa RFV	133	25	83	177
Intake data set (N = 48)				
DM intake, lb/day	47.5	5.8	34.8	57.6
4% FCM, lb/day	59.7	8.4	44.0	79.2
Forage, % of DM	52.4	10.5	25.0	76.0
Alfalfa NDF, % of DM	43.9	5.5	35.9	54.9
Alfalfa RFV	134	25	88	177

[1]FCM = fat-corrected milk, RVF = relative feed value, SD = standard deviation, DM = dry matter, and NDF = neutral detergent fiber.

Table 4. Simple statistics for the data set used to compare nutritional value of grass and alfalfa forages when fed to dairy cows (10 means per species type).[1]

	Mean	SD	Minimum	Maximum
DM intake, lb/day	45.6	3.1	37.6	51.0
4% FCM, lb/day	58.2	9.0	42.0	70.0
Forage, % of DM	57.9	12.7	40.0	80.0
Grass NDF, % of DM	54.8	6.3	46.8	63.6
Grass RFV	106	12	90	123
Alfalfa NDF, % of DM	44.7	3.8	40.1	49.5
Alfalfa RFV	129	14	113	146

[1]DM = dry matter, FCM = fat-corrected milk, NDF = neutral detergent fiber, RFV = relative feed value, and SD = standard deviation.

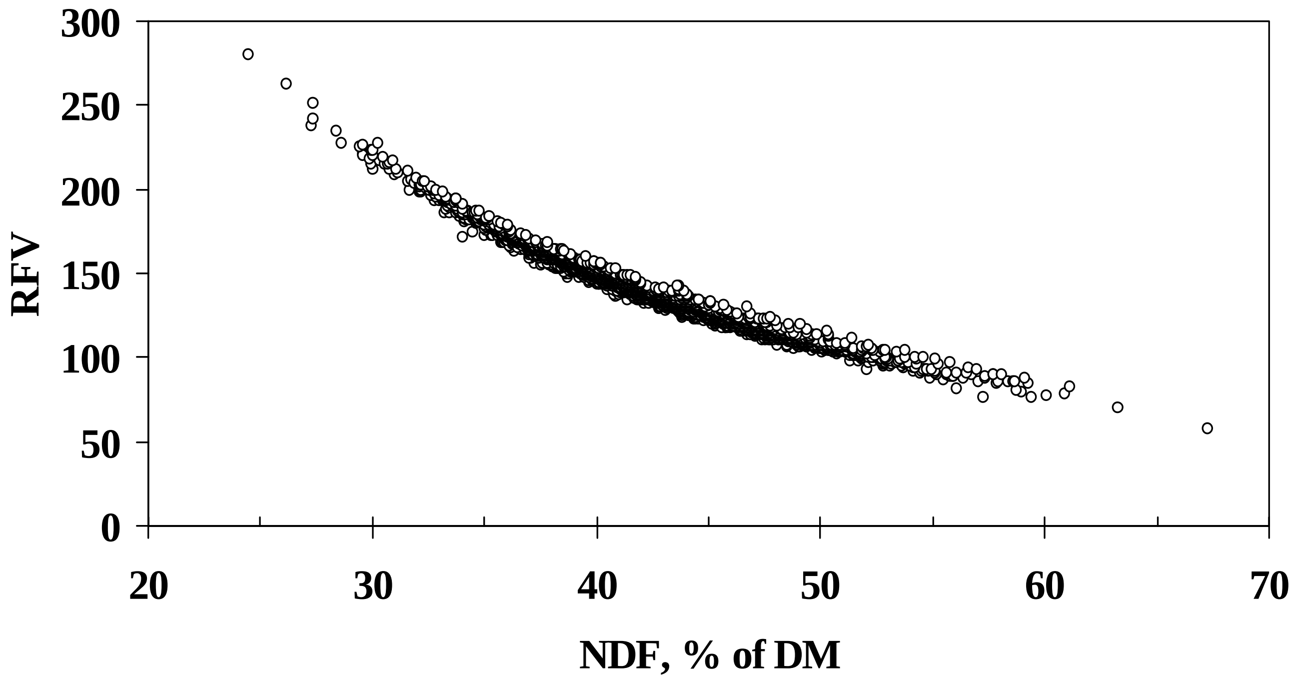

Figure 1. The relationship between relative feed value **(RFV)** and concentration of NDF in alfalfa samples (N = 2596). The regression line is: Y = -0.076 + 1.001X (r^2 = 0.98).

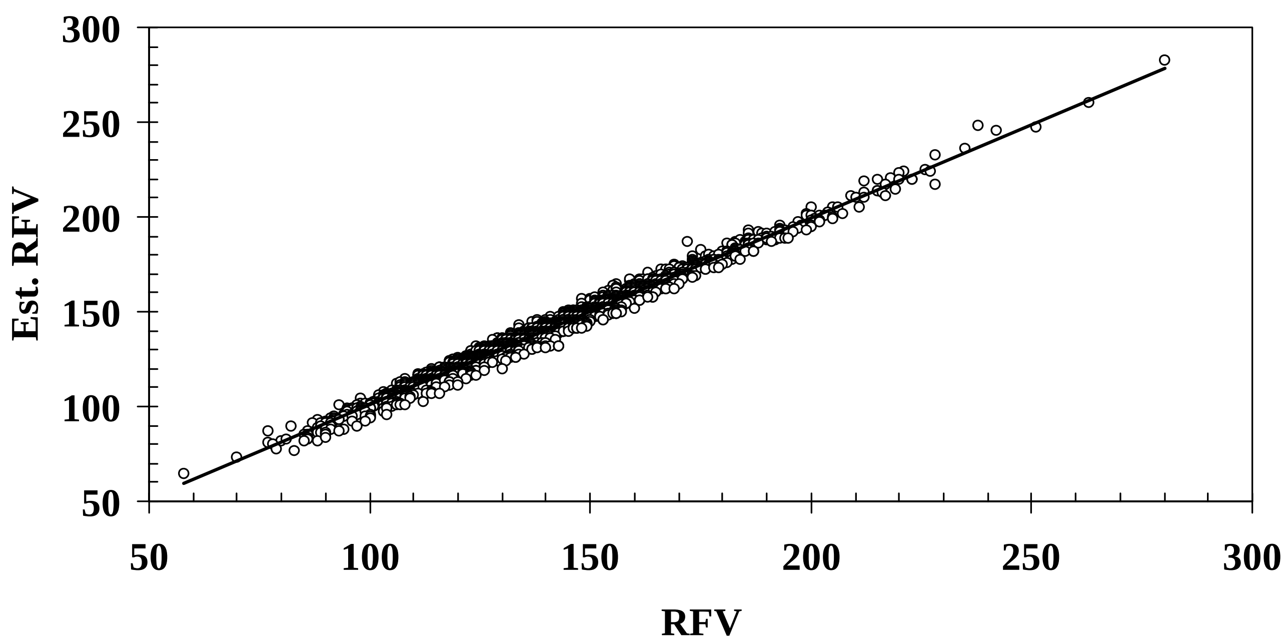

Figure 2. The relationship between relative feed value **(RFV)** calculated from measured concentrations of ADF and NDF and RFV calculated only from measured NDF (Est. RFV) in alfalfa samples (N = 2596).

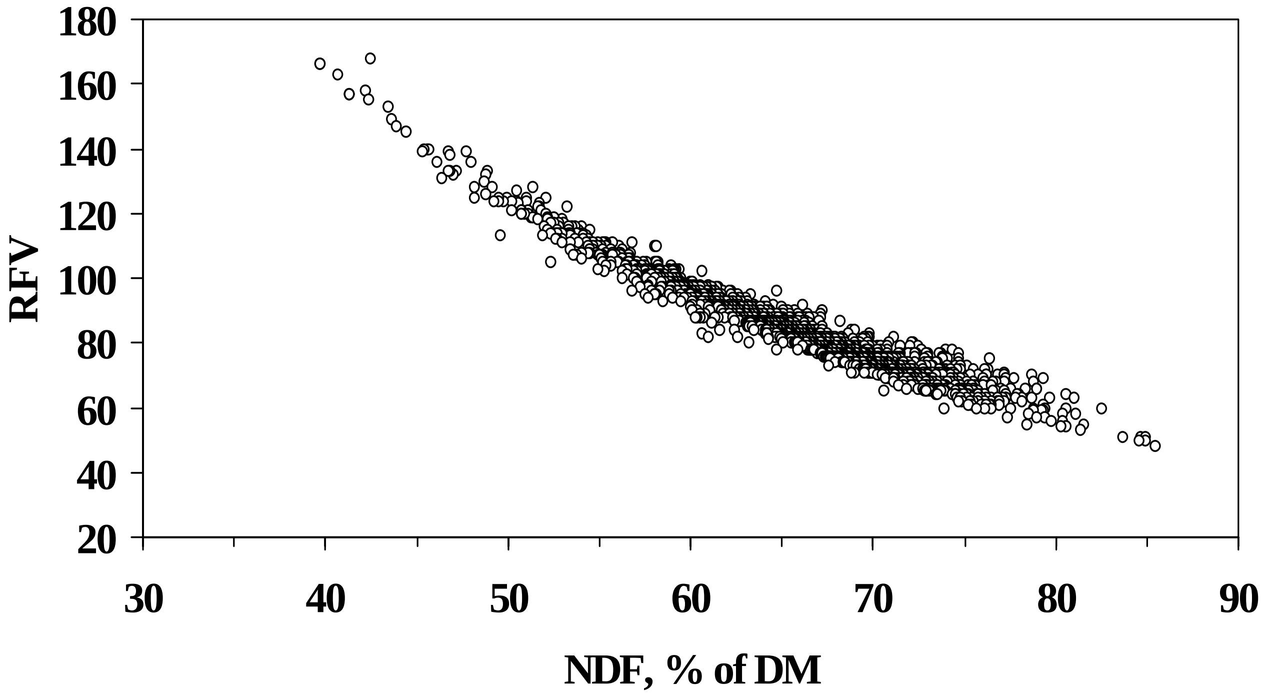

Figure 3. The relationship between relative feed value **(RFV)** and concentration of NDF in grass samples (N = 3056).

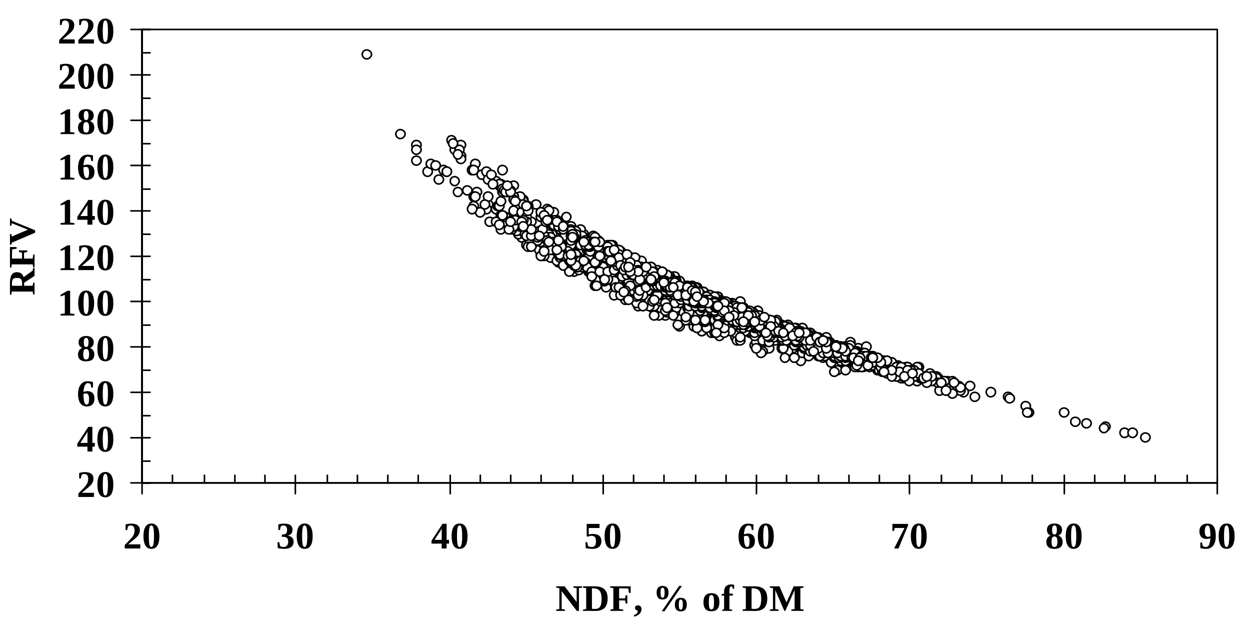

Figure 4. The relationship between relative feed value **(RFV) a**nd concentration of NDF in samples of grass and legume mixtures (N = 5434).

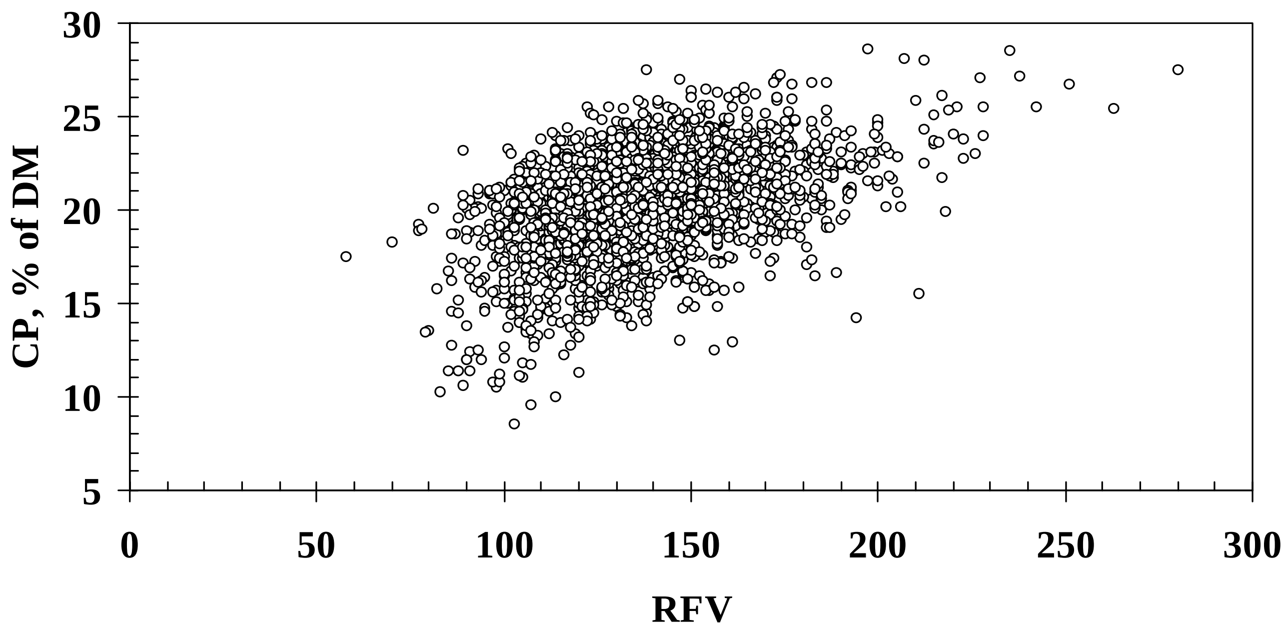

Figure 5. Relationship between concentrations of crude protein **(CP)** and relative feed value **(RFV)** in alfalfa samples (N = 2504).

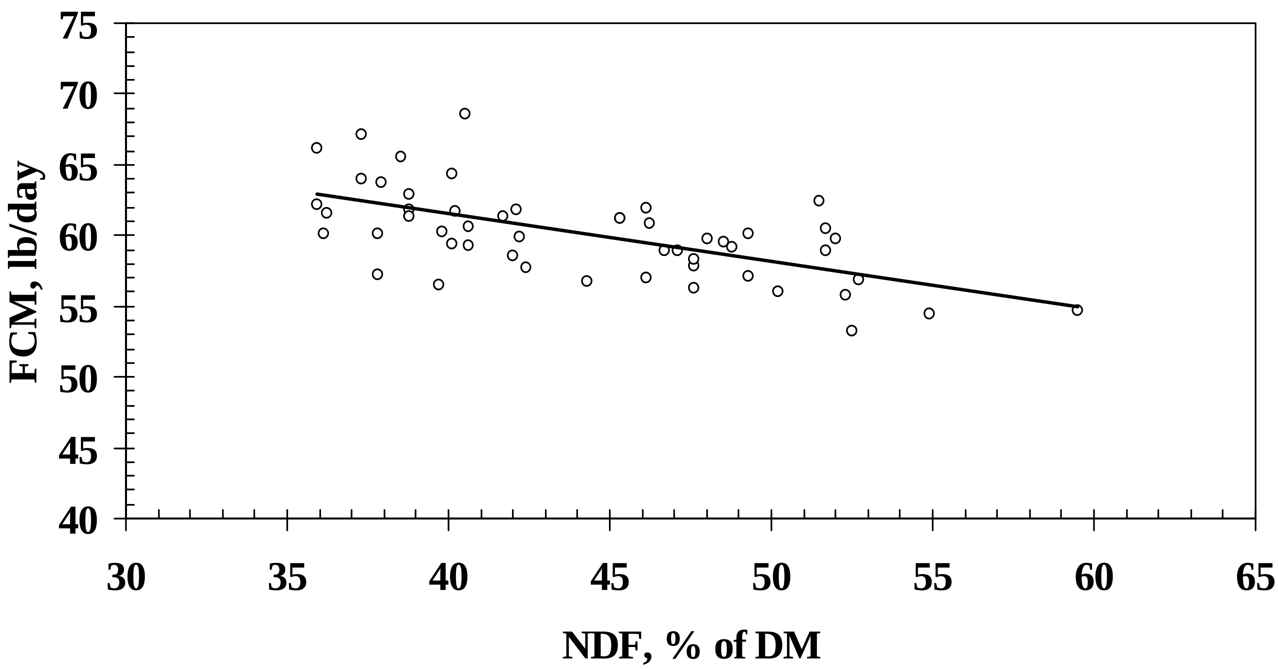

Figure 6. Effect of NDF concentration of alfalfa on yield of 4% fat-corrected milk **(FCM)** when the alfalfa was fed in mixed diets to lactating dairy cows. Data were adjusted for trial effects. The regression line is: Y = 75.0 - 0.34X.

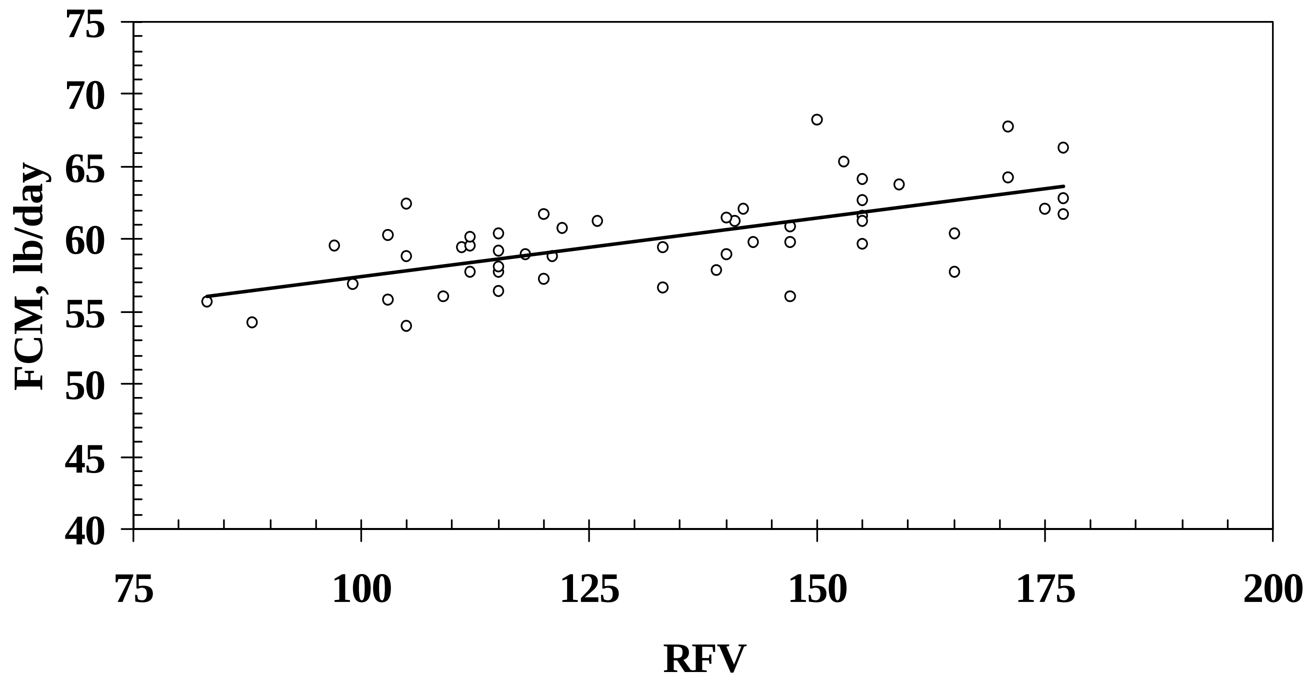

Figure 7. Effect of relative feed value **(RFV)** of alfalfa on yield of 4% fat-corrected milk **(FCM)** when the alfalfa was fed in mixed diets to lactating dairy cows. Data were adjusted for trial effects. The regression line is: Y = 49.5 + 0.080 X.

Characteristics of Manure: What Do They Mean?

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Abstract

Evaluation of manure can provide a simple method to evaluate site and extent of feed digestion/fermentation in cattle. Key factors that affect the texture and particle size of manure include adequacy of the physically effective fiber to maintain rumen function and the impact of the types of non-fiber carbohydrates **(NFC)** on ruminal pH. Both of these factors can affect the ruminal residence time or extent of digestion of feeds. Escape of large amounts of undigested feed from the rumen can result in extensive fermentation in the hindgut (cecum and large intestine). As the hindgut fermentation yields gas and acid, manure can appear foamy, or as diarrhea, or may contain mucin casts. With insufficient effective fiber consumption, particle size and appearance of undigested feed in the feces increases. This information should be used in context with other evaluations of animal performance, feeding management, and cow comfort to determine if and what changes are needed in ration formulation or management.

Introduction

Evaluation of manure is one of the simplest methods to evaluate site and extent of digestion/fermentation in cattle. For years, people have "toe-tested" manure to evaluate rations. In fact, there is good biological basis as to why manure looks the way it does. Key elements that affect the texture and particle size of manure include adequacy of the amount of physically effective fiber consumed and the impact of the types of NFC on ruminal pH. Either of these factors can change the residence time or extent of fermentation of a feed in the rumen. If a feed is not extensively fermented in the rumen, its protein, fats, and starches may be digested and absorbed in the small intestine. If not digested there, the proteins and carbohydrates may be fermented in the hindgut (cecum and large intestine). If the rumen is functioning properly, hindgut fermentation is minimized. In high producing cows with high DM intakes, the rate of passage of feed through the rumen is increased, so more undigested feed will likely reach the hindgut. However, there are relative degrees of hindgut fermentation, and high intakes should not be used to excuse clear symptoms of rumen dysfunction.

If the rumen is not functioning properly, such as during bouts of ruminal acidosis, hindgut fermentation can be extensive. Ruminal problems can often be traced to feeding management in need of improvement, misfeeding of highly digestible carbohydrates, underfeeding of effective fiber, or all of the above. Symptoms associated with subclinical ruminal acidosis include:

- Reduction in ruminal pH
- Rumen stasis
- Reduced rumination (cud chewing)
- Great daily variation in feed intake (in-

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dividual animals, may not be noticed in groups)

- Feces in the same feeding group varies from firm to diarrhea
- Feces foamy, contains gas bubbles
- Appearance of mucin/fibrin casts in feces
- Increase in fiber particle size (> 0.5 inch) in feces
- Appearance of undigested fiber/feed in feces
- Appearance of much undigested, ground (< 1/4 inch) grain in feces
- Reduced feed efficiency
- Reduced production compared to what the ration is calculated to support

How to Evaluate Manure

Manure evaluation includes the assessment of manure appearance and particle size. Evaluate appearance by feeding group: animals that receive the same ration should have similar looking manure unless they are sorting their feed. About 5% of the cows will have manure that differs from the majority of the animals in their group, and this can be accepted as normal. Is the manure very stiff? Is there some diarrhea? Is the manure variable? Is it foamy or does it contain lots of larger bubbles? Is mucous visible in the manure? (If you drag the tip of your boot across a cow pie and something moves after your boot has passed, it's likely a mucin cast.) Is undigested feed apparent in the manure? Is it ground or whole grain? When you evaluate the manure, examine the cows and feed for more information: the proportion of the cows ruminating, body condition, general appearance of cows, cleanliness/presence of waterers, feedbunk conditions (feedbunk space, how well feed is mixed, etc.), feed sorting by the cows, cow comfort, etc. Also examine the individual feeds and where they are stored to look for mold, spoilage, or other problems. These other observations may well explain why the manure looks the way it does.

For each group of cows, take 4 or 5 samples of feces from individual cow pies: try to pick for variation in appearance representative of the group. Make sure the samples are not contaminated with feed. Eight ounce sample cups with lids are very good for this purpose. Fill the cup completely and cap. Use a screen or kitchen strainer (do not return it to the kitchen) with 1/16 inch (1.66 mm) openings. This is a qualitative on-farm evaluation, so getting very specific about mesh size is not crucial. A strainer that is 7 inches (17.8 cm) in diameter and 4 inches (10.2 cm) deep works well. Transfer a manure sample into the strainer, using a steady stream of water to rinse the manure in the cup into the strainer. Rinse the sample gently but thoroughly until the water runs clear. The sample can be transferred back to the sample cup so that all of the samples taken can be compared side by side. Does fiber in the sample appear to be coarse (more than 0.5 inches long, whole pieces of corn stalk)? Does any cottonseed present still have the lint still on it? Does the feed retain its color (grass that's still green, citrus that's still orange, etc.)? Is there much (relative term) whole grain in the sample? Ground grain? Manure evaluation is qualitative, so you can assess whether there appears to be too much or an acceptable amount of coarser fiber or undigested grain in the manure (see "In Context"). There is no common, on-farm way to evaluate the proportion of manure your that samples represent, so do not try to overinterpret the information they offer.

Particle Size/Undigested Material in Feces

Large fiber particles or noticeable ground grain in the feces suggest that feed is not being retained in the rumen for a sufficient period to be reduced in size through rumination or microbial fermentation. The depression in ruminal digestion may be related to low pH (Strobel and Russell, 1986). An inadequate ruminal fiber mat may not effectively retain larger particles in the rumen. Both of these situations can be related to inadequate intake of physically effective fiber **(peNDF)**. The peNDF is fiber in the ration that enhances rumination and rumen motility. Generally, when adequate peNDF is consumed, fecal particle size is smaller and ground grain is less apparent, than when fiber requirements are not met. Sorting of feed by the cows is a very common reason that peNDF needs are not filled. Providing palatable sources of forage and processing them (chopped to ~1 to 2 inch lengths) so they can be blended into a moist total mixed ration that cows cannot readily sort through can help to prevent sorting.

My Observation: Effectiveness of fiber is not only related to particle size but to a variety of factors that affect rate of digestion. For example, grass NDF tends to ferment more slowly than does that in legume forages. Additionally, the particles from grass tend to be more needle-shaped and those from legumes to be more cuboidal. In my experience, grass has tended to be a more effective peNDF source than legume forages, possibly because the fiber is retained in the rumen for a longer period of time. One to 3 inch long pieces of very tender or pliable grasses can sometimes be found in the feces - they seem to be able to bend and escape the rumen. The peNDF has to be in the rumen to be effective. A greater amount of NDF from a more rapidly fermented peNDF source would have to be fed to provide the same amount of peNDF as from a more slowly fermenting source. Take as an example that a small amount of chopped straw included in a ration can quickly resolve problems due to peNDF inadequacy of the ration. Alfalfa can be an excellent feed, but it can be a poor choice as a major source of effective fiber. The need to provide adequate peNDF to allow for proper rumen function and ration digestion is a balancing act with providing adequate nutrients. This is best done with high quality forages and feeds in adequate quantities.

Undigested feed in feces is indicative of an overall reduction in digestibility of the ration. Both fiber and starch can escape digestion. Long pieces of fiber from forage, or even cottonseed with the lint intact, can pass undigested through the gastrointestinal tract if they are not retained in the rumen for digestion. The visible particles of ground grain in feces may contain 6 to 18% starch (M. B. Hall, unpublished). Much whole or coarsely ground grain in the manure usually indicates problems with silage harvest methods or inadequate grinding of dry grain. Finer grinding of the dry grain can help to reduce appearance of grain in the manure. Problems with silage usually need to be addressed the following year. Reduced digestion of feed represents a loss of ration nutrients. Consequently, the predicted protein and energy supplies from the ration overestimate what the cow actually receives. High producing cows with high DM intakes may also show an increased passage of undigested feed, but they should not show evidence of ruminal acidosis.

Mucin/Fibrin Casts or Gas Bubbles in Feces

When feed is fermented in the rumen, the organic acids are absorbed across the rumen wall, the gas (carbon dioxide and methane) is eructated (belched) out by the cow, and the microbial cells pass to the small intestine for digestion and absorption. When fermentable substrates pass to the hindgut (cecum and large intestine) they are fermented there by bacteria (Figure 1). The microbial protein produced is not absorbed but passes out with the manure. Gas produced from hindgut fermentation can appear as bubbles in the manure, sometimes to the point that the feces have the texture of shaving cream. The organic acids can be absorbed by the gut. However, a major difference between the hindgut and the rumen is the potential for the fermentation to be buffered. Where rumination and mixing with saliva provide buffers to reduce the extent of pH decline in the rumen, a system of that magnitude does not exist for the hindgut. When a great deal of fermentable carbohydrate reaches the hindgut, its fermentation to organic acids may result in injury to the gut. The increased acidity may result in a damage to and sloughing of the surface cells (epithelium) in the large intestine. When the damage is sufficiently severe, the intestine secretes mucous or fibrin to protect the injury (Argenzio, et al., 1988; Argenzio and Meuten, 1991). Depending upon the severity of the damage, the gut can repair itself in a few hours to a day (R. A. Argenzio, personal communication). The mucin/fibrin casts found in the feces often have the tubular form of the gut; they are evidence that intestinal damage has occurred.

Diarrhea

Damage to the large intestine and increased concentrations of organic acids in the gut lumen may play a role in causing the diarrhea often seen with ruminal acidosis. Feeding spoiled or moldy feed can also cause diarrhea.

Reduced Feed Efficiency

If the site of digestion is shifted from the rumen to the hindgut due to a poorly functioning rumen, it is no wonder that feed efficiency suffers. Compared to our usual predictions for digestion in the rumen or small intestine (Figure 2), the amounts of nutrients available to the cow are diminished. The argument has been raised that increased grain and decreased forage are necessary to meet the energy requirements of the cow. However, if concentrate levels are increased to the point that fiber needs are not met, the analyzed or tabular total digestible nutrients or net energy levels used to formulate the ration are meaningless. In the pursuit of providing the cow with more energy, violation of the rules for formulating a balanced ration actually reduces the amount of energy that the ration provides. This quote by Dr. Paul W. Moe, a USDA researcher who did much work in the area of net energy, explains the situation (Moe, 1976):

"…The net energy value of a single feedstuff, however, is not a constant but is influenced by such factors as the composition of the remaining portion of the diet, the level of the feed intake, the physiological state of the animal that consumes the feed, etc. This means that while a net energy value may represent the best estimate of the real energy value of a feed in a given situation, it should not be considered as a constant. ….The net energy value listed in a table usually represents an optimum value, that is the value of that feed when incorporated into a "normal" or "balanced" diet. The value may be considerably less than that if fed in excessive amount or in a diet which has a nutrient deficiency."

In this light, including excessive amounts of concentrates in an effort to increase ration energy levels is self-defeating.

Heat Stress

Another cause of abnormal manure is heat stress. Changes in a cow's behavior and acid-base balance during heat stress predispose her to ruminal acidosis. Heat stress alters a cow's acid-base balance. As a cow pants and exhales carbon dioxide, it appears that the total amount of buffering capacity within her system may be decreased, as evidenced by increases in her blood pH (Dale and Brody, 1954). In addition, changes in feeding behavior, such as consuming feed in fewer meals (slug feeding) and decreased rumination, may lead to decreases in ruminal pH even with rations containing adequate fiber. In a study that tested the effect of ambient temperature on the rumen environment (Mishra, et al., 1970), lactating Holstein cows were fed high roughage or high concentrate diets at ambient temperatures of 65°F (cool) or 85°F (hot) with relative humidities of 50% and 85%, respectively. Ruminal pH was lower at the higher temperature and on the higher concentrate ration ($P < 0.01$) (Figure 3). There was an interaction of diet and temperature ($P < 0.01$). Ruminal ammonia and lactic acid concentrations were higher for the hot treatment ($P < 0.01$). Other studies have reported decreased ruminal pH at hotter versus cooler ambient temperatures (Niles, et al., 1998; Bandaranayaka and Holmes, 1976). Ruminal changes appear to be responses to ambient, not ruminal temperatures (Gengler et al., 1970).

In this light, the recommendation of adding more concentrate to rations in summer is not well advised. The rationale for decreasing forage and increasing grain during heat stress is to meet animal energy demands in the face of decreasing DM intake. If, as in the Missouri study (Mishra et al., 1970), feeding more concentrate further depresses ruminal pH, little may be gained and more may be lost by compromising the cow's health. Fiber should be provided at levels to meet animal requirements under all conditions. Reports from commercial dairies suggest that increasing forage or fiber levels with palatable feeds may reduce the negative effects of heat stress on production and health.

The most effective management for reducing the impact of heat stress on ruminal pH is to cool the cows. Fans, sprinklers, misters, cooling ponds, or shade can be used in cooling systems.

In Context

So, what to do with the information from evaluating manure in a herd? Combine it with information on cow health (digestive upset, acidosis, laminitis, etc.), cow performance (milk and milk fat yields), rumination (at least 40% of cows not eating or sleeping should be chewing their cuds), cow observations (sorting the ration or not, comfortable or not), ration & feed evaluation, etc. Manure evaluation describes the interaction of the cow and her ration. The story it tells adds to a body of evidence that something within the ration or in cow and feeding management does or does not need to be modified. If everything else looks fine, but the manure does not seem quite right, keep observing the cows to make certain that they continue to do well and question what you haven't checked. Transient problems like eating patterns changing with weather fronts, a passing problem with silage, etc. can also generate changes in the manure.

Summary

Manure evaluation offers a simple way to assess rumen function and how well and where a cow is digesting/fermenting her feed. It is a qualitative system. When used in context with other observations, it can offer confirmation and direction for ration and management changes.

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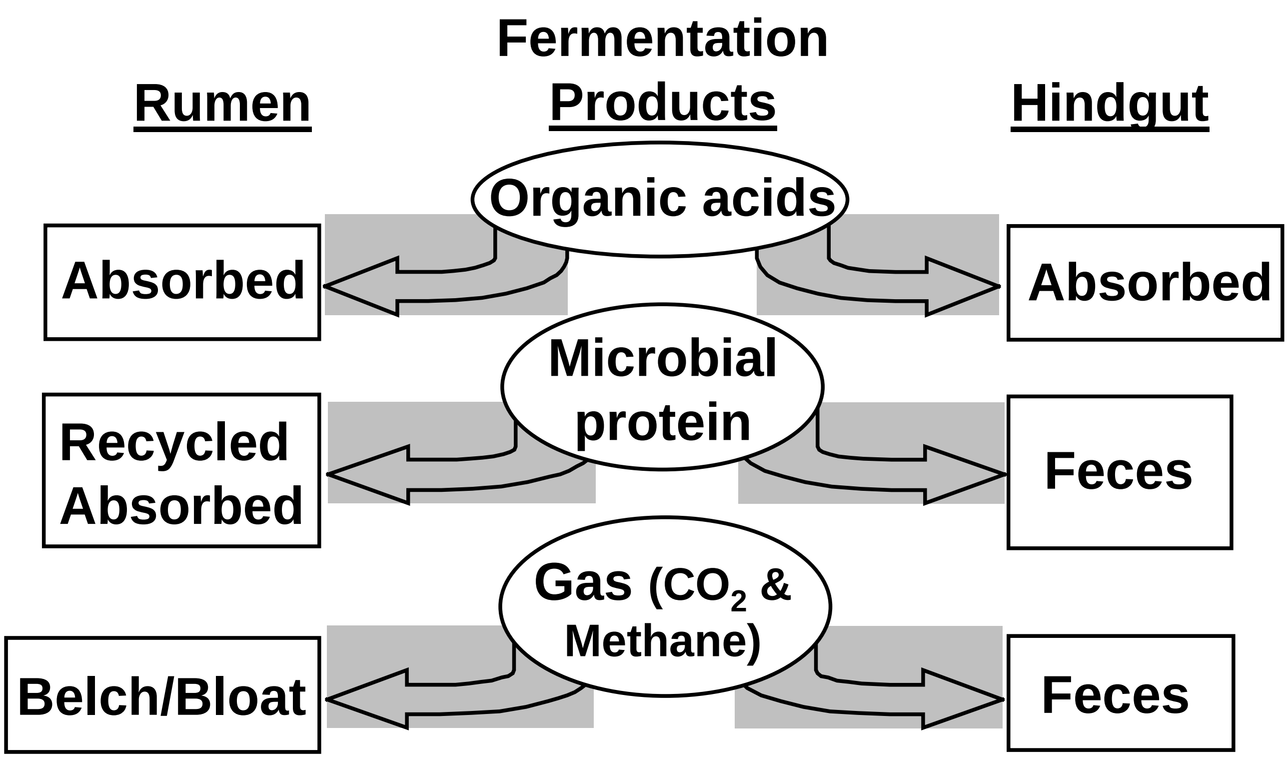

Figure 1. Fates of fermentation products from rumen and hindgut (cecum and large intestine) fermentations.

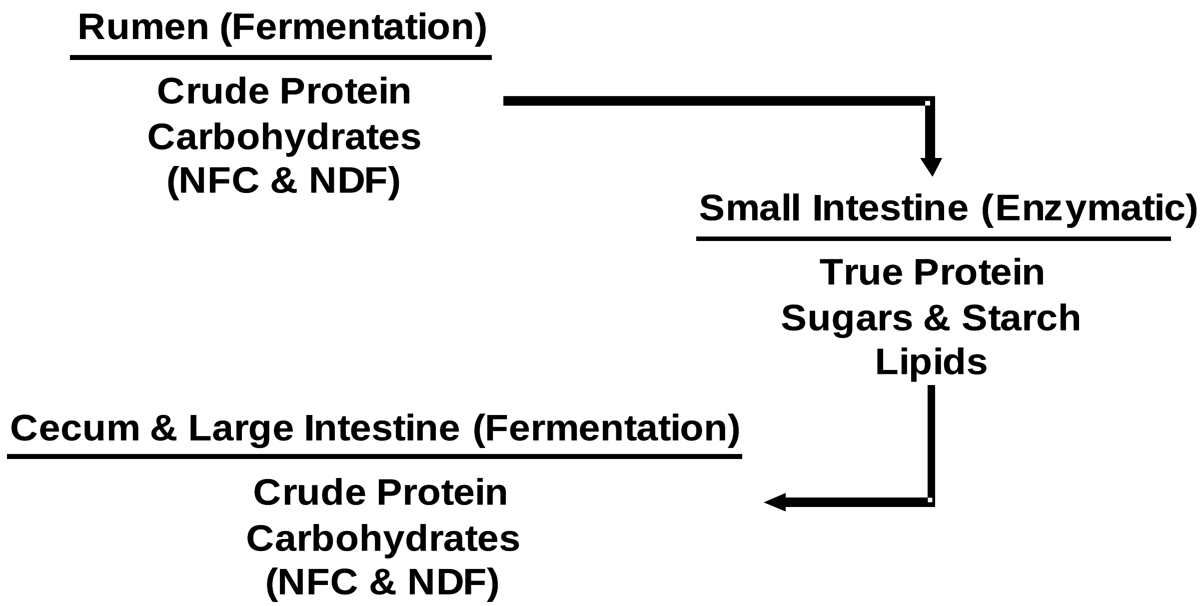

Figure 2. Sites of digestion and fermentation for different nutrients (NFC = nonfiber carbohydrates and NDF = neutral detergent fiber).

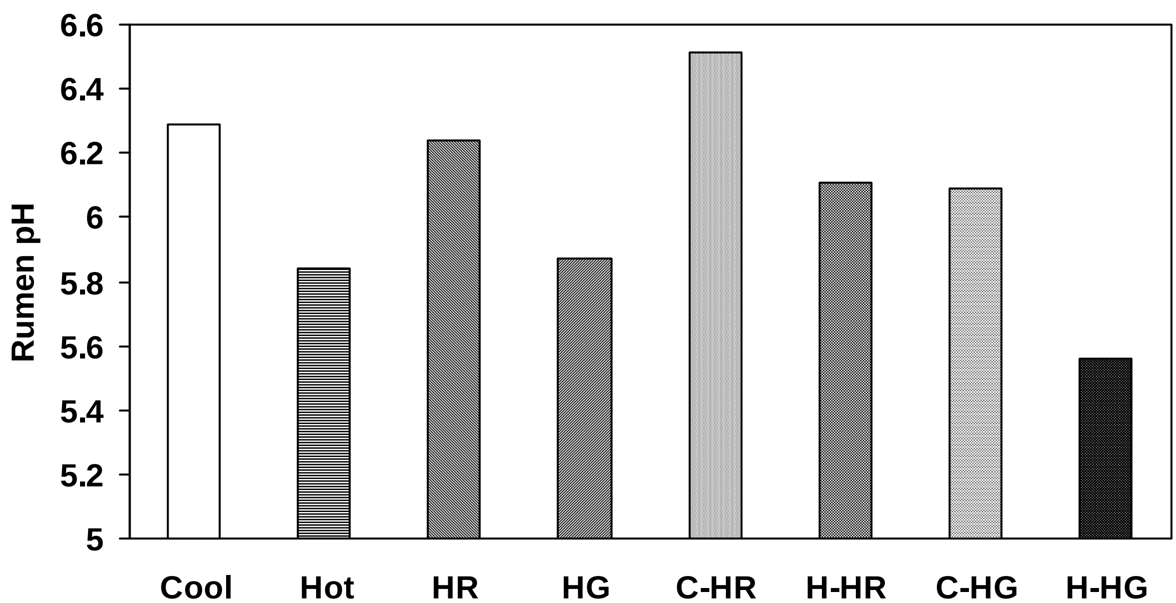

Figure 3. Ruminal pH changes with ambient temperature and diet (Mishra et al., 1970). Cool (C) = 65°F ambient temperature, hot (H) = 85°F ambient temperature, HR = high roughage diet, and HG = high grain diet.

Predicting Optimum Time of Alfalfa Harvest

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Abstract

Optimum timing of alfalfa harvest is critical to obtain high quality forages for lactating dairy cows. Three methods used to estimate neutral detergent fiber **(NDF)** of alfalfa were evaluated in a field research project conducted during 2000 on 35 farms in Michigan. The three methods evaluated are growing degree-days **(GDD)**, predictive equation for alfalfa quality **(PEAQ)**, and scissors cut. Predicted NDF based on the three prediction methods were compared to NDF of chopped alfalfa both before and after ensiling in laboratory silos. Based on results from this project and previous research, PEAQ and GDD methods adequately predict NDF of first cutting alfalfa; however, only the PEAQ stick should be used for second cutting. The GDD is not reliable when there is inadequate soil moisture, which often occurs during second cutting growth. Neither GDD nor PEAQ adequately predicted NDF for third cutting alfalfa. The scissors-cut method can be considered for predicting NDF for the third cutting.

Introduction

Alfalfa is an important forage for dairy cows because it provides fiber that effectively stimulates chewing, while also providing energy and protein for milk production. There is an optimum quality for alfalfa that should be fed to dairy cows. Quality can be too high or too low for maximum milk production.

The measure of fiber most commonly used to balance diets of lactating dairy cows is NDF. The optimum concentration of NDF for alfalfa is 40%. Alfalfa containing 40% NDF allows reasonable grain concentrations in the diet while maintaining adequate NDF concentrations. The protein concentration of alfalfa with 40% NDF is usually moderate (approximately 20% of DM) and additions of low protein grains like corn allow flexibility in diet formulation for ruminally-undegraded protein while avoiding excessive protein concentrations (Allen, 1997).

Delaying alfalfa harvest increases NDF percentage and reduces protein concentration. More grain will be required to increase energy density and decrease the NDF concentration (and filling effect) of the diet. In addition, more supplemental protein will be required to meet the cows' protein requirements, and DM intake and milk production will be reduced.

Methods of Predicting NDF

Several methods recently have been proposed to predict timing of first cutting alfalfa harvest based on NDF concentration:

- growing degree-days (GDD, base 41° F),
- predictive equation for alfalfa quality (PEAQ) based on plant height and stage of maturity, and
- scissors-cut samples.

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At the farm level, procedures need to be easy to use, require minimal time, and provide relatively accurate predictions of the NDF concentration of the alfalfa that is to be fed.

GDD

The GDD calculation for alfalfa is based on the minimum and maximum daily temperature beginning on March 1 and using a base of 41 °F. The daily calculation is:

$$[(\text{max. temp.} + \text{min. temp.})/2] - 41$$

The total GDD is the sum of the positive daily growing degree-day values across days beginning March 1.

Based on research at Michigan State University (Allen and Beck, 1996), alfalfa averages 40% NDF at about 750 GDD. An NDF concentration of 35% is approximately equivalent to 600 GDD. It takes a total of about 970 GDD to reach 45% NDF.

These GDD predictions of NDF concentration are for pure alfalfa stands. Grass matures earlier than alfalfa. Consequently, significant amounts of grass in alfalfa fields will result in higher NDF concentrations if the forage is harvested based on GDD estimates of NDF.

The GDD also is most effective in predicting harvest of first cutting alfalfa. Predicting NDF concentration using GDD cannot be done when there is inadequate soil moisture because GDD accumulates with little or no response in plant growth. Consequently, GDD has been used only for first cutting alfalfa harvest.

PEAQ

The PEAQ method (Hintz and Albrecht, 1991) is based on an equation that uses the length of the tallest alfalfa stem and the stage of the most mature alfalfa plant (will likely be two different plants) in the area sampled. The current modified PEAQ method uses a scale of three stages of maturity (late vegetative, bud, and flower). Measuring sticks, calibrated for the three plant maturity stages, are used to obtain estimates of NDF.

While obtaining PEAQ estimates of NDF, producers can scout their alfalfa fields for winter injury, disease development, insect damage, and weed encroachment (Sulc et al., 1999). Good sampling technique is critical to obtaining reliable NDF estimates. It is important to obtain NDF estimates from the PEAQ method at 5 or more locations across the field

As with GDD, the PEAQ method was developed for pure stands of alfalfa. The NDF estimates from PEAQ will not account for weeds or grasses in the stands. The PEAQ is not reliable for estimating NDF when alfalfa is very short (longest stem is less than 16 inches) or very tall (longest stem is more than 40 inches).

Scissors-cut Samples

Scissors-cut samples provide a direct measurement of NDF in the collected plant material. Sampling technique is critical. A representative sample must be obtained from across the field. Sample handling is also important in minimizing respiration losses prior to the sample arriving in the analytical lab. In addition, errors can occur with near infrared reflectance spectroscopy **(NIRS)** analysis of scissors-cut samples because equations for fresh alfalfa are not generally available (Sulc et al., 1999).

Description of Project

In the year 2000, we conducted a field research project in Michigan to compare different methods of predicting alfalfa NDF concentrations over first, second, and third cuttings. The methods compared included GDD (base 41° F), PEAQ, and scissors cut.

The project consisted of samples and data collected at alfalfa fields in 35 locations throughout Michigan, including five locations in the Upper Peninsula. Daily maximum and minimum temperatures were collected with electronic data loggers at each field. Temperatures were recorded every 10 minutes beginning on March 1 and continued through the duration of the project (approximately mid-August).

We compared the NDF predicted from these samples with the NDF analyses of chopped alfalfa both before and after ensiling in laboratory silos. Immediately prior to cutting the alfalfa field, the PEAQ stick was used to predict NDF and the scissors-cut sample was taken. The field-wilted alfalfa was sampled immediately prior to chopping. This sample was manually "chopped", and either dried within 24 hours or immediately ensiled in laboratory silos. The scissors-cut, chopped, and ensiled samples were analyzed for NDF concentration by wet chemistry procedures at the MSU Department of Animal Science.

Results

The NDF concentration of the ensiled alfalfa ranged from 35 to 46% for first and second cuttings. Third cutting NDF ranged from 35 to 52%.

The NDF concentration of ensiled alfalfa samples was predicted adequately by all three methods for the first and second cuttings. Although there was little difference between GDD and PEAQ for first and second cutting alfalfa, we do not recommend using GDD for predicting NDF concentration of second cutting alfalfa. There is often inadequate soil moisture for second cutting growth, and we believe the GDD method is not reliable in these conditions.

The scissors-cut method was the only method that adequately predicted NDF for third cutting. It should be noted that these samples were handled under controlled conditions. The cut samples were chilled immediately and delivered to the lab within 24 hours of collection.

The error associated with the methods was slightly lower for PEAQ compared to GDD and scissors cut for the first and second cuttings. When PEAQ was used to predict NDF, about 2/3 of the samples were predicted within +2.3 units of NDF for first cutting and within +2.8 units of NDF for second cutting. When GDD was used, about 2/3 of the samples were predicted within +2.6 units of NDF for first cutting and within +3.1 units for second cutting. The corresponding measurements of error for the prediction of NDF from scissors-cut samples were 2.4 units of NDF for first cutting and 3.0 units of NDF for second cutting.

There was good agreement between NDF concentration of the fresh chopped and ensiled samples. The regression equation is:

NDF%-ensiled = 10.8 + 0.72 * NDF%-fresh chopped , with an R^2 of 0.55, RMSE (root mean square error) of 2.2, and P <0.0001.

Please note, though, that these samples were handled under ideal conditions. It is likely that you would see greater differences in NDF between fresh chopped and ensiled samples with standard ensiling procedures on the farm.

What We Recommend

The following recommendations are based on the results of this project and previous research:

- ♦ Use the PEAQ stick or GDD to predict NDF for first cutting alfalfa. Only the PEAQ stick should be used for second cutting alfalfa. Neither PEAQ nor GDD are recommended for third cutting alfalfa.

- Begin cutting alfalfa at 40% NDF (750 GDD, base 41° F) for upright silos and 38% NDF (680 GDD, base 41° F) for horizontal silos. Start even earlier for horizontal silos if it takes more than a week to finish harvesting.

- The GDD and PEAQ methods cannot be used for fields containing grass.

- Fields containing grass should be harvested first. Start with the fields with the most grass and finish with the purest alfalfa fields.

- Consider using the scissors-cut method for fields containing grass and for third cutting alfalfa. Shipping samples to the analytical lab by next-day delivery will help to minimize deterioration in sample quality. Wet chemistry analysis is most appropriate for scissors-cut samples.

Acknowledgments

We would like to express our appreciation to the 19 MSU Extension Agents and MSU Research Associates who diligently collected data and alfalfa samples. We also acknowledge the efforts of Dave Main who conducted the laboratory analyses. Lastly, we thank the 35 dairy producers across Michigan that cooperated in this project by allowing us to collect alfalfa samples and temperature data from their fields.

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Bunker Silo Management: Four Important Practices

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The points of the silage triangle are represented by persons responsible for (1) the dairy cattle, (2) the forage, and (3) the harvesting process. In some dairy operations, one person is responsible for all three points. But in many instances, both growing the silage crop and harvesting and ensiling the crop are done completely on a contract basis, creating a situation where a different person is at each point of the triangle. When communication between the points of the triangle is ineffective, inefficiencies can result that directly affect the bottom line.

Although a dairy cattle operation's nutritionist – often an outside consultant – is not a direct part of the triangle, he or she has an obvious vested interest in how well the triangle performs. The nutritionist might be the key person in assuring effective communication between the triangle's three points.

The nutritionist's major responsibility is generally to the dairy cattle point of the triangle, so among his/her major responsibilities could be (1) educating the client about proper silage management, and (2) fostering communication. Ideally, the nutritionist should moderate an annual meeting between the dairy manager, the forage crop grower, and the custom harvester. This can ensure that all involved are on the "same page" regarding expectations and implementation of the entire silage program. In other cases, a small dairy producer might be on the wrong end of a tight supply/demand situation and therefore lack the economic power to make demands on the crop grower and/or custom harvester. Then, the nutritionist must focus directly on the dairy producer and make sure that the things directly under the producer's control are done correctly.

This paper focuses on four important silage management practices that are in the control of dairy producers and that are sometimes poorly implemented or overlooked entirely. These are (1) achieving a high silage density, (2) effective sealing, (3) properly managing the feedout face, and (4) discarding spoiled silage.

Achieve a Higher Silage Density

First, density and crop dry matter **(DM)** content determine the porosity of the silage, which affects the rate at which air can enter the silage mass at the feedout face. Second, the higher the density, the greater the capacity of the silo. Thus, higher densities typically reduce the annual storage cost per ton of crop by both increasing the amount of crop entering the silo and reducing crop losses during storage. Recommendations have usually been to spread the chopped forage in thin layers and pack continuously with heavy, single-wheeled tractors. But the factors that affect silage density in a bunker, trench, or drive-over pile silo are not completely understood. Ruppel et al. (1995) measured the DM losses in alfalfa silage in bunker silos and developed an equation to relate these losses to

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the density of the ensiled forage (Table 1). They found that tractor weight and packing time per ton were important factors; however, the variability in density that occured suggested there were other important factors that the researchers did not consider.

In a recent study, Muck and Holmes (1999) measured silage densities over a wide range of bunker silos in Wisconsin, and the densities were correlated with crop/forage characteristics and harvesting and filling practices. Samples were collected from 168 bunker silos and a questionnaire completed about how each bunker was filled. Four core samples were taken from each bunker feedout face and core depth, height of the core hole above the floor, and height of silage above the core hole were recorded. Density and particle size distribution were also measured.

The range of DM contents, densities, and average particle size observed in the hay crop and corn silages are shown in Table 2. As expected, the range in DM content was narrower for the corn silages compared to the hay crop silages. The average DM content of the corn silages was in the recommended range of 30 to 35%. But several of the haylages were too wet (less than 30% DM), which can lead to effluent loss and a clostridial fermentation, or too dry (more than 45% DM), which can lead to extensive heat damage, mold, and the risk of a fire. The average DM density for the hay crop and corn silages was similar and slightly higher than a commonly recommended minimum DM density of 14.0 lbs/ft^3. Some producers were achieving very high DM densities, while others were severely underpacking. One very practical issue was packing time relative to the chopped forage delivery rate to the bunker. Packing time per ton was highest (1 to 4 min/ton on a fresh basis) under low delivery rates (less than 30 tons/hour on a fresh basis). Packing times were consistently less than 1 min/ton (on a fresh basis) at delivery rates above 60 tons/hour.

There are several key factors that dairy producers can control to achieve higher densities, which will minimize DM and nutrient losses during ensiling, storage, and feedout.

Forage Delivery Rate

Reducing the delivery rate is somewhat difficult to accomplish, as very few dairy producers or silage contractors are inclined to slow the harvest rate so that additional packing can be accomplished.

Packing Tractor Weight

This can be increased by adding weight to the front of the tractor or 3-point hitch and filling the tires with water.

Number of Tractors

Adding a second or third packing tractor as delivery rate increases can help keep packing time in the optimum range of 1 to 3 minutes per ton of fresh forage.

Forage Layer Thickness

Chopped forage should be spread in thin layers (6 to 12 inches). In a properly-packed bunker silo, the tires of the packing tractor should pass over the entire surface before the next forage layer is distributed.

Filling the Silo to a Greater Depth

Greater silage depth increases density. But there are practical limits to the final forage depth in a bunker, trench, or drive-over pile. Safety of employees who operate packing tractors and who unload silage at the feedout face becomes a concern. Packing in bunkers that are filled beyond their capacity and the chance of an “avalanche” of silage from the feedout face pose serious risks.

Protect Silage from Air and Water

Until recently, most large bunker, trench, or drive-over pile silos were left unsealed. Why? Because producers viewed covering silos with plastic and tires to be awkward, cumbersome, and labor intensive. Many believed that the silage saved was not worth the time and effort required. But if left unprotected, DM losses in the top 1 to 3 feet can exceed 60 to 70% (Bolsen et al., 1993). This is particularly disturbing when one considers that in the typical "horizontal" silo, 15 to 25% of the silage might be within the top three feet. When the silo is opened, the spoilage is only apparent in the top 6 to 12 inches of silage, obscuring the fact that this area of spoiled silage represents substantially more silage as originally stored (Holthaus et al., 1995).

The most common sealing method is to place a polyethylene sheet (6 mil) over the ensiled forage and weight it down with discarded tires (approximately 20 to 25 tires per 100 ft^2 of surface area). Dairy producers who do not seal need to take a second look at the economics of this highly troublesome "technology" before they reject it as unnecessary and uneconomical. The loss from a 40 x 100-foot silo filled with corn silage can exceed $2,000. Loss from a 100 x 250-foot silo can exceed $10,000.

Manage the Feedout Face

The silage feedout "face" should be maintained as a smooth surface that is perpendicular to the floor and sides in bunker, trench, and drive-over pile silos. This will minimize the surface area exposed to air. The rate of feedout through the silage mass must be sufficient to prevent the exposed silage from heating and spoiling. An average removal rate 6 to 12 inches from the "face" per day is a common recommendation. However, during periods of warm, humid weather, a removal rate of 18 inches or more might be required to prevent aerobic spoilage, particularly for high-moisture **(HM)** ensiled grains and whole-plant corn, sorghum, and winter cereal silages. Hoffman and Ocker (1997) fed aerobically stable and unstable HM shelled corn to mid-lactation cows for three, 14-day periods. Milk yield of the cows fed the aerobically deteriorated HM corn declined by approximately 7 lb/day per cow during each period compared to cows fed fresh, aerobically stable HM corn.

Discard Spoiled Silage

Sealing a silage mass using a polyethylene sheet weighted with tires is not 100 % effective. Aerobic spoilage occurs to some degree in virtually all sealed silos, and discarding of surface spoilage is not always a common practice on the farm. But, results of a recent study at Kansas State University (Table 3) showed that feeding surface spoilage had a significant negative impact on the nutritive value of a whole-plant corn silage-based ration (Whitlock et al., 2000). The original top 3 ft of corn silage in a bunker silo was allowed to spoil, and it was fed to steers fitted with ruminal cannulas. The four experimental rations contained 90% silage and 10% supplement (on a DM basis), and the proportions of silage in the rations were: A) 100% normal, B) 75% normal:25% spoiled; C) 50% normal:50% spoiled, and D) 25% normal:75% spoiled.

The proportion of the original top 18-inch and bottom 18-inch spoilage layers in the composited surface-spoiled silage was 24 and 76%, respectively. The original top 18-inch layer was visually quite typical of an unsealed layer of silage that had undergone several months of exposure to air and rainfall. It had a foul odor, was black in color, and had a slimy, "mud-like" texture. Its extensive deterioration during storage was reflected in very high pH, ash, and fiber values. The original bottom 18-inch layer had an aroma and appearance usually associated with wet, high-acid corn silages, i.e., a bright yellow to orange color, a low pH, and a very strong acetic acid smell.

The addition of surface-spoiled silage had large negative associative effects on DM intake and organic matter **(OM)**, neutral detergent fiber **(NDF)**, and acid detergent fiber **(ADF)** digestibilities. The first 25% increment of spoilage had the greatest negative impact. When the rumen contents were evacuated, the spoiled silage had also partially or totally destroyed the integrity of the forage mat in the rumen. The results clearly showed that surface spoilage reduced the nutritive value of corn silage-based rations more than was expected.

For more information about these and other silage management practices visit the Kansas State University Silage Team's website at http://www.oznet.ksu.edu/pr_silage.

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Table 1. Dry matter loss as influenced by silage density[1].

Density (lb of DM/ft^3)	DM loss at 180 days (% of the DM ensiled)
10	20.2
14	16.8
16	15.1
18	13.4
22	10.0

[1]Data taken from Ruppel et al. (1995).

Table 2. Summary of core sample analysis from bunker silos[1].

Silage characteristic	Hay crop silage (87 silos)		Corn silage (81 silos)	
	Average	Range	Average	Range
Dry matter, %	42	24-67	34	25-46
Density on a fresh basis, lb/ft^3	37	13-61	43	23-60
Density on a DM basis, lb/ft^3	14.8	6.6-27.1	14.5	7.8-23.6
Particle size, inches	0.46	0.3-1.2	0.43	0.3-0.7

[1]Data taken from Muck and Holmes (1999).

Table 3. Effect of the level of spoiled silage on DM intake and nutrient digestibility[1].

	Ration[3]			
Item[2]	A (0)	B (5.4)	C (10.7)	D (16.0)
DM intake, lb/day	17.5^a	16.2^b	15.3^{bc}	14.7^c
	------------------------- Total Tract Digestibility, % -------------------------			
OM	75.6^a	70.6^b	69.0^b	67.8^b
CP	74.6^a	70.5^b	68.0^b	62.8^c
NDF	63.2^a	56.0^b	52.5^b	52.3^b
ADF	56.1^a	46.2^b	41.3^b	40.5^b

[1]Data taken from Whitlock et al. (2000).
[2] DM = dry matter, OM = organic matter, CP = crude protein, NDF = neutral detergent fiber, and ADF = acid detergent fiber.
[3]The percentage of the “slimy” layer silage in the ration (DM basis) is shown in parenthesis.
[abc]Means within a row with no common superscript differ ($P < 0.05$).