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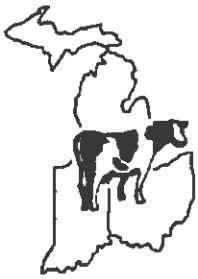

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The Conference Planning Committe extends appreciation to Mrs. Amanda Hargett for her assistance in organizing the Conference and acknowledges Mrs. Michelle Milligan for assistance with preparation of the *Proceedings*.

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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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Does Milking Frequency Affect Feeding Behavior?

Geoffrey E. Dahl[1]
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Abstract

Increased milking frequency is a common management practice to improve overall yield and production efficiency in dairy cattle, but it is typically imposed throughout lactation. Recent studies support the concept that cows milked at higher frequency in early lactation, for example 4 to 6 times daily, continue to produce more milk than contemporaries milked only 2 to 3 times daily, even after frequency is reduced. In addition to the production response, other positive effects may result from high frequency milking in early lactation cows. Limited data suggests that dry matter **(DM)** intake increases with milking frequency as cows attempt to match greater energetic demand in regard to milk output. The mechanism that drives the greater feed consumption is unknown, but its potential impact is considered. Regardless of the mechanism, higher milking frequency in early lactation increases milk yield and DM intake and thus serves as a method to improve overall animal performance.

Introduction

Although milk production is influenced by numerous physiological and management factors, total milk yield is a direct function of the frequency of milk removal. Stelwagen (2000) summarized the relationship of milking frequency to yield and reported that total milk output was increased ~20 % when the milk removal frequency increased to 3 times daily (3X) from the usual twice daily (2X) approach. Thus, milking cows more frequently is clearly an approach to improving overall efficiency of milk production.

Though a number of theories have been put forth to explain the increased milk yield noted with greater milking frequency (reviewed in Stelwagen, 2000), it is likely that any increase is associated with greater numbers of mammary epithelial cells, greater metabolic activity of those cells, or a combination of both processes. Comparing those two processes, it is reasonable to consider the expected persistency of metabolic versus cell number mediated responses. Any factor that directly impacts mammary cell metabolism would be expected to exert its action and result in greater milk yield only when that factor was administered to the cow. In contrast, an increase in the number of mammary epithelial cells would be expected to produce responses that would persist because mammary epithelial cell numbers are generally thought to diminish at a constant rate following the peak of lactation (Capuco et al., 2003; Tucker, 1981).

As it is commonly implemented in the field, cows are milked 3X throughout lactation. This precludes the ability to distinguish between the two theories described above, i.e. cell number versus metabolism, because the stimulus is present throughout lactation. But recent studies (Bar-Peled et al., 1995; Dahl et al., 2004a; Hale

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et al., 2003) support the concept that at least a portion of the response to increased milking frequency has a persistent impact, especially during a window of time in early lactation. In addition, there is evidence that high frequency milk removal in early lactation has other beneficial actions, including promotion of DM intake and udder health (Dahl et al., 2004a).

Because depressed DM intake has been implicated with numerous periparturient dysfunctions, it follows that every attempt should be made to stimulate DM intake as soon as possible after calving (Hayirli et al., 2003). Yet, studies comparing DM intake of 2X with 3X cows indicate that there is no overall increase in DM intake as milking frequency increases (discussed below). However, limited evidence from early lactation milking frequency studies indicates that DM intake improves during the immediate postpartum period when milking frequency is increased. It is best to begin with a brief review of the impact of milking frequency on milk production, and then consider the effects on DM intake.

Milking Frequency and Yield

Traditional implementation of higher milking frequency (i.e., 3X vs. 2X) is made throughout lactation. Relative to 2X, continuous 3X milking throughout lactation increases yields by 7.7 lb/day and parity does not affect the response (Erdman and Varner, 1995). The effect of 3X on components is characterized by reductions in fat and protein percentages, yet overall yield of fat and protein improves compared with 2X. Similar incremental patterns of response are reported for 4X, but data sets are limited for the comparison of 2X to 4X. Collectively, the studies suggest that total milk and component yields increase as frequency of removal increases.

Higher milking frequency in fresh cows causes immediate increases in milk and component yield, but greater milk yield persists after cows return to a lower frequency of milk removal. For example, Bar-Peled et al. (1995) reported that cows milked 6X for the first 6 weeks of lactation produced more milk than control cows milked 3X over the same period. After 6 weeks, the 6X cows were milked 3X, yet they continued to produce more milk than those milked 3X from parturition. Under field conditions, we found similar effects of early lactation milking frequency but also noted that 21 rather than 42 days was sufficient time to produce the persistency effect on milk yield (Table 1 and Dahl et al., 2004a).

In the first study designed to compare milk yields of cows milked 4X for the first 21 days of lactation to the typical 2X approach, Hale et al. (2003) reported that 4X caused significant increases in yield relative to 2X, and the greater yields persisted until week 36 of lactation when milk yields of the groups converged. Similar responses were noted in Jersey cows milked 4X or 2X for the initial 3 weeks of lactation (Dahl et al., 2002). Cows milked 4X had higher yields of milk (Figure 1) for the first 21 days in milk, and this persisted through 100 days in milk (Dahl et al. , 2002; though only results through day 42 are presented in Figure 1).

Milking Frequency and Dry Matter Intake

A number of studies have examined the effect of higher milking frequency throughout lactation on DM intake. Despite greater milk yields in 3X versus 2X cows, DM intake was not affected in any of the studies that reported data on DM intake (Amos et al., 1985; Andersen et al., 2002; Barnes et al., 1990; DePeters et al., 1985). Indeed, Pearson et al. (1979) reported that 2X cows consumed more DM relative to 3X cows. The consistency of the lack of effect of milking

frequency across studies suggests that cows accommodate the greater energetic requirement of milk yield increases by mobilizing body reserves. Consistent with that hypothesis is the observation in many studies that 3X cows did not gain body weight to the extent that 2X cows gained during lactation. Further, 3X cows had lower milk fat percentage compared with 2X cows in the studies cited above.

In contrast to 3X milking effects on DM intake, it appears that frequent milking in early lactation produces a significant, though perhaps transient, increase in DM intake. Bar-Peled et al. (1995) observed that cows milked 6X for the initial 6 weeks of lactation consumed 5.7 lb/day more DM than those milked 3X during that period, and the 6X cows ate 5.1 lb/day more DM than the 3X cows from week 7 to 18 of lactation. Also, the 6X cows took longer to recover postpartum for body weight and body condition compared with those milked 3X and had lower milk fat percentages. Bar-Peled et al. (1998) later reported that 6X cows had greater DM digestibility compared with 3X cows, but that observation was made in only week 5 of lactation when the cows were still being milked 6X. Therefore, whether or not the improved diet digestibility persisted as lactation advanced remains unknown.

Relative to cows milked 2X, 4X milking frequency increased DM intake by Jersey cows during the initial 3 weeks of lactation (Dahl et al., 2002; Figure 2). Of interest, DM intake of both groups converged to a peak by 6 weeks in milk, suggesting that other factors, perhaps physical or other limitations, were causing a plateau of DM intake. There was no effect of milking frequency on non-esterified fatty acids **(NEFA)** concentrations during the initial 21 days in milk (2X = 414 $\pm$ 69 vs. 4X = 386 $\pm$ 64 ueq/L), though some variation in milk fatty acid profiles suggest that 4X cows may have been mobilizing greater tissue reserves relative to 2X cows. Overall, the responses of 4X cows support the concept of an earlier postpartum increase in DM intake when compared with 2X cows, which should be a benefit to cows as they transition into lactation.

Implementing Early Lactation Frequent Milking

Realizing the benefits of early lactation frequent milking requires more than just milking fresh cows more often. Consideration must be made for the time cows spend away from feed, water, and stalls, and when they are being milked or moving to milking. The milkings need not be equally spaced throughout the day, as a minimum of 2 hours between milkings has been shown to produce the persistency effect (Dahl et al., 2004a; Hale et al., 2003). Many producers implement a system whereby fresh cows are milked first, followed by the remaining cows in the herd, and then fresh cows are milked again before the milking system is cleaned. Ideally, cows should return rapidly to pens where feed, water, and stalls are available after each milking, rather than remaining in a holding pen between milkings.

With regard to other management issues, reports thus far give no indication that reproductive competence suffers with greater milking frequency, and therefore, milk yield in early lactation. No dietary adjustment has been made in any of the studies cited above to accommodate the higher milk yields, though cows must be provided feed ad libitum. We have shown that cows milked 6X in early lactation respond to bovine somatotropin **(bST)** when it is provided according to label directions (Dahl et al., 2004b), further supporting the concept that properly managed cows can adapt to and respond to multiple stimulators of milk yield.

Conclusions

In summary, increased milking frequency in early lactation causes persistent increases in milk yield. Greater milking frequency per se does not stimulate increases in DM intake, although high frequency milking in early lactation does appear to stimulate intake from the onset of lactation. This improvement in DM intake is expected to ameliorate many of the metabolic and digestive diseases observed in the peripartum period, and therefore, positively impact transition cow health. Increased milking frequency is easily integrated into dairy production systems that have high level management and can be combined with other stimulators of yield.

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Table 1. Comparisons of various production traits of cows milked 3 (3X) or 6 times each day (6X) for the initial 21 days of lactation. (Dahl et al., 2004).[1]

Trait	3X	6X	P
Summit milk, kg	103.0 ± 4.2	121.5 ± 4.0	0.017
Peak milk, kg	112.7 ± 4.0	125.7 ± 4.0	0.071
DIM at peak	101.0 ± 12	56.4 ± 11	0.020
Actual milk, 305 days, kg	27,022 ± 803	29,487 ± 1,019	0.078
ME milk, 305 days, kg	29,183 ± 959	33,064 ± 1,021	0.015
Actual corrected milk, 305 days, lb	27,580 ± 820	29,719 ± 961	0.051

[1]DIM = Days in milk and ME = mature equivalent.

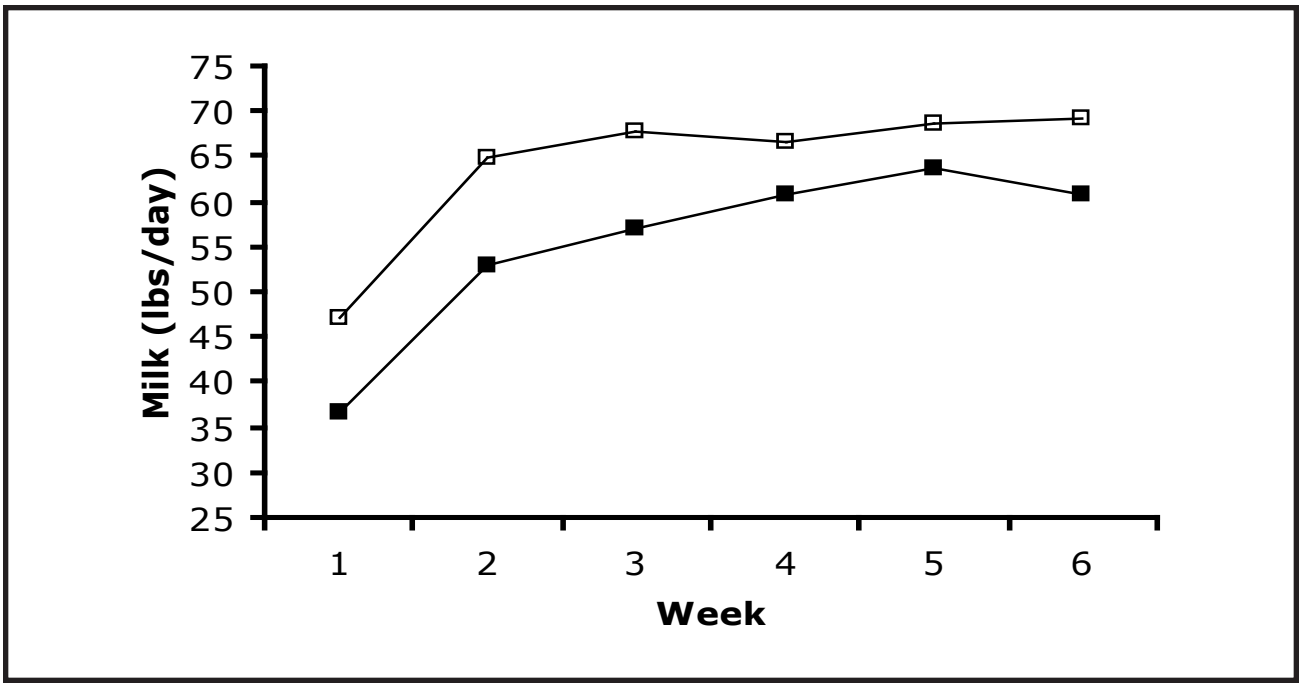

Figure 1. Milk yield of cows milked 2 (2X; solid boxes) or 4 (4X; open boxes) times daily for the initial 21 days of lactation (Dahl et al., 2002). Each symbol represents the average daily yield in pounds for that group (n = 8/group) by week of lactation. Pooled standard error = 3.1 lb/day. After 3 weeks in milk, all cows were milked 2X. The 4X cows had greater milk yields throughout the

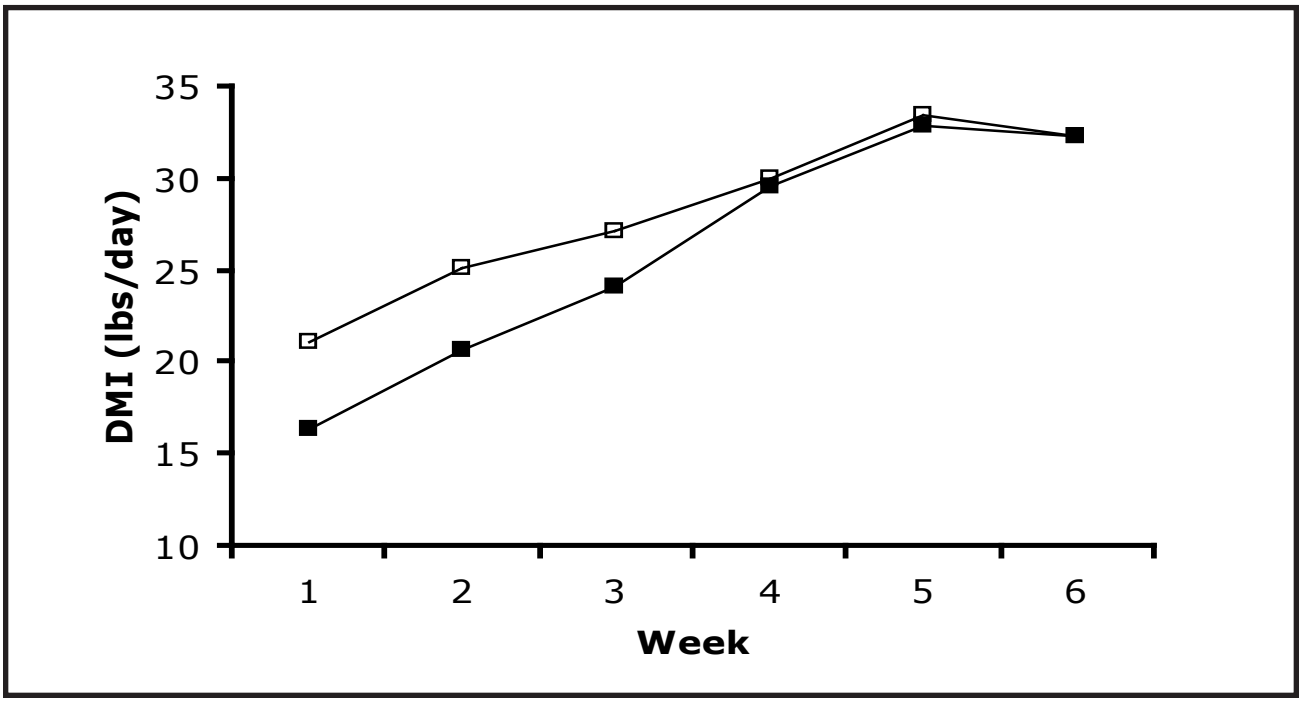

Figure 2. Dry matter intake (DMI) of cows milked 2 (2X; solid boxes) or 4 (4X; open boxes) times daily for the initial 21 days of lactation (Dahl et al., 2002). Each symbol represents the average daily DMI in pounds for that group (n = 8/group) by week of lactation. Pooled standard error = 3.1 lb/day. After 3 weeks in milk, all cows were milked 2X. The 4X cows had greater DMI for the first 3 weeks the study ($P < 0.05$).

Dry Period: Length and Feeding Management

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Abstract

There is sufficient evidence to question if the most appropriate dry period length for a modern Holstein dairy cow is 60 days. Recent studies suggest that a 30-day dry period may not significantly alter health, reproduction, and production the next lactation. Future studies, particularly ones conducted on commercial dairy farms, are needed to provide additional verification that this is a reasonable approach. There is inherent variation in gestation length, and cows with abnormally short gestations (e.g. twins) may be compromised when implementing a short dry period that is based on a fixed gestation length. Cows that have incorrect breeding/calving dates may also be negatively affected when implementing a short dry period. However, shortening the dry period should seriously be considered for herds that 1) have a low incidence of twinning, 2) practice timed artificial insemination **(AI)** (e.g. ovsynch), and 3) have records (e.g. Dairy Comp 305) that can document a history of achieving the targeted number of days in a close-up group with low variability among cows. Thirty to 40-day dry periods seem reasonable for herds that fit those criteria and have the capability of monitoring results of a shortened dry period.

Introduction

The transition period has been defined as three weeks before calving until three weeks following calving. Many people have argued that this is the most important period in a cow's life. How many times have you heard: "get her through this period and she is set". Many of the recommendations that have been the cornerstones for dry/transition cow programs have been in place for years. Yet, we continue to have problems with metabolic disorders during the early postpartum period. Perhaps, it is time to challenge some of the "time honored" traditions of dry cow management. For example, the recommendation for a 60-day dry period consisting of a far-off dry period followed by a three-week transition period to "steam cows up" can be traced back to before all of us were born. Is this really the best approach? The objective of this paper is to examine if the dry period can be shortened, and if so, are there are alternative approaches to dry cow management that can be employed.

Potential Benefits from Shortening the Dry Period

The most obvious potential benefit from shortening the dry period is increased income from milk. This will occur if the extra income from milk obtained by extending the lactation is greater than lost income if less milk is produced in subsequent lactations. There may be numerous management-related benefits as well. For example, if the dry period can be

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reduced sufficiently, the need for a "far-off" dry cow group may be eliminated. This can alleviate over-crowding of dry cow facilities that is common on farms that have recently expanded milking cow facilities without a commensurate increase in dry cow facilities. On many farms, it would eliminate the need to transfer far-off cows to a second farm and the cow stress and inconvenience associated with such moves. The traditional dry cow program involves two dietary changes within a three week period. One change occurs when the cow is moved to a "close-up" pen and another occurs when the cow begins lactation. If the dry period could be shortened sufficiently, it may be possible to feed a more uniform diet throughout the lactation-gestation cycle. Fewer diet changes should result in fewer off-feed problems during the transition period.

Historical Basis for a 60-Day Dry Period

The typical recommendation is for a 6 to 8 week dry period. There is abundant evidence in the literature that supports this recommendation. However, the applicability of these results can be questioned. Almost all of these investigations used data from farm records (e.g. DHI data). With this type of study, what do cows with short dry periods represent? The outliers are cows with twins, cows that calved unusually early, cows in which the breeding dates were incorrect, etc. Although these studies had the advantage of large animal numbers, they did not utilize animals that were intentionally managed for a shortened dry period. Additionally, the vast majority of these studies were conducted 20 or more years ago when level of milk yield was different than today. Studies utilizing farm records also showed that cows with extended dry periods produce less milk the next lactation. However, cows with dry periods greater than 60 days probably represent low producing cows that were dried-off early. Some studies tried to statistically adjust for confounding factors, but in reality, it is very difficult to eliminate these biases.

Mammary involution requires 2 to 3 weeks, while a similar period of time is required for re-initiation of milk synthesis prior to calving (Oliver and Sordillo, 1989). Mammary physiologists often speak of the requirement for a steady state involution, or "rest" phase, in between active involution and redevelopment of secretory tissue. The absence of a rest phase supposedly accounts for less than optimum milk production the following lactation when dry periods are less than 6 weeks. However, a biological explanation for the "requirement" for a rest phase has never been established. We speculate there may not be a requirement for a rest phase. Rather, the requirement for a rest phase probably came about because researchers were trying to "fit" biology to DHI data sets that indicated milk production during the subsequent lactation increases as dry period length approaches 60 days.

Basis for Reconsidering the 60 Day Dry Period

There have been several studies that were specifically designed to examine the effects of reducing the dry period to approximately 30 days on milk production. Results are summarized in Figures 1 and 2. Measurements reflect performance following the treatment period and do not include any data (e.g. additional milk) from the period prior to calving. Measurements made on cows with a shortened dry period are expressed as a percentage of the control cows that experienced a dry period of traditional length. The length of time cows were followed after calving varied among studies and ranged from 70 to 305 days. Of the six studies summarized in Figure 1, two indicated a significant drop in milk yield. The study by Sorenen and Enevoldsen (1991), which indicated a significant drop in

milk and fat-corrected milk **(FCM)** yields, was conducted on eight commercial dairy farms in Denmark and included Danish Black and White, Red Danish, and Jersey cattle. There was a significant drop in milk yield, but not FCM yield, in the study of Rastani et al. (2003). Several studies reported a numerical drop in milk yield that was not statistically significant. This likely reflects inadequate replication (cow numbers) to detect a significant difference. By pooling data from all six studies, it seems reasonable to conclude that one might expect a 5% drop in milk yield the following lactation if the dry period is shortened from 50 to 60 days to approximately 30 days.

Not all studies have reported milk composition (Figure 2). Of the three that reported milk protein percentage, all indicated an increase and it was statistically significant in two of the three studies (Gulay et al., 2003; Rastani et al., 2003). In contrast, milk fat percentage responses were more inconsistent; only one study reported a significant increase (Rastani et al., 2003).

University of Wisconsin Study

Our laboratory was interested in feeding a single diet the entire gestation-lactation cycle to eliminate dietary changes and the stress of dietary changes around parturition. Our hypothesis was that this would help foster continuous high feed intake throughout the transition period and reduce metabolic disorders. The only way we thought that we could accomplish this goal was to shorten the dry period to lessen the likelihood of over-conditioning cows. We designed an experiment with three treatments (Rastani et al., 2003). Multiparous cows were fed the same "prepartum" lactation diet (Table 1) from -90 to -57 days prior to expected calving (here on referred to as days prepartum). Cows were assigned to treatments at -56 days prepartum. The three treatments were: 1) 56 days dry; cows fed a far-off diet from -56 to -29 days prepartum and a close up diet from -28 days to parturition, 2) 28 days dry; cows fed high energy lactation diet throughout the dry period, and 3) 0 days dry; cows fed prepartum high energy diet until calving. After calving, all animals were fed a postpartum high energy ration. The only difference between the pre- and postpartum high-energy diets was the addition of buffer after parturition.

Actual days dry for the 56, 28 and 0 day treatments were 54, 29 and 5. Some cows on the 0 day treatment spontaneously dried up. Continuation of milking resulted in higher dry matter **(DM)** intakes prior to calving (Figure 3). However, even cows on the 0 day treatment experienced a decline in feed intake as calving approached. Differences in feed intake between treatments continued but to a lesser magnitude after calving. There was no significant difference in 4% FCM production between 56 and 28 day treatments (Figure 4); cows on 0 day produced about 11 lb/day (5 kg/day) less FCM than those on 28 days. Cows on the 28 day treatment produced milk with a higher fat percentage. Consequently, there were differences in milk yield between cows on the 56 and 28 day treatments (data not shown).

Body condition score (Figure 5) and body weight losses postpartum increased as days dry increased. This reflected a more favorable energy balance as days dry decreased. As one might expect, shortening the dry period resulted in a reduction in plasma nonesterified fatty acids (NEFA, Figure 6), beta-hydroxybutyrate (BHBA, Figure 7), and liver triglyceride (TG, Figure 8). However, the differences were only significant between cows on the 0 and 28 day treatments (liver TG and plasma NEFA only).

Ovarian dynamics were monitored by ultrasound three times per week. Clearly,

reducing the dry period resulted in a more rapid resumption of ovarian activity (Table 2). Although this trial ended at 70 days postpartum, reproductive performance of cows was monitored beyond 70 days. Cows that were on the 0 day dry treatment had fewer days to first AI, higher first service conception rate, fewer services per conception, and fewer days open. However, because these cows were not on experiment beyond 70 days, these results must be interpreted with caution. It is not known whether these differences in reproductive performance were a consequence of differences in days dry, energy balance, or milk yield.

There were no differences in calf size due to treatment (93.9, 94.4, and 94.8 lb for 56, 28 and 0 day treatments). Incidences of metabolic disorders are shown in Table 3. Insufficient animal numbers dictated that we refrain from a statistical analysis of these data.

Commonly Asked Questions

How short can we go? The answer to this question ultimately depends on economics, which can become very complex when housing and management issues are considered. Our study indicated that a 30 day dry period was economically feasible when considering milk yield and composition. We are recommending a 40 day dry period to accommodate cows that have shorter than normal gestation lengths (e.g. cows with twins) and dry cow mammary treatments (see next question). Data indicate a 20 to 25% drop in milk the following lactation if cows are not provided a dry period. Researchers from Arizona (Annen et al., 2003) have indicated that this decrease may be avoided if cows are continuously treated with bovine somatotropin (**bST**; Monsanto, St. Louis, MO); however, that represents off-label use of bST.

Will there be antibiotic residues in milk of cows dry treated and then allowed a 30 day dry period? There may be. Field reports indicate that positive tests for antibiotic residues may occur for 6 to 10 days following calving when cows are provided a 30 day dry period. Unfortunately, we have no information on what can be expected with the various treatments, so caution must prevail and producers should send milk samples from individual cows to the milk plant for testing when first implementing a short dry period.

Does shortening the dry period increase the likelihood of mastitis? More data are needed, but the available data suggest that there is no negative effect on somatic cell counts. There is some evidence to suggest that shortening the dry period reduces the number of new infections during the dry period.

What should I feed during a shortened dry period? Research is lacking to answer this question. Our data indicate that there are no negative effects when continuing to feed a high energy diet throughout a shortened dry period. If a lactation-type diet is fed during a shortened dry period, remove sodium bicarbonate so that the diet is not highly cationic and likely to cause milk fever. Also consider lowering protein because cows do not need 17 to18% crude protein during this time. Typical transition diets, particularly those that are a bit aggressive in energy content (0.72 to 0.74 Mcal/lb NE_L), are probably a good starting point if cows are not overconditioned.

If cows are fed a high energy diet or an aggressive transition diet during the shortened dry period, how should they be dried off? Keep in mind that cows will be further advanced in lactation, therefore, their milk yield will be lower than if they were dried off at 60 days prior to calving. "Persistency" often declines quite dramatically for some cows that are allowed an extended lactation. If cows are high producing,

feed and water restriction for a couple of days may be used as a tool to assist dry off.

Is it detrimental to feed anionic salts to dry cows for 30 or 40 days? Researchers at the USDA Animal Disease Center in Ames Iowa (personal communication) have indicated that an extended period of calcium mobilization from bone due to feeding anionic salts should not adversely affect bone health. The primary drawback is the cost of feeding salts for a longer period of time.

Will cows "burn out" if I shorten the dry period to 30 days? There are no research data for cows given a 30 day dry period for two consecutive gestation/lactation cycles. Nevertheless, it is unlikely that they would "burn out". Our data reveal that cows are most likely to be in positive energy balance during the extended lactation period.

Will extending the lactation cause a diversion of nutrients away from the fetus? No. Again, cows should be in positive energy balance and our data suggest that there is no difference in calf weights when the dry period is shortened to 28 or 0 days.

Is there a problem with colostrum quality? Only if cows are not allowed a dry period. Cows that are continuously milked produce more colostrum (defined as milk at first milking) but with lower immunoglobulin concentrations.

Are some cows better candidates for a short dry period? There are some data to suggest that cows in their second pregnancy may be less likely to successfully negotiate a shortened dry period. Cows with a longer calving interval may be more likely to tolerate a shortened dry period.

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Bachman, K.C. 2002. Milk production of dairy cows treated with estrogen at the onset of a short dry period. J. Dairy Sci. 85:797-804.

Gulay, M.S., M.J. Hayen, K.C. Bachman, T. Belloso, M. Liboni, and H.H. Head. 2003. Milk production and feed intake of Holstein cows given short (30-day) or normal (60-day) dry periods. J. Dairy Sci. 86:2030-2038.

Table 1. Diets fed to cows managed for 56, 28, or 0 day dry periods (Rastani et al., 2003).

Ingredient[1]	Postpartum High Energy Ration	Prepartum	56 to 28 days High Energy Ration	28 to 0 days Far-Off Ration
Close-Up Ration				
		--- % of DM ---		
Corn silage	29.9	29.9	55.6	43.7
Alfalfa silage	14.9	15.0	16.0	16.3
Corn grain, ground	33.55	33.65	10.0	22.95
Corn gluten meal	4.2	4.25	2.0	3.0
Roasted soybeans	13.2	13.2	0.0	4.1
Tallow	0.75	0.75	0.0	0.25
Megalac-R®	0.75	0.75	0.0	0.25
Straw	0.0	0.0	15.0	7.5
Sodium bicarbonate	0.6	0.0	0.0	0.0
Other: min/vit/yeast	2.15	2.5	1.4	1.95
NE_L (Mcal/ lb)	0.79	0.79	0.68	0.77
CP (%)	16.8	16.8	10.6	13.1
NDF (%)	23.2	23.2	39.2	31.4
EE (%)	5.8	5.8	2.3	3.5
Ca (%)[2]	0.6	0.6	0.4	0.4
P (%)[2]	0.4	0.4	0.3	0.3

[1]Megalac-R®, Church and Dwight Co., Inc., Princeton, NJ; NE_L = net energy for lactation, CP = crude protein, NDF = neutral detergent fiber, EE = ether extract, and DCAD = dietary cation-anion difference.

Table 2. Ovarian dynamics and reproductive performance of cows fed and managed for 56, 28, and 0 day dry periods (Rastani et al., 2003).

	56 days	28 days	0 days
Follicle size at first ultrasound, mm	6.3[b]	8.2[ab]	9.5[a]
Days to first 10 mm follicle	10.5[c]	8.9[d]	8.0[d]
Days to first ovulatory follicle	29[b]	22[ab]	14[a]
Days to first AI	75[b]	68[a]	69[a]
First service conception rate, %	20[b]	30[ab]	55[a]
Services per conception	3.1[b]	2.5[ab]	1.7[a]
Days open	145[b]	124[ab]	94[a]

[ab]Means in the same row with different superscripts differ ($P < 0.06$).
[cd]Means in the same row with different superscripts differ ($P < 0.05$).

Table 3. Number of cows treated for various postpartum disorders (Rastani et al., 2003).

	56 days	28 days	0 days
Displaced abomasum	1	1	2
Hypercalcemia	1	3	1
Ketosis	1	1	0
Mastitis	2	6	3
Metritis	2	0	0
Retained placenta	3	1	2

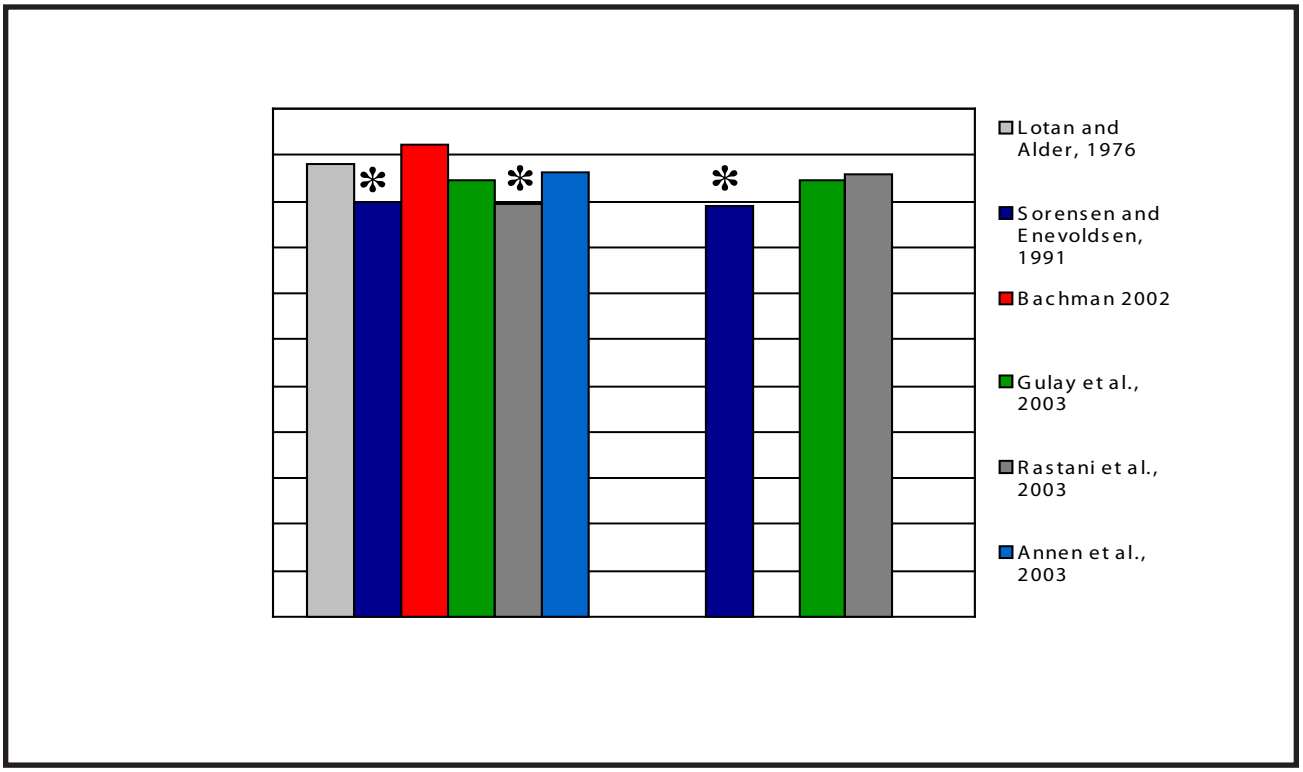

Figure 1. Milk and fat-corrected milk **(FCM)** yield responses by cows that had the dry period shortened to approximately 30 days. Values are expressed as a percentage of control cows that had dry periods of approximately 50 to 60 days. Responses are for periods following calving that ranged from 70 to 305 days depending on the study. *Represents a significant difference from control.

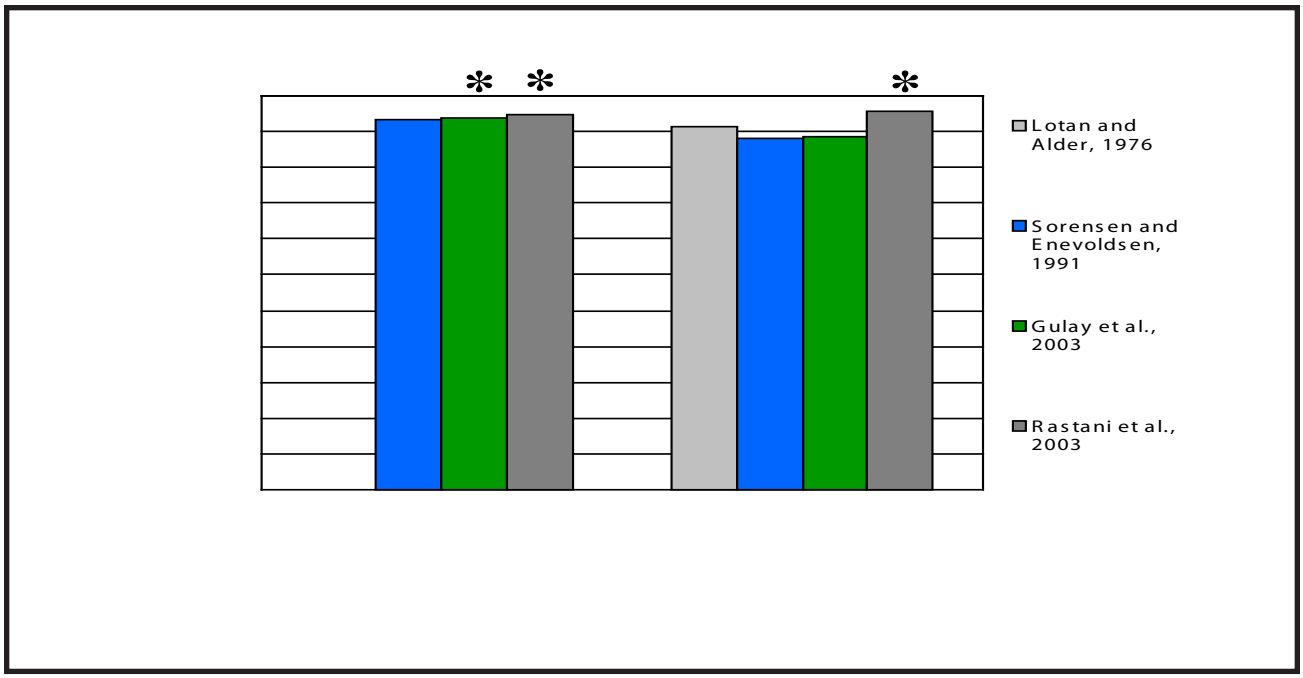

Figure 2. Milk fat and protein percentage responses by cows that had the dry period shortened to approximately 30 days. Values are expressed as a percentage of control cows that had dry periods of approximately 50 to 60 days. Data are for the period following calving that ranged from 70 to 305 days depending on the study. *Represents a significant difference from control.

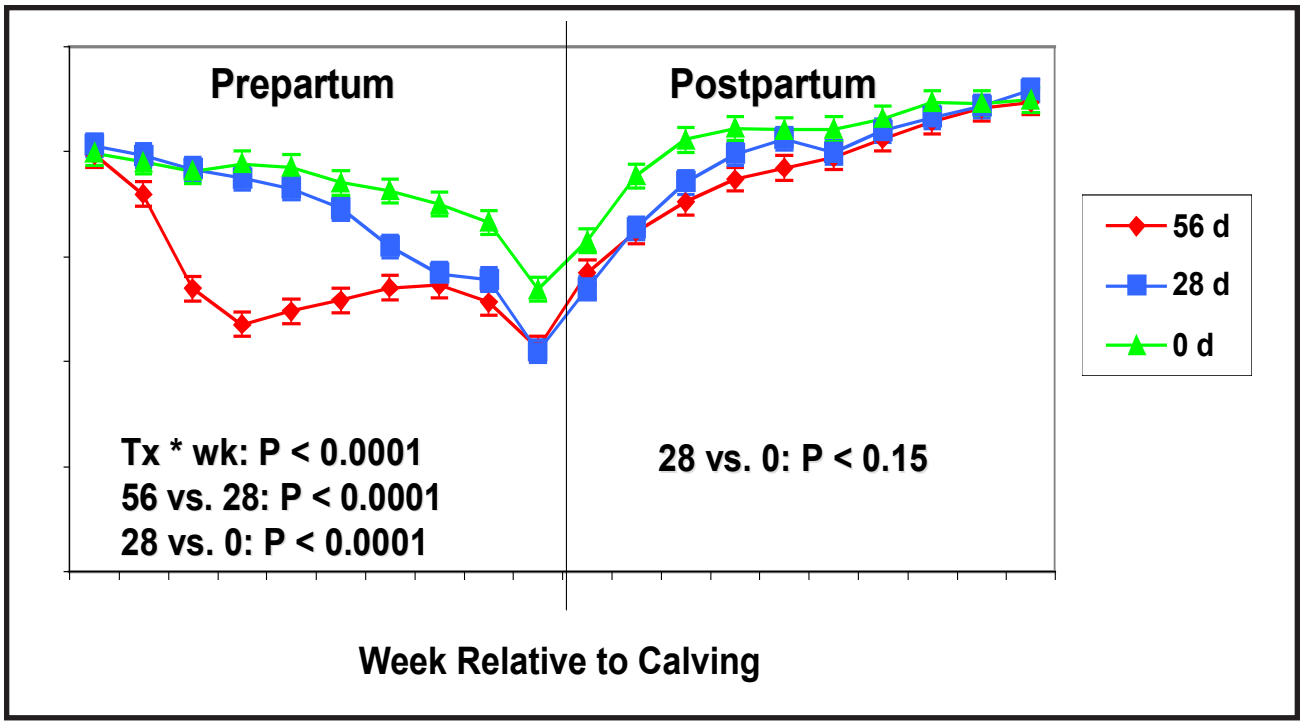

Figure 3. Dry matter intake (kg/day) of cows fed and managed for 56, 28, or 0 day dry periods (Rastani et al., 2003). Tx = treatment effect. Tx*wk = treatment by week interaction. If Tx was significant, then contrasts were 56 versus 28 and 28 versus 0 days dry.

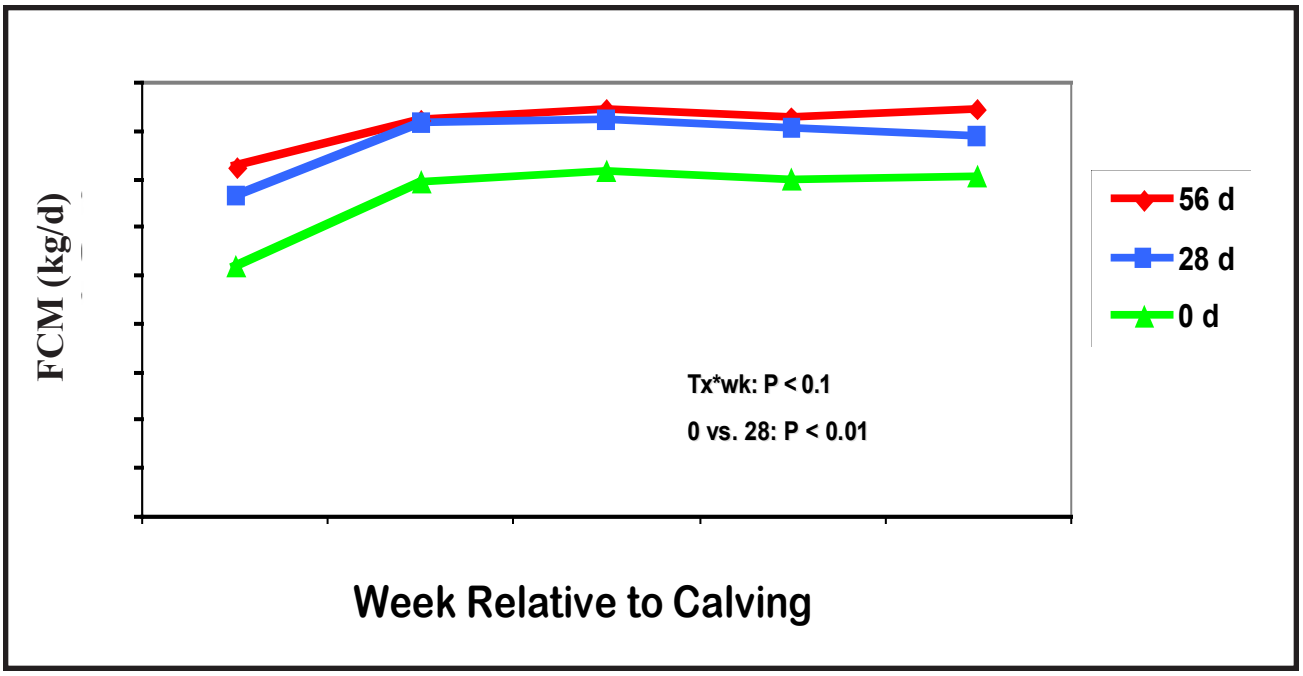

Figure 4. 4% fat-corrected milk **(FCM)** production by cows fed and managed for 56, 28, or 0 day dry periods (Rastani et al., 2003). Tx*wk = treatment by week interaction. If Tx was significant, then contrasts were 56 versus 28 and 28 versus 0 days dry.

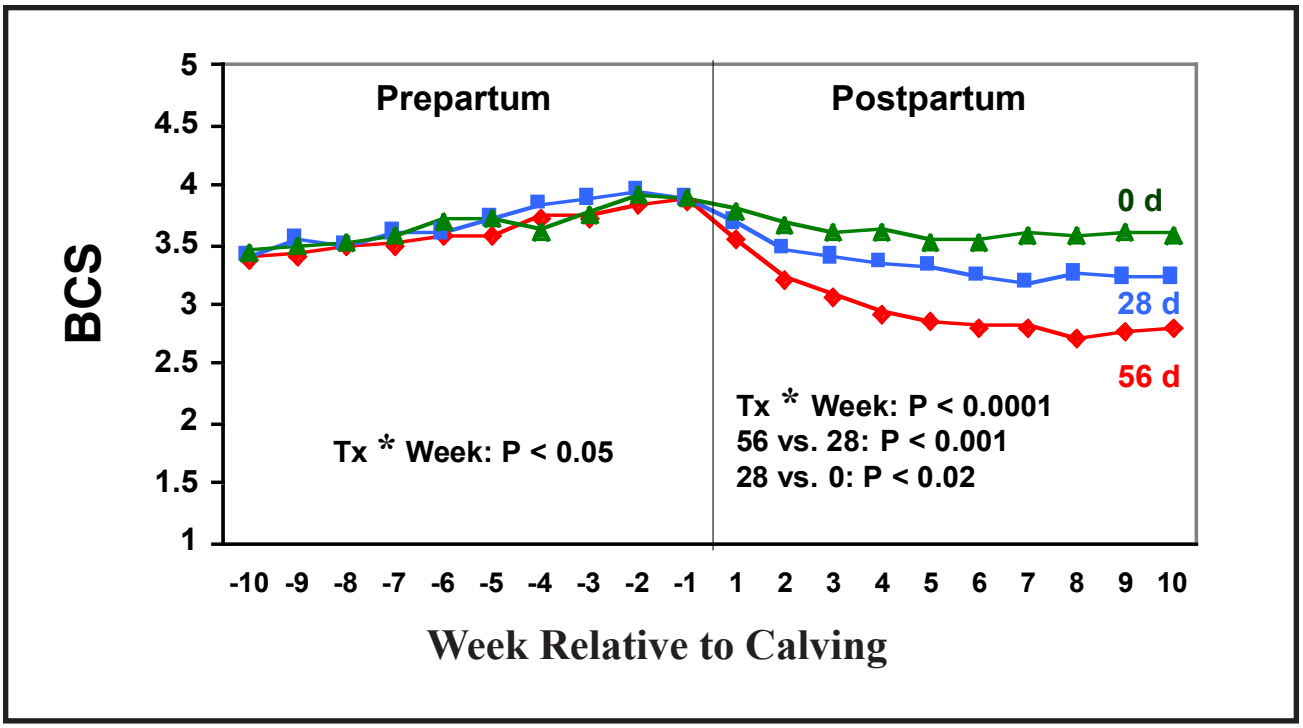

Figure 5. Body condition scores **(BCS)** of cows fed and managed for 56, 28, or 0 day dry periods (Rastani et al., 2003). Tx*wk = treatment by week interaction. If Tx was significant, then contrasts were 56 versus 28 and 28 versus 0 days dry.

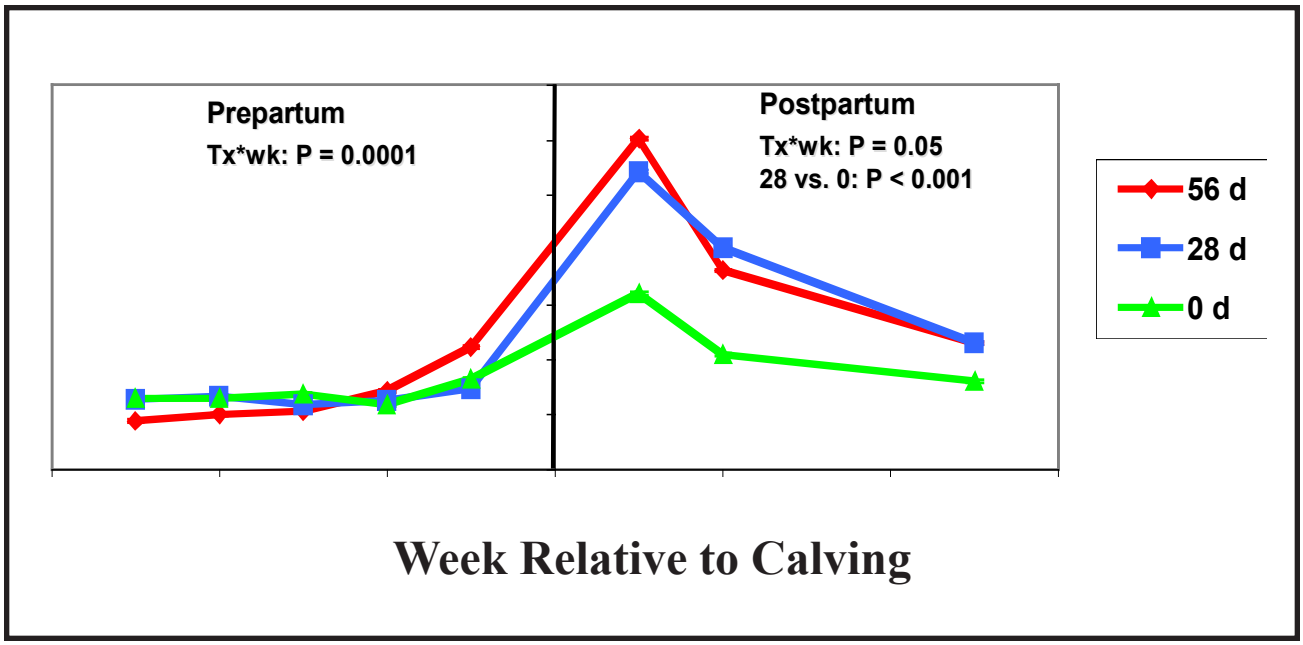

Figure 6. Plasma nonesterified fatty acid **(NEFA)** concentrations (µEg/L) in cows fed and managed for 56, 28, or 0 day dry periods (Rastani et al., 2003). Tx*wk = treatment by week interaction. If Tx was significant, then contrasts were 56 versus 28 and 28 versus 0 days dry.

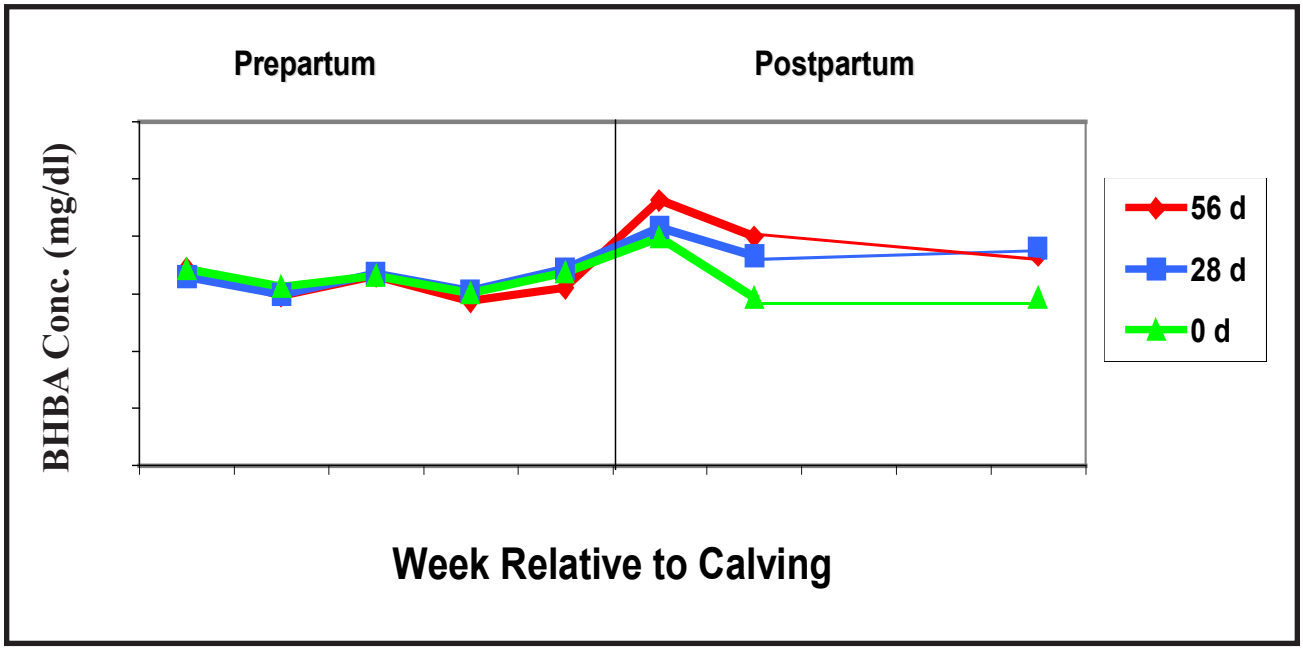

Figure 7. Plasma beta-hydroxybutyrate **(BHBA)** concentration in cows fed and managed for 56, 28, or 0 day dry periods (Rastani et al., 2003).

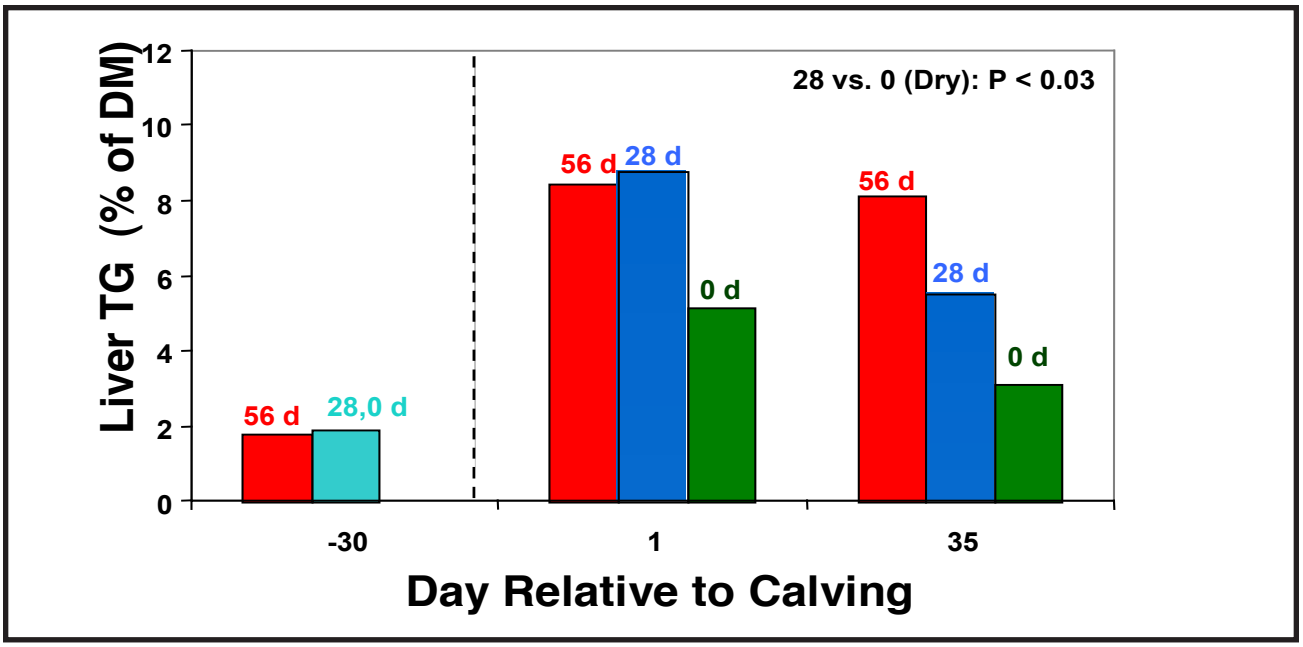

Figure 8. Liver triglyceride **(TG)** at 30 days prepartum and 1 and 35 days postpartum when cows were managed for 56, 28 or 0 day dry periods (Rastani et al., 2003). If treatment was significant, then contrasts were 56 versus 28 and 28 versus 0 days only.

Implications of Grouping Strategies on Feeding Dairy Cows

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Abstract

Dairy farms in California are profitable, at least partly due to their animal grouping management decisions. Mature cows after dry-off, and heifers within 60 days of calving, are commonly grouped separately and, within parity groups, are divided into far-off dry and transition dry groups, with the break commonly found at about 14 days prepartum. Lactating cows are commonly grouped into those of all parities that have just calved (just fresh), first calvers, mature cows in early lactation that are open or not yet confirmed in calf, and later lactation cows of all parities into those that are within about 210 days in milk from those that are within about 14 days of dry-off. Feeding management decisions follow cow groupings, with higher nutrient density rations provided to transition dry, versus far-off dry groups, as well as to heifers/first calvers versus mature cows. Higher cost feed additives tend to be restricted to transition dry, just fresh, and the high group rations for open cows and those not yet confirmed in calf. Grouping decisions on large California dairy farms represent owner/manager decisions on strategies that improve overall performance and profitability, in their opinions.

Introduction

The dairy industry in California has been the growth center of the US dairy industry for the past 20 years and projections suggest further growth in the foreseeable future. This growth can be defined in many ways, including total milk production, milk production per cow, total number of cows, numbers of cows per farm and even the numbers of dairy farms. As the average size of dairy farms in California has doubled, and then doubled again, dairy farms in the +3000 lactating cow range are now common, and dairy producers have been faced with challenging opportunities as to how best to group and manage their cows to maximize their performance and profitability.

While commercial management of dry dairy cows has received a lot of ink over the past decade, and has arguably resulted in one of the fastest and most wide-spread fundamental changes in management of one class of dairy cows in recent history, large dairy producers have also been changing the way that they group and manage lactating cows. Unfortunately, the ability to critically evaluate the benefits of these grouping strategies through controlled research studies is very limited due to the long-term nature of the benefits and need for several large groups of cows, both being characteristics that are very rarely available at university or government research facilities.

Thus, large dairy producers have had to make grouping and feeding management decisions that can potentially save or lose them tens, if not hundreds, of thousands of dollars per year, based on their perceptions of the

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impacts of their decisions on productivity and/or profitability. Such an approach is obviously fraught with the risk of making an incorrect decision based on an incorrect perception of the outcome. Nevertheless, in the absence of an alternative, there are no options. This author has learned, often the hard way, over the years that when groups of dairy producers make a similar decision over time, and stay with it, that it is very often supported. For example, there was a widespread decision by dairy producers to use yeast and yeast culture products in their rations well before experimental data was available that documented their benefits, and while most dairy cattle nutritionists were not recommending their use and/or referring to them in one of several unflattering terms.

The purpose of this article is to describe grouping management decisions that seem (i.e., in the author's experience) to be increasing in prevalence on large dairy farms in California, and the implications that these grouping decisions have on ration formulation strategies. This article will not, in general, address the scientific reasons why those decisions are being made, but will address the author's perceptions of why dairy producers are making them. While herd sizes in the Midwest can be substantially smaller than those in California, the principles that have driven grouping and feed management decisions in California also hold for smaller herds in different climates. However, whether these grouping and feeding strategies are practical in smaller herds is an issue for each individual dairy producer.

Dry Cows

Dry cows are no longer the forgotten animals on commercial dairy farms. Indeed the dry period of dairy cows, particularly the transition dry period (i.e., from about 20 days prepartum to calving) is now widely recognized as a critical period in which the quality of all inputs should be increased, as they will directly impact the cow's productive performance in the next lactation as well as the incidence of diseases associated with calving. Many of the commercial cow grouping and feeding management practices that have been introduced in the last decade address these issues.

Dry period groups based on time

Most commercial dairy producers now divide dry cows based upon time before calving. When asked, the most commonly quoted time by dairy producers to move cows to a transition dry group is 21 days pre-partum. Producers often quote this time, it would seem, as they perceive that it is the 'correct' answer (i.e., in articles that they have read, it is the most recommended by 'experts'). However, examination of the actual records of dairy farms, or merely counting the number of cows in the transition dry group relative to the number in the far-off dry group, suggests that a more common time is actually closer to 14 days, with values as low as 10 days not being uncommon, since pen sizes often limit the size of the transition dry group. Is this shorter period a problem? A recent study on a large commercial facility (Robinson et al., 2001; Figure 1) showed no benefit to extending the transition period beyond about 12 days. This finding is consistent with biological modeling of nutrient requirements of dry cows, which suggests that dry cows will go into negative protein and energy balance between 8 and 12 days prepartum, and this is largely independent of the ration that they are offered during this period.

The division of the dry period into far-off and transition dry groups facilitates use of higher energy and protein levels in the ration of the transition dry group to compensate for the reduction in feed intake that occurs in the

final 10 days prior to calving. These higher protein and energy levels often are achieved, at least partially, by selection of higher nutrient forages, such as legumes, that also have higher intake potential. The parity division also allows producers to add a number of high value feed additives to transition dry group rations, including yeasts or yeast cultures, B vitamins, and anionic salts.

However, one of the difficulties of using legumes for transition dry cows is that they often consume levels of calcium and/or potassium that make it very difficult to achieve a desirable dietary cation anion difference **(DCAD)** without the use of anionic salts. However, many producers want to avoid the use of anionic salts, because they believe that anionic salts suppress feed intake when the overall objective is to prevent its depression. Thus, many large dairy farms have active programs to identify lots of alfalfa hay with lower levels of potassium for use in the transition dry rations, thereby giving a whole new meaning to the term 'dry cow hay'. This practice is growing in popularity, as it allows legumes to be used, while maintaining a desirable DCAD balance.

Dry period groups based on parity

Many commercial dairy producers now divide transition dry cows by parity. They have been convinced, to at least some degree, by controlled research that has shown first calvers to be more productive in their lactation if they are fed a higher nutrient density ration in the transition dry period (e.g., Robinson et al., 2001; Figure 2) and recent recommendations by the Dairy Subcommittee of the National Research Council (2001) that suggest higher nutrient levels in transition dry rations for heifers versus mature cows.

In addition, they are well aware that transition dry heifers tend to be more reluctant than mature cows to compete for space in free stalls, and that bullying by mature cows can negatively affect feed intake and subsequent performance. The parity separation also allows heifers to develop a social structure that carries into the lactation groups (discussed below). Thus, many large California dairy farms group the transition dry cows based on parity, with heifers grouped separately from mature cows, and the incidence of its use is increasing.

Dry period: The bottom line

There are four dry cow groups that are most commonly found on large commercial dairy farms in California. These divide dry cows (i.e., any mature cow after dry-off or any heifer within 60 days of calving) into either far-off or transition groups (dividing at 10 to 20 days prepartum) and within each of these groups into heifer or mature cow groups. However the far-off mature group is seldom considered to actually be a dry cow group by dairy producers, who tend to classify it as the older group of bred heifers. Feeding management decisions are consistent with these grouping decisions by providing higher nutrient dense rations to the transition dry cows, and a higher nutrient dene ration to the heifers within either dry cow group, but particularly the transition dry heifers.

Lactating Cows

Grouping strategies for lactating cows have received much less research attention than those for dry cows over the past decade. Nevertheless, California dairy producers have instituted a number of changes in grouping and feeding strategies in response to their perceptions of those that improve overall lactation performance.

Just fresh group

Once cows calve, and if they are moved to large high groups of up to 200 cows, they can become 'lost in the crowd'. This means that unresolved health issues from calving may re-occur and not be treated promptly. Thus, many dairy farms have instituted a just fresh group into which most cows are moved directly after calving, and where they stay until it has been determined that they are fully recovered from calving, by at least daily visual assessment, and ready to move to the high group, or until a fixed time, ranging up to 40 days but often as little as 5 days, has passed. This pen is frequently close to the milking parlor to minimize imposed walking for milking and keep them in close proximity to the calving pens so that employees are often nearby. Thus, there is a continuing surveillance of the cows from these employees from the time they are moved into the transition dry group until they are moved to a large high group pen.

Producers try to under-populate pens of just fresh cows so that those cows with walking problems or illnesses, or a general reluctance to approach the feed bunks, have plenty of room to maneuver. Generally, although not always, these cows are fed the high group ration, often the high group first calver ration, in preparation for the impending move to the high group. Since calving problems tend to be much less prevalent in heifers than in mature cows, and mature cows tend to require more time to recover, the just fresh groups tend to have a preponderance of mature cows.

Parity splitting in the just fresh group appears to be increasing in use due, at least partially, to the ability to feed these parity split fresh groups the parity split high group rations, which they will be fed when they are moved to the parity split high groups.

Lactation groups based on parity

Separate grouping of first calvers from mature cows is becoming much more prevalent on large California dairy farms. Producers have been convinced to do this by their perceptions that heifers are more productive in their first lactation if fed a higher nutrient dense ration. They are well aware that first calvers can be more reluctant than mature cows to compete for bunk space and space in free stalls, as in the dry period, and that bullying by mature cows can negatively affect feed intake and performance. Thus, many large dairy farms divide the early lactation group based upon parity, with first calvers grouped separately from mature cows.

Separate penning of first calvers allows them to develop a self-confidence that carries into the groups where parities are often, but not always, combined in later lactation. In addition, the nutrient density of the ration for the first calvers is sometimes increased to compensate for their lower feed intake and higher nutrient requirements for maternal growth, compared to mature cows.

Lactation groups based on bred status

The prevalence of grouping lactating dairy cows by their breeding status is increasing. After clearing just fresh pen(s), cows are moved into parity split high group pens, discussed above, of open cows and bred cows that have not been confirmed in calf. The ration, or rations (as the nutrient density of the ration for the first calvers is sometimes higher than that of the mature cows), often contains relatively high cost feed additives such as yeasts or yeast cultures, B vitamins, buffers, and rumen inert fats.

Once confirmed in calf, generally between 90 and 120 days in milk, cows are moved from these early lactation parity split high

groups to parity combined high groups that are generally fed a ration very similar to that of the parity split high groups, except that many of the higher cost feed additives are removed. Cows stay in this group until 2 to 4 weeks prior to dry-off, at which time they may be moved to a near dry group (discussed below). The prevalence of parity split bred cow groups is increasing.

This practice represents a fundamental shift from the formerly popular, and widely recommended, system of a progressive shift of cows from high to medium to low nutrient dense rations as they progressed through lactation and milk production declined. The change of strategy reflects the recognition that moving cows to lower nutrient dense rations as they progress through lactation *causes* reductions in milk production due to lower nutrient delivery, rather than meeting lower nutrient requirements with lower nutrient delivery.

Lactation length and the near dry group

On most larger dairy farms, the lactation length is set by the upcoming calving date rather than the past calving date. Thus, dry off dates have very little to do with the cow's days in milk and everything to do with the days carried calf. Thus, cows stay in the combined parity bred high group until they reach about 225 days in calf, at which time they are dried off and moved to the far-off dry group. However, this strategy means that cows can be dried off as early as 260 days in milk or as late as, well, years, and that milk production at dry off can range from 10 to 100 lb/cow/day. To facilitate dry off of the higher producing cows, all cows may be moved to a near dry group 2 to 4 weeks prior to dry-off. Cows would have BSt injections terminated at this time and be fed a lower nutrient dense ration to cause, rather than adjust for, lower milk production that will ease the transition from lactation to the dry state.

The incidence, and characteristics, of near dry groups varies widely in California. On many dairy farms, cows are moved to a near dry group but continue to be fed the high group ration right up to dry-off in order to maximize milk yield. However in such cases, the cows would be moved to a just dry group at dry-off that would be water restricted and fed a very low nutrient dense ration to stop milk secretion.

Lactation period: The bottom line

There are five lactation groups that are most commonly found on large commercial dairy farms. These group lactating cows into those of all parities that just calved, group first calvers, and mature cows in early lactation that are open or not yet confirmed in calf separately, and group later lactation cows of all parities into those that are within about 210 days in milk from those that are within about 14 days of dry-off. Feeding management decisions are consistent with these grouping decisions by providing a lower nutrient dense ration only to those cows that are close to dry-off (i.e., near dry), to cause a reduction in milk yield, but restrict the use of higher value feed additives to the high group open and yet to be confirmed in calf cows, and sometimes results in higher nutrient dense rations being fed to the high group of first calving cows.

Practices that are now widespread include the use of a just fresh group, grouping lactating cows by breeding status, and grouping open and not-yet-confirmed-in-calf cows by parity. The use of either a near dry or just dry group is also common, but declining in prevalence. Parity grouping open and not-yet-confirmed-in-calf cows by parity is increasing in prevalence.

Finally, many producers are questioning the traditional 60 day dry period as being too long and expensive in terms of investment in a non-productive cow. As there is very little

data to support benefits of dry periods in excess of 40 days (mammary involution is complete in 30 days) and because many dry treatments require 42 days to clear the cow, some producers have reduced target dry periods to 40 days. This practice will almost certainly increase in the drive to further increase productivity and profitability.

Summary

In business, everybody needs an edge to succeed. In most businesses, this involves putting a literal or metaphysical brand stamp on your product. For example, Coca Cola may differ very little from Bob's Cola, but the Coca Cola logo causes brand recognition and so buyers are willing to seek it out, as well as pay more for it, than Bob's Cola.

But in the dairy business, all dairy farms produce milk that, within the context of the pricing system, sells and does so at a similar price. Thus, the only area that dairy farms can get a real edge that increases their profitability is to reduce costs of production (i.e., do dairy farmers make money selling milk or buying feed?). Many large dairy farms in California have made similar decisions on grouping and

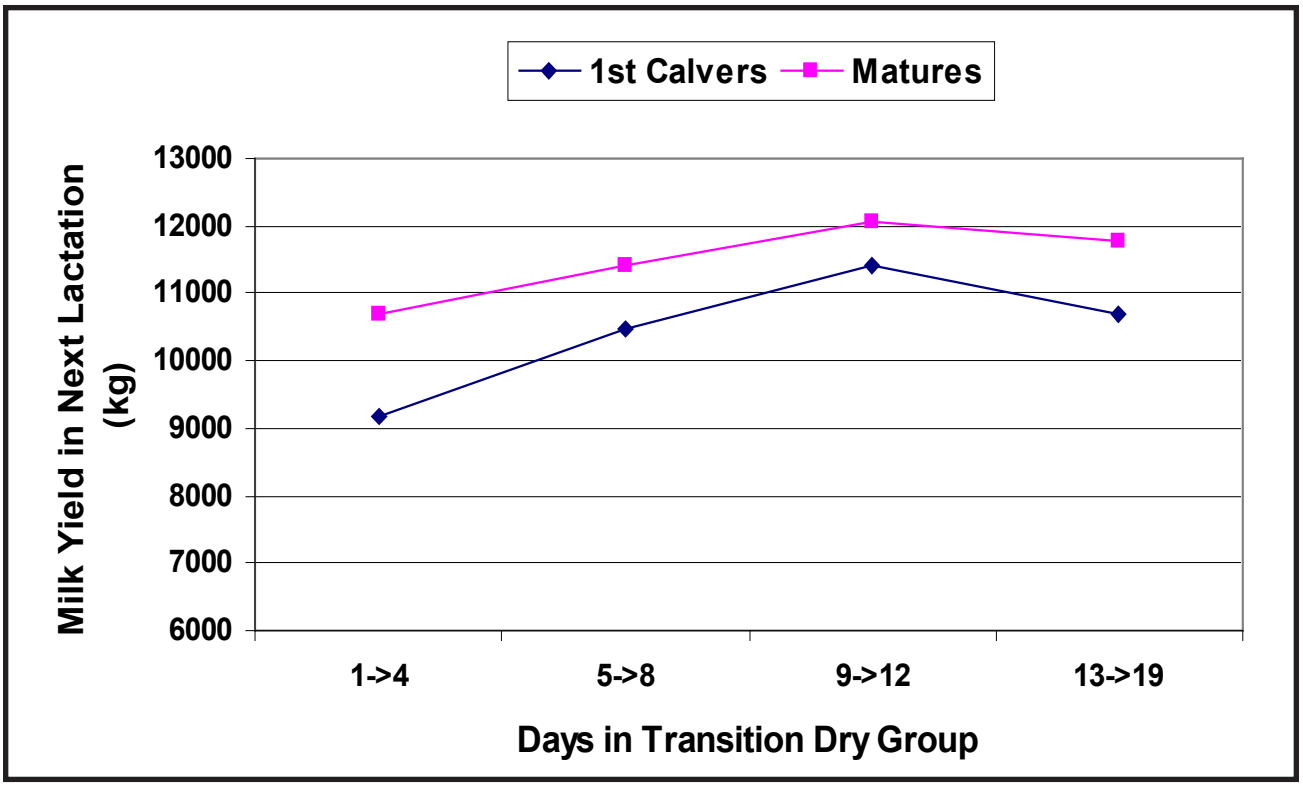

Figure 1. Impact of days in the transition dry group on milk yield in the next lactation (Robinson et

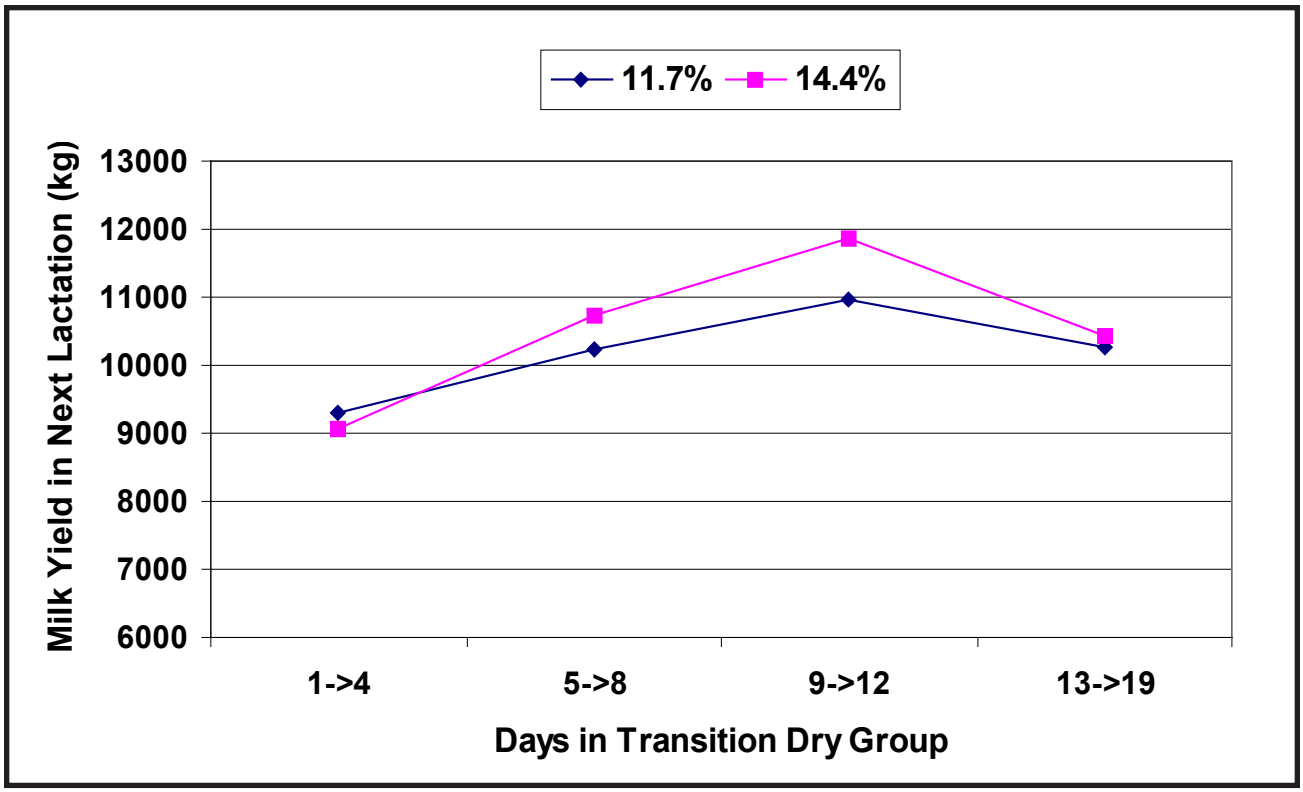

Figure 2. Impact of crude protein level (% of DM) of the transition dry group on milk production in the next lactation (Robinson et al., 2001).

Research Update on Requirements for Microminerals

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Abstract

Although they are relatively inexpensive to supplement, deficiencies of trace elements can be economically devastating. The effects of nutritional deficiencies of selenium on livestock are well-established, and supplementation of diets with selenium is a routine practice. The approval by the Food and Drug Administration **(FDA)** of selenized yeast as a selenium supplement has renewed interest in differences in selenium metabolism between selenite and selenomethionine. Because of greater maternal transfer of selenium to the fetus and milk, supplemental selenium as selenomethionine should be considered in some feeding programs. Cobalt, another micromineral, is required by ruminants for microbial synthesis of vitamin B_{12}, and transition cows probably are in a negative B_{12} balance. Dietary cobalt levels greater than 0.1 ppm enhance ruminal synthesis of vitamin B_{12} and may improve productivity of multiparous cows and feedlot cattle. Work continues to be needed to define the changes in trace element requirements during the productive cycles of livestock.

Introduction

In conducting research studies with trace elements, detecting treatment responses often is easier than interpreting the importance of those responses. For example, supplemental dietary copper **(Cu)** increases liver Cu but does not necessarily improve the health or performance of the animal. Similarly, lactation changes the body composition of cows and concurrent changes in tissue concentration of mineral elements are to be expected. Recent work with phosphorus **(P)** intakes of dairy cows suggests limited loss of endogenous P in early lactation does not affect milk yield (Knowlton and Herbein, 2002; Wu et al., 2001). Similar to milk synthesis, fetal growth during late gestation is a significant drain on maternal stores of trace elements (Abdelrahman and Kincaid, 1993). However, without transfer of substantial amounts of selenium **(Se)** and Cu to the fetus, the health of the newborn calf is jeopardized and disease incidences increase in the transition cow. Thus, although fluctuations in tissue concentrations of trace elements are normal, there are critical times in the production cycle when reductions in tissue concentrations of trace elements can affect health and productivity of animals. This paper reviews some recent findings concerning selenium and cobalt, and discusses how these findings affect trace element nutrition.

Selenium

The commercial availability of selenized yeast **(SeY)** as a Se source for cattle has renewed interest in Se intakes and differences in metabolism between supplements containing inorganic (sodium selenite) and organic (largely selenomethionine, SeM) Se. An important difference between Se sources is that Se, as selenite, must be chemically reduced from

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a + 4 to a 2 oxidation state for synthesis of selenoproteins, whereas Se in SeM is already present in the 2 oxidation state. Compared to selenite, Se as SeY is probably absorbed to a greater extent from the intestinal tract and retained more in tissues. The mechanism of intestinal absorption of SeM is identical to methionine; however, based on differences in selenite absorption between ruminants and nonruminants, some selenite is probably chemically reduced to less available chemical forms in the rumen and competes with sulfur compounds for absorption. Thus, compared to selenite, absorption of SeM should be less affected by supplemental dietary sulfur that can be present in anionic salts of close-up diets. When Se is absorbed as SeM, much of the SeM is nonspecifically incorporated into general body proteins, effectively removing some Se from immediate circulation (Schrauzer, 2000). Cattle have been safely fed Se levels of > 10 ppm Se for short-terms (105 days) when the Se was naturally present in the feeds, presumably most of the Se was as SeM (Hintze et al., 2002). These large intakes of Se from feeds that have naturally high concentrations of Se cause accumulation of Se in tissues (Hintze et al., 2001; 2002). The nonspecific incorporation of SeM into general body protein explains the increased Se deposition in liver and muscle, and also probably accounts for much of the increased placental (Table 1; Rock et al., 2001) and mammary transfer (Knowles et al., 1999) of Se when supplemented as SeY instead of sodium selenite. The concentration of Se in whole blood is increased more by supplemental SeY than selenite because greater amounts of Se are retained in the hemoglobin of the red blood cell. The pattern of Se distribution among serum proteins is affected by Se intake and the chemical form of the Se (Awadeh et al., 1998a; Hintze et al., 2002). However, other differences in biological responses to supplements of SeY and selenite have been reported but are not easily explained.

In addition to preventing white muscle disease in young calves, Se supplementation increases concentrations of immunoglobulins **(Ig)** G and M in the cow and her calf (Table 2). Because the calf is dependent on colostral transfer for Ig, it is easy to envision how increased Ig concentrations in the maternal serum and colostrum lead to increased Ig levels in serum of the calf. However, intestinal transfer of IgG, at least in the lamb, is reduced in newborn lambs of ewes fed low Se diets (Table 1). This work (Rock et al., 2001) was done with newborn lambs fed a standardized amount of pooled colostrum. In addition, SeY was more effective than selenite in increasing IgM when the pregnant cows were fed for a common rate of Se intake (Table 2). Whether the difference in Ig response was due to greater Se retention or a difference in Se metabolism between the two Se sources is not known.

The deiodinase enzymes responsible for the conversion of thyroxine (T_4) to the more biologically active 3,5,3 tri-iodothyronine (T_3) are Se dependent. An immediate importance of deiodinases to the newborn is that T_3 activates brown adipose tissue thermogenesis to keep the calf warm. When calves were born of cows supplemented with higher levels of Se in their salt fed free-choice, serum T_3 levels were increased (Awadeh et al., 1998b). Although Se supplementation affects T_3 levels, the practical importance is unclear because of compensatory mechanisms that help protect the newborn. For example, in lambs, we could not detect a difference in measures of thermometabolism, even though T_3 levels were reduced in the ewes and tended ($P < 0.10$) to be reduced in the lambs (Rock et al., 2001). Similarly, Wichtel et al. (1996) found Se supplementation increased T_3 in dairy heifers and increased growth in one herd but not another herd. Thus, the practical importance of Se supplementation to increase T_3 in cattle is unclear.

Nutritional requirements for trace elements are hard to determine because there is no clearly defined criteria to set requirements. If factorial estimates are used to set trace mineral requirements, then the estimated percent absorption has a very large effect on the dietary requirement level. If a biological assay is used to determine nutrient requirement level for a trace element, then which biological measure is most indicative of nutritive status? In a recent study on the effect of Se intake on reproduction in sows (Hostetler and Kincaid, 2004), total lipid peroxides (H_2O_2 and malondialdehyde) increased in liver of fetal pigs (day 30 to term) even though fetal liver glutathione peroxidase **(GPx)** activity was not affected (Table 3). Polyunsaturated fatty acids are good targets for ·OH because of their multiple double bonds, and attack by ·OH leads to derangement of lipid bilayers and loss of cellular function (Fang et al., 2002). Thus, when maternal Se intake was low, production of H_2O_2 in the fetus was greater than the capacity of GPx to convert H_2O_2 to H_2O and O_2. An increase in cellular H_2O_2 increases formation of ·OH through the Haber-Weiss (Elstner et al., 1980) and Fenton (Walling et al., 1975) reactions. Accordingly, peroxidative stress can occur with low Se intakes before measurable changes in GPx occur. Thus, at least in some instances, short-term nutrient deficiencies can affect performance of the animal before known enzymatic activity is reduced.

Cobalt

The importance of cobalt **(Co)** in ruminant nutrition is well-established due to its central role in ruminal synthesis of vitamin B_{12}. Sheep are known to be more sensitive to inadequate Co than are cattle, and young animals more sensitive than older animals. A series of papers by Elliot and others (Elliot et al., 1979; Sutton and Elliot, 1972) reported reduced blood B_{12} during early lactation and reduced ruminal synthesis of vitamin B_{12} when ruminant diets were supplemented with grain, i.e., fed typical lactation diets. More recently, Tiffany et al. (2003) reported increased ruminal synthesis of vitamin B_{12} in feedlot cattle when 1.0 ppm Co was supplemented to the diet, although based on growth, a minimum requirement of 0.15 ppm Co was suggested. This compares to the current requirements of 0.1 ppm Co for beef cattle (NRC, 1996) and 0.11 ppm Co for dairy cattle (NRC, 2001). Although greater ruminal synthesis of vitamin B_{12} is to be expected in cattle fed a dairy diet compared to a finishing diet, the dairy cow secretes a relatively large amount of vitamin B_{12} daily into milk (2 to 4 mg/L; Puls, 1988). Cobalt also is secreted into milk, and while most studies have focused on vitamin B_{12} metabolism, relatively little is know about the metabolism of Co.

In a study in which dry, nonpregnant cows were supplemented with Co for 60 days, we found that although serum Co increased with time in all cows, Co supplementation did not significantly increase serum Co (Kincaid et al., 2003). Liver samples obtained at the end of the study revealed no effect of Co supplementation on liver Co; however, there was an effect of age of the cow such that younger cows (2.5 years) had higher liver Co concentrations than older cows (6.5 years; 2.4 versus 0.95 ppm Co, respectively). In a subsequent study (Kincaid et al., 2003) with lactating cows, serum B_{12} concentrations were higher in primiparous than multiparous cows and serum B_{12} declined rapidly after parturition in all cows (Table 4). This is not surprising because serum B_{12} values respond rapidly to either B_{12} absorption or loss, and milk yield is a substantial drain on endogenous B_{12}. Serum Co also declined with days in milk **(DIM)**, and Co supplementation did not prevent the decline in serum or liver Co concentrations. In fact, calculations of probable Co balance reveal a negative Co balance for the lactating cows (Table 5). Endogenous reserves of vitamin B_{12} and Co may have affected the response of cows to Co supplementation. Statistical analysis

of the milk production data revealed a 3-way interaction of parity, treatment, and DIM (Table 6). In general, older cows appeared to benefit from higher dietary Co, whereas younger cows did not.

An explanation why lactating primparous and multiparous cows responded differently to Co supplementation is not clear. Possibly, the effect is due to a progressive loss of Co during subsequent lactations. There are at least three possible modes of action by which Co could affect ruminant animal production. First, additional dietary Co increases ruminal synthesis of vitamin B_{12}, which leads to greater absorption of vitamin B_{12}. Endogenous reserves are greater in primiparous than multiparous cows as evidenced by higher Co concentrations in serum, colostrum, and milk and higher B_{12} in serum. Secondly, supplemental Co could enhance ruminal fermentation, possibly by an increased vitamin B_{12} supply to bacterial strains that need but do not synthesize B_{12}. Several studies (Allen, 1986; Hussein et al., 1994; Odens et al., 2003) have been conducted on supplemental Co and fiber digestion *in vitro* and these studies have yielded few positive results. Thirdly, there could be a metabolic function for Co other than vitamin B_{12}. Cobalt is distributed throughout the liver cell, with the largest percentage in the subcellular fraction (Kincaid et al., 2003). Perhaps Co has a nonB_{12} function in one of these subcellular fractions; however, no such function is presently known.

Although endogenous Co is reduced during lactation, the Co loss may have little or no effect on the cow except as an indicator of B_{12} depletion. At present, there is no recommendation to increase the current dietary Co of 0.11 ppm; however, there is justification to further investigate the reduction of endogenous Co and vitamin B_{12} during lactation and the possible carryover effects on subsequent lactations. Some repletion of endogenous Co appears to take place during the dry period, and this repletion may be affected by dry period length.

Summary

Current considerations in trace element nutrition include whether to use inorganic or organic Se supplements. Although inorganic Se (selenite) has been our main Se supplement for many years, there is greater fetal and mammary transfer of Se from SeM. A second consideration is whether to increase dietary Co levels above the current recommendation of 0.11 ppm. At this time, multiparous cows appear to benefit from > 0.11 ppm Co; however, more work is needed before a definitive recommendation can be made.

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Table 1. Effect of selenium source on transfer of selenium in newborn lambs.[1]

	Control 0.04 ppm Se	Selenite 0.35 ppm Se	SeY[2] 0.35 ppm Se
Blood Se, ppm	0.101[a]	0.234[b]	0.434[c]
GPx, EU/ml	145[a]	414[b]	640[c]
Liver, ppm	0.63[a]	1.34[b]	1.80[b]
Colostrum, ppm	0.012[a]	0.132[b]	0.226[c]
T_3, ng/ml	2.81[d]	3.98[e]	3.32[e]
IgG, g/dl	2.39[a]	2.94[b]	2.92[b]

[1]Rock et al., 2001; GPx = glutathione peroxidase, EU = enzyme units, T_3 = 3, 5,3-tri-iodothyronine, and IgG = immunoglobulin G.
[2]SeY = selenized yeast (Selplex®, Alltech Biotechnology Center, Nicholasville, KY.
[abc]Means followed by different superscripts are different, $P < 0.05$
[de]Means followed by different superscripts are different, $P < 0.10$.

Table 2. Effect of level and source of selenium supplement on blood measures of beef cows and calves at birth.[1]

	Concentration of Se in Free-Choice Salt Mix		
	20 ppm Se as selenite	60 ppm Se as selenite	60 ppm Se as SeY[2]
Cows			
Se in blood, ppm	0.13[a]	0.16[b]	0.17[b]
Se in colostrum, ppm	0.07[a]	0.09[ab]	0.14[b]
Serum IgM, g/L	2.4[a]	3.9[b]	5.3[c]
Serum IgG, g/L	24[a]	35[b]	33[b]
Calves			
Se in blood, ppm	0.12[a]	0.14[a]	0.17[b]
GPx, EU/ml	0.6[a]	0.8[b]	0.9[b]
T_3, ng/ml	3.4[a]	3.0[a]	5.3[b]
IgM, g/L	2.5[a]	3.2[ab]	4.0[b]
IgG, g/L	26	31	32

[1]Awadeh et al., 1998b; IgM = immunoglobulin M, IgG = immunoglobulin G, GPx = glutathione peroxidase and T_3 = 3,5,3 tri-iodothyronine.
[2]SeY = selenized yeast (Selplex®, Alltech Biotechnology Center, Nicholasville, KY).
[abc]Means followed by different superscripts are different, $P < 0.05$.

Table 3. Gestational changes in lipid peroxides, Se, and glutathione peroxidase **(GPx)** in maternal and fetal liver homogenates in sows fed adequate (0.39 ppm) and low (0.05 ppm) Se gestation diets.[1]

	Se Concentration in Gestation Diet	
	0.05 ppm Se	0.39 ppm Se
Sows		
Selenium, ppm	0.25[a]	0.45[b]
GPx, mU/mg protein	1250[a]	1700[b]
H_2O_2, µM/mg protein	2.4[a]	1.9[b]
MDA[2], µM/mg protein	1.95[a]	1.55[b]
Fetuses, day 45		
Selenium, ppm	0.24[a]	0.36[b]
GPx, mU/mg protein	280[a]	275[a]
H_2O_2, µM/mg protein	6.1[a]	3.5[b]
MDA[2], µM/mg protein	3.4[a]	2.6[b]

[1]Hostetler and Kincaid, 2004.
[2]MDA = malondialdehyde
[ab]Means followed by different superscripts are different, $P < 0.05$.

Table 4. Effect of parity number on cobalt and vitamin B_{12} in cows[1]**.**

	Primiparous Cows	~~Multiparous Cows~~
Cobalt in		
Serum, µg/ml	0.099	0.094
Colostrum, µg/ml	0.119[a]	0.093[b]
Milk, µg/ml	0.099[a]	0.082[b]
Liver, µg/g (samples taken 120 DIM)	2.16	1.82
Vitamin B_{12} in serum at		
30 days prepartum, ng/ml	2.7[a]	1.5[b]

[1]Kincaid et al., 2003; DIM = days in milk.
[ab]Means followed by different superscripts are different, $P < 0.05$.

Table 5. Estimated cobalt balance of cows.[1]

	Cobalt Concentration in Total Mixed Ration		
	0.37 ppm Co	0.68 ppm Co[2]	1.26 ppm Co[2]
Co intake, mg/day	9	15.6	30
Co secreted in milk, mg/day	3.3	3.1	3.3
Absorbed Co, mg/day, assumes 2% of intake	0.18	0.31	0.60
Absorbed Co minus milk Co, mg/day	-3.1	-3.0	-2.7
Co absorption needed to equal secretion in milk, %	37	20	11

[1]Kincaid et al., 2003.
[2]Supplemental cobalt added as Co glucoheptonate (Zinpro Corp., Eden Prairie, MN).

Table 6. Effect of dietary cobalt supplementation on yield of milk and milk components[1].

	Cobalt Concentration in Total Mixed Ration			
	0.37 ppm Co	0.68 ppm Co[2]	1.26 ppm Co[2]	SE
Milk yield, lb/day*	79.9	76.3	79.9	3.0
3.5 FCM, lb/day*	77.9	78.3	85.4	3.4
Fat, lb/day*	2.82	2.82	2.99	0.16
Protein, lb/day*	2.31	2.29	2.33	0.09
Fat, %*	3.54	3.73	3.73	0.12
Protein, %*	2.88	2.94	2.90	0.04

[1]Kincaid et al., 2003; FCM = fat-corrected milk and SE = standard error.
[2]Supplemental cobalt added as Co glucoheptonate (Zinpro Corp., Eden Prairie, MN).
*Significant 3-way interaction of treatment x parity x week, $P < 0.05$.

Progress in the Understanding of Hemorrhagic Bowel Syndrome

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Abstract

Hemorrhagic bowel syndrome **(HBS)**, a deadly digestive tract disease, has been reported with increasing frequency in adult dairy cows. Cattle affected with HBS usually die within 12-36 hours after the onset of clinical disease. Cattle present with acute enteritis and concurrent dehydration and shock, with or without signs of abdominal pain. The case fatality rate is 85 to 100%. Pathologic examination of affected animals reveals severe hemorrhagic enteritis with intraluminal hemorrhage or blood clots. Both *Clostridium perfringens* and *Aspergillus fumigatus* have been implicated in the development of HBS, though neither have been conclusively demonstrated to be the cause. Suggested risk factors for HBS include a high amount of fermentable carbohydrate in the diet, the level of dry matter **(DM)** intake, the level of milk production, feeding a total mixed ration, lactation number, herd size, season, and the presence of the causative organism in the feedstuff.

Introduction

The HBS is a relatively new disorder affecting dairy cattle across North America and throughout the world. The HBS is a sporadic, acute intestinal disease of milking cows. The syndrome is characterized by large blood clots in the intestine that result in the obstruction and severe enlargement of the bowel. It was first noted by Bruce Anderson at the University of Idaho in 1991 (Anderson, 1991). At that time, he referred to it as "point source hemorrhage". It is now referred to by a variety of names including HBS, "jejunal hemorrhagic syndrome **(JHS)**", "acute hemorrhagic enteritis of the small intestine", and "dead gut".

The cause of HBS is not known, but *Clostridium perfringens* type A and more recently *Aspergillus fumigatus* have been implicated in the disease syndrome. *Clostridium perfringens* type A is ubiquitous in the jejunum (small intestine) of all adult cattle and is well known to proliferate rapidly post-mortem. The *A. fumigatus* is also ubiquitous in the digestive tract of cattle, making its significance in HBS difficult to ascertain in the absence of visible fungal hyphae in the wall of the affected portion of gut.

The HBS was evaluated nationally for the first time during the National Animal Health Monitoring System's **(NAHMS)** Dairy 2002 study (USDA: APHIS, 2003). According to the study, herd size, level of production, season, and region were suggested as risk factors for HBS. In other studies, nutritional factors have been suspected to be involved in the development of the disease (Godden et al., 2001; Kirkpatrick et al., 2001).

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Review of the Hemorrhagic Bowel Syndrome

Clinical syndrome and treatment

The HBS is characterized by acute signs of profound depression, decreased milk production, tachycardia (rapid heart rate), ruminal stasis, abdominal distention, and dark clotted blood in the feces (Dennison et al., 2002). At necropsy, segmental lesions localized to the jejunum are observed (Kirkpatrick et al., 2001). These areas consist of frank hemorrhage with immediate clotting, forming a functional occlusion of the lumen of the small intestine. Treating acutely affected cows with antimicrobial agents and supportive therapy (e.g. anti-inflammatories, fluid therapy, and dextrose) has generally been reported to be ineffective (Dennison et al., 2002; Godden et al., 2001; Kirkpatrick et al., 2001). Affected cattle are extremely poor candidates for surgical intervention. Surgical intervention has included intestinal resection and anastomosis or, alternatively, manual massage of the affected area to breakdown the offending clot (Dennison et al., 2002; Godden et al., 2001; Kirkpatrick et al., 2001). Usually, the prognosis for an affected animal is extremely guarded.

Epidemiology

The HBS was documented as early as 1966 but with few cases reported in the next 20 years. Over the past 5 to 6 years, there has been a significant increase in the number of reported HBS cases. Presentation of HBS has been sporadic, but herd outbreaks involving up to 10% or more of the cows on a given dairy farm have been reported (Kirkpatrick et al., 2001). Morbidity rates of 1 to 2% of the mature cow population would be typical, with mortality approaching 85 to 100% due to the peracute nature and severity of the disease (Kirkpatrick et al., 2001).

Possible risk factors for HBS as suggested by a survey of Minnesota bovine practitioners (Godden et al., 2001), as well as the NAHMS Dairy 2002 study include:

1. Parity: more common in 2nd lactation and older cows
2. Herd size: more common on large dairy farms ($\geq$ 100 cows)
3. Stage of lactation: higher incidence in cows during the first 100 days of lactation
4. Feeding system: greater frequency of the disease in herds fed a TMR
5. Level of production: the percent of operations with one or more HBS case increased as rolling herd average for milk yield increased
6. Region: higher incidence in the western region
7. Season: the majority of cases occurred in cooler months; winter and fall

Some of these factors deserve investigation in future studies, as the association between the disease and some of them may be an artifact. For example, the association between the disease and herd size could be due to the greater likelihood that an animal that dies suddenly will be necropsied on a larger dairy farm, or even just because of larger numbers of animals. The same for other risk factors, such as level of milk production. Higher rolling average for milk yield may be associated with improved management, which may include an increased likelihood that dead cows will be necropsied.

Etiology and pathogenesis

Several investigators have thought that *Clostridium perfringens* type A may be a cause of HBS (Dennison et al., 2002; Godden et al., 2001; Kirkpatrick et al., 2001; St. Jean and Anderson, 1999). Dennison et al. (2002) conducted a retrospective analysis of all dairy

cows examined at the Colorado State University Veterinary Teaching Hospital which were submitted with dysentery, melena (changed blood in the feces), or colic. The *C. perfringens* was isolated from fecal samples in 17 of 20 cows. Genotyping of the *C. perfringens* in 10 cows revealed type A in five cows and type A with the b2 toxin gene in the remaining five cows. Dennison et al. (2002) commented that "it is unclear whether proliferation of *C. perfringens* is part of the primary disease process in cows with HBS or occurs as a secondary response". Doubt about this etiological agent has come from the fact that *C. perfringens* type A is normally found in low numbers in the gastro-intestinal **(GI)** tract of normal, healthy cattle, but its numbers increase rapidly following the death of an animal. Furthermore, immunization against *Clostridium* spp. does not appear to protect animals from HBS.

More recently, a group at Oregon State University has reported that infection of dairy cattle by a common mold (*Aspergillus fumigatus*) likely is a cause of the disease (Forsberg, 2003). The hemorrhagic condition seen in HBS cows is similar to enteric hemorrhagic diseases caused by *A. fumigatus* in immuno-suppressed humans. The *A. fumigatus* is one of the few mold species which has the ability to digest its way through GI tract or pulmonary epithelium and to enter the blood. Once in the blood, *A. fumigatus* continues to secret toxins which suppress blood clotting. As a result, uncontrolled bleeding is typical of spreading aspergillosis and in humans can result in bleeding into the jejunum. Forsberg (2003) proposed that *A. fumigatus* may infect cows that are stressed, and/or immuno-suppressed that are fed feedstuffs containing the common mold *A. fumigatus*.

The investigations involved samples collected from eight HBS cows and 17 healthy cows from Idaho, Iowa, Oregon, and Washington. Samples included feed, blood, gut contents, and tissues (gut wall, mesenteric lymph node, and liver) from HBS cows, while only blood samples were taken from the negative control cows. All cows with HBS were infected with *A. fumigatus* in blood and tissues. Fourteen negative control cows have tested negative for *A. fumigatus*, while the remaining cows contained very low levels of the organism. The *C. perfringens* was not detected in all HBS cows. Moreover, *A. fumigatus* was detected in 3 of 3 feed samples. However, limitations of this analysis exist, such as the small data set and lack of GI tissues from negative control cows. In addition, *A. fumigatus* is ubiquitous in the GI tract of cattle. Finally, the investigators evaluated antifungal compounds for their potential to inhibit the growth of *A. fumigatus* in culture and in the field. The investigators formulated a combination of GRAS (generally recognized as safe) ingredients based on their abilities to inhibit fungal growth in the laboratory and then tested them in the field. The field trial involved 1,700 cows which had experienced incidence of HBS. The study revealed that the experimental product appeared to successfully prevent the occurrence of HBS (Forsberg, 2003). However, neither the data nor the identity of the ingredients have yet been published

HBS and Nutrition

High fermentable carbohydrate

Consumption of large amounts of fermentable carbohydrate could be considered as a potential risk factor. Kirkpatrick et al. (2001) reported an association of increased death rates with increased management-level milk. Maximal milk production is a product of carbohydrate consumption and dry matter intake, both of which could be considered as possible risk factors for HBS.

Feeding TMR

Feeding TMR has been suggested as a risk factor for HBS. The Minnesota survey (Godden et al., 2001) found that 83% of affected herds were fed a TMR. The identification of TMR feeding as a risk factor is supported by the fact that only 38% of the herds in Minnesota at the time of the survey were fed a TMR.

Presence of the organism in the feedstuff

The presence of both *C. perfringens* and *A. fumigatus* has been reported in the feedstuffs of affected herds. Kirkpatrick et al. (2001) isolated *C. perfringens* type A from alfalfa haylage that had been fed to the cows. No outbreaks occurred during times when alfalfa haylage was not in the ration. Likewise, Forsberg (2003) detected *A. fumigatus* in all three of the feed samples that were tested. Additionally, when an antifungal product was used in the field study, the incidence of the disease was reduced (Forsberg, 2003). Therefore, the presence of the causative organism in the feedstuff may be a risk factor for the development of HBS. However, the wide range of investigational items would suggest that the presentation of HBS may not be solely dependent on presence of a causative organism but on the combination of a range of conditions.

Summary

The HBS is a highly fatal intestinal disease. Animals with HBS have a poor prognosis, regardless of treatment. The HBS is more prevalent in large herds, herds with high production, and herds in the western region. However, HBS has been a significant problem in herds of all sizes, production levels, and regions of the country. The cause of the disease is not known yet, but *C. perfringens* and *A. fumigatus* have been suggested as causative agents. However, the ubiquitous nature of both of these organisms makes its significance in HBS difficult to ascertain. Some nutritional factors are also suspected to be risk factors for the disease. However, more studies and research need to be done to illuminate the disease process.

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Johne's Disease: A Brief Overview

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Abstract

Johne's disease is an important infectious disease of both dairy and beef cattle. It is caused by the bacterium *Mycobacterium paratuberculosis*. It is estimated that greater than 50% of dairy farms in the US are infected with Johne's disease. Johne's disease is a chronic progressive disease that is essentially untreatable. Cattle become infected at an early age, most commonly at less than a year of age. Following a long incubation period, which typically lasts greater than two years, cattle develop clinical signs that include chronic diarrhea and weight loss despite a normal appetite. Infection occurs by ingestion of the bacteria, which is shed in large numbers in feces, milk, and colostrum. Control of the disease is focused on decreasing the risk of transmission from infected cows that are shedding the bacteria to the most susceptible animals on the farm, that being young replacement animals. This is done by identifying and managing infected cows and managing routes of transmission from infected cows to young calves. Control of Johne's disease requires a long-term commitment to making the management changes necessary to stop the disease transmission. It is important that everyone involved in the operation of cattle operations be aware of the disease and the management strategies necessary to control the disease.

Introduction

Johne's disease (pronounced Yo-nees) is a serious disease of cattle that can cause significant economic loss if not controlled. A recent survey found that approximately 55% of Michigan dairy herds contained at least two cows infected with the Johne's disease organism (Johnson-Ifearulundu and Kaneene, 1999). Despite this, many cattle producers are unaware of the disease and the potentially devastating effect that it can have if left unchecked. Fortunately, some basic knowledge about Johne's disease can go a long way towards getting a handle on this serious disease.

The Organism

Johne's disease is caused by a bacterium called *Mycobacterium avium subspecies paratuberculosis (M. paratuberculosis)*. Other than on artificial media, this bacterium only grows inside cells of a living animal. However, it can survive in the environment for at least one year and probably longer. When an animal becomes infected, the bacteria grow very slowly. In fact, once an animal is infected, it can take years for the bacteria to replicate enough to

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cause clinical disease. Animals affected by Johne's disease include cattle, sheep, goats, and camelids.

The Disease

Johne's disease is unique in that the initial infection usually occurs years before clinical signs of the disease are seen. The majority of cattle become infected with the causative agent of Johne's disease as calves less than six months of age. As cattle get older, they become less susceptible to infection with *M. paratuberculosis*. Calves become exposed to the bacteria by ingesting material contaminated with the Johne's disease organism. The bacteria then infects and replicates in the small intestines. As the bacteria grows slowly over time, the animal's immune system tries to attack the bacteria. Unfortunately, the immune response is usually ineffective in eliminating the bacteria. In fact, a combination of the growing bacteria and the immune system response leads to chronic damage of the intestines. This damage, which can take years to occur, eventually results in diarrhea and weight loss despite a good appetite; these responses are the characteristic clinical signs of Johne's disease. Once clinical signs begin, progression of the disease is very rapid and cows may become debilitated within a matter of weeks. Before diarrhea and weight loss begin, there is evidence that the smoldering disease may contribute to an increased rate of other problems in infected cattle. This is referred to as subclinical Johne's disease. These problems may include decreased milk production and increased susceptibility to other infectious diseases such as mastitis.

Survival in the Environment

Early studies demonstrated that *M. paratuberculosis* could be found for up to nine months in artificially inoculated sterilized pond water held at room temperature (Lovell et al., 1944). When distilled water (pH 7.2) was inoculated with 10^6 (1 million) cells/ml of *M. paratuberculosis* and viable counts determined on a monthly basis, the time for a one log reduction was just over 68 days, and viable *M. paratuberculosis* cells were found up to 455 days (Collins et al., 1984).

Lovell et al. (1944) conducted studies using naturally infected bovine feces in which the infected fecal matter was exposed to a variety of natural conditions, such as freezing, drying, sunlight, changes in ambient temperature, and rain, with regular attempts to re-isolate *M. paratuberculosis*. In general, they found survival of *M. paratuberculosis* in feces kept outdoors up to 152 to 246 days. Drying of soil appeared to shorten the survival (Lovell et al., 1944). This work has generated the commonly made statement that *M. paratuberculosis* survives a year on pastures.

Reports on the survival of *M. paratuberculosis* in manure slurries indicate that, although the concentration of organisms drops off rapidly, the organism can be re-isolated from various types of artificially inoculated slurry material for as long as 252 days (Jörgensen, 1977). No research on survival of *M. paratuberculosis* in composted animal wastes has been reported. However, the physical profiles of properly composted animal waste suggests that such conditions would be lethal to the organism.

Observations regarding the associations among soil pH, calcium, or iron and the incidence of paratuberculosis have been made in England, France, The Netherlands, and the U.S. By careful epidemiological analysis in the state of Michigan, the practice of application of lime to pastures (a practice that should increase soil pH) in 1993 was associated with 10-fold lower odds of a dairy herd being serologically test-positive for *M. paratuberculosis* infection in

1996 (Johnson-Ifearulundu and Kaneene, 1977). These epidemiological observations have led to speculation concerning mechanisms by which soil pH, or its interaction with soil calcium and iron contents, affect *M. paratuberculosis* survival. No laboratory studies have been done to verify if a particular soil type affects *M. paratuberculosis* survival or to explain the mechanism.

Understanding that *M. paratuberculosis* can survive for long periods of time is important when designing Johne's disease control programs. Because of the long survival time, a variety of environments can easily become contaminated with *M. paratuberculosis* and serve as a source of transmission to susceptible populations. Some of the more important environments include calving areas, calf and replacement housing, feed and feed handling equipment, water sources, and pastures.

Transmission

The primary source of infection is feces that contain the causative bacteria. Infected cattle can produce large amounts of the bacteria and shed this organism in their feces. Typically, in cows with clinical Johne's disease (diarrhea and weight loss), one gram of feces can contain one billion Johne's disease organisms. Even infected cattle not yet showing the typical clinical signs of diarrhea may shed the bacteria in their feces. Most infected cattle do not begin shedding the Johne's organism until they are adults. Calves less than six months of age are most susceptible to infection. **Any method by which calves become exposed to fecal material from adult cattle may serve as a source of infection with the Johne's disease organism**. This may include being born in a dirty maternity pen, nursing a dirty teat, being housed in direct contact with adult cows, using common feeding/manure handling equipment (skid-loader), or manure run-off from mature cow areas going through the environments of young calves.

Another important source of transmission is milk and colostrum. Viable *M. paratuberculosis* are present in the colostrum and milk of cows with Johne's disease (Streeter et al., 1995; Sweeney et al., 1992). About one-third of cows infected with Johne's disease, whether they are showing clinical signs or not, will shed the bacteria in their colostrum or milk. Cows with clinical disease or asymptomatic cows with heavy fecal shedding may shed 5 to 8 cfu of *M. paratuberculosis*/50 ml of milk (Sweeney et al., 1992). Although the natural shedding of organisms into milk may be low, it has been suggested (Nauta and van der Giessen, 1998) that fecal contamination of colostrum and milk from cows that are shedding high numbers of *M. paratuberculosis* may be a significant risk of transmission to the young calf. Regardless, feeding of *M. paratuberculosis* contaminated colostrum or milk to young calves can lead to their infection with the disease. One management practice that has been used to decrease this risk is to pasteurize waste milk prior to feeding. Although published studies on the heat resistance of this bacterium in milk have given widely differing results (Lund et al., 2002), it has been shown that batch pasteurization of milk at 65°C (150°F) for 30 minutes will eliminate or reduce the amount of bacteria to an insignificant level (Stabel, 2001). Pasteurization of waste milk may be beneficial in preventing other important calf hood diseases that can be passed thru milk, including Salmonellosis and *Mycoplasma bovis*.

Finally, calves can become infected in utero before they are born. Approximately 20% of cows with Johne's disease will pass the causative bacteria across their placenta to the developing fetus. The risk of this happening increases dramatically in cows with clinical signs of Johne's disease.

Diagnosis

Chronic diarrhea, rapid weight loss, and good appetite in cattle older than two years of age is highly suggestive of Johne's disease. These findings warrant further laboratory investigation. There are two basic ways to diagnose Johne's disease in cattle. The first is to identify the organism in the feces of an infected animal. This is most commonly done by culturing feces for the Johne's bacterium. Unfortunately, shedding of the bacteria in feces does not start until later in the progression of the disease, and even then, shedding can be intermittent. In other words, although infected with Johne's disease as a calf, cattle usually do not shed the bacteria in feces until the disease has progressed during adulthood. Therefore, cattle early in the course of the disease that are not shedding bacteria in their feces will be missed using fecal culture. Another problem with culturing for Johne's organisms is that using standard methods, it takes between 8 to 16 weeks for the bacteria to grow. This is a problem when rapid answers are needed concerning the status of an animal or herd. Faster culture methods are being developed and coming on line, such as the BACTEC® system, which can cut the culture time by 50%. In general, the sensitivity of culture for *M. paratuberculosis* is in the range of 50%. The specificity is 100%. A cow with positive culture result should be considered infected with Johne's disease. Given a sensitivity of 50%, a negative culture result cannot rule out the possibility that a cow is infected with Johne's disease.

The second method of diagnosing Johne's disease is to look for an immune response by the infected animal to the Johne's organism. Currently, the most commonly used test is called a Johne's ELISA. Other less commonly used immune detection assays include the agar gel immunodiffusion **(AGID)** assay and the compliment fixation **(CF)** assay. These tests identify antibodies that are produced by the cow in response to the Johne's disease bacteria infecting the intestinal tract. However, as with fecal shedding, the development of these antibodies is slow to occur. So, although infected as a calf, an immune response sufficient enough to produce detectable antibodies usually does not occur until adulthood. Again, the further the disease has progressed, the more likely that detectable antibodies are being produced. Therefore, cattle early in the course of the disease that have not mounted a sufficient immune response will test negative on the Johne's disease ELISA (false negative). A general rule of thumb is that if all cattle two years of age and older are tested for Johne's disease, the ELISA will identify 50% of the infected cows. The advantage of the ELISA test is that it is rapid and relatively inexpensive. The Johne's ELISA has historically been used on blood samples. Recent work has adapted the ELISA to milk samples and shown comparable results to those found with blood (Hendrick et al., 2003). The ELISA is typically used as a herd-monitoring tool and to assign risk to cows as to the likelihood that they are infected with Johne's disease. This is a powerful management tool that is important in the control of Johne's disease.

Control and Prevention

Because of the nature of the disease, the number of cattle infected with Johne's disease will increase over time if control measures are not instituted. There are two major strategies used to control Johne's disease: 1) reduce the risk of calves becoming exposed to and subsequently infected with *M. paratuberculosis* and 2) identify and manage infected cows.

Good management of calves is important to reduce their risk of being exposed to the

Johne's organism. The first step is to make sure that calves are born in a clean, manure free environment. Calves should then immediately be removed from their dams. Colostrum should be fed from Johne's test negative cows only. If the Johne's status of cows is unknown, feed colostrum from individual dams to their calves only. Do not pool colostrum because this increases the risk of spreading Johne's disease from one infected cow to many calves. Following colostrum, a high quality milk replacer, or pasteurized whole milk should be fed. Feeding of unpasteurized pooled waste milk can infect many calves if any cows are shedding the *M. paratuberculosis* in their milk. Calves should be housed separately in a clean environment that has no contact with the adult herd. Equipment that is shared between the calf and cow environments should be properly disinfected or, if possible, avoided. Feeding of weigh-back feed from adult animals to replacement heifers should be discouraged. Sharing of pastures between adults and young stock should be avoided. Similarly, application of manure to pastures used by young stock is not recommended. Good biosecurity should be practiced among personnel that handle both adult and young cattle. This includes washing hands and cleaning and disinfecting boots and clothing.

Purchasing of new animals is an important risk for introducing Johne's disease into an operation. Because of the low sensitivity of current tests, testing of individuals on arrival should not be relied on for reducing the risk of purchasing infected cows. Instead, animals should be acquired from low risk operations. These would include herds that have had no evidence of Johne's disease or have done some type of surveillance testing to establish the likelihood that they are free of Johne's disease. It is important to realize that many of these practices are good management practices that will reduce the incidence of other diseases. This "spill over" effect will likely be beneficial in improving overall herd health and performance.

Reducing the farm contamination with *M. paratuberculosis* is the goal with managing infected cows. Cows that are in the clinical stages of Johne's disease are the biggest source of infection for young calves and should be culled immediately. Several testing strategies can be employed to identify and assign risk to other cows in the herd and then manage them accordingly. All strategies should have a common goal in mind, that being to reduce the risk that *M. paratuberculosis* is flowing from infected or potentially infected cows to susceptible populations, that being young calves.

For an excellent web resource on Johne's disease, go to www.johnes.org.

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Nutrition and Reproduction: Formulating for Bovine Fertility

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Abstract

Dietary nutrients not only affect productive but also reproductive performance. Supplying sufficient amounts of vitamins A and E may improve the immune status of the periparturient cow, thus reducing the incidence of mastitis and/or retained fetal membranes, which in turn may improve pregnancy rates. Based on a limited number of studies, the current feeding recommendation (NRC, 2001) for vitamin A (50 IU/lb of body weight) appears sufficient, whereas that for vitamin E (0.73 IU and 0.36 IU per lb of body weight for pre- and postpartum cows, respectively) may be conservative in situations where plasma concentrations of α-tocopherol are < 3.0 to 3.5 ug/ml. The recovery of healthy embryos may improve from cows undergoing superovulation if vitamin A is injected. Reproductive performance will not be improved by increasing the dietary concentration of P above 0.37% (DM basis). Feeding crude protein **(CP)** or ruminally degradable protein **(RDP)** in gross excess of need will reduce pregnancy rate or delay first ovulation. Concentrations of urea nitrogen in blood **(BUN)** of > 19 to 20 mg/100 ml for cows and > 16 mg/100 ml for virgin heifers may indicate that the animal is at risk of reduced reproductive performance. Evidence is accumulating that the design and delivery of supplemental unsaturated fatty acids to the lower gut for absorption [specifically linoleic acid, linolenic acid, eicosapentaenoic acid **(EPA;** C20:5**)**, and docosahexaenoic acid **(DHA;** C22:6**)**] may target reproductive tissues to improve reproductive function and fertility. It is unclear whether these improvements are mediated through the endocrine system, by alleviating an essential fatty acid **(EFA)** nutrient deficiency, by changing the phospholipid composition of membranes, or by some other avenue.

Introduction

The scientific literature contains evidence that the nutrient status of lactating dairy cows can have a direct bearing on reproductive status. Pregnancy rate has been improved by manipulating the mineral (Hurley and Doane, 1989), vitamin (Seymour, 2001), energy (Butler, 2001), protein (Butler, 1998), and lipid fractions (Staples et al., 1998) of the diet. Nevertheless, the amount of knowledge in this area is not great. Collective efforts of nutritionists, reproductive physiologists, immunologists, and veterinary practitioners and researchers are needed in order to advance our understanding of both the extent of potential impact and the physiological mechanisms by which these nutrients act in vivo. The challenge to characterize the factors contributing to conception and embryo development, as well as developing strategies to use to improve embryo survival is complex, involving steroidogenesis, cell proliferation, follicle development, ovulation, fertilization, corpus luteum development and maintenance, oviductal and uterine functions,

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embryo implantation, and subsequent fetal growth. Indeed, our current daily production and reproductive management systems impact all of these coordinated events and need to be optimized if reproductive efficiency in lactating dairy cows is to be enhanced. Dietary vitamins A and E, protein, fat, and phosphorus are nutrients selected to briefly review in this paper in terms of their potential impact on reproductive health and fertility of dairy cows.

Vitamins A and E The Immune System, Health, and Reproduction

The incidence of diseases and disorders can have a negative impact on reproductive performance. In a study involving 2087 cows, those that had clinical mastitis during the first 45 days postpartum were at 2.7 times greater risk of abortion within the next 90 days compared to those without mastitis (Risco et al., 1999). Coliform organisms that can cause mastitis liberate lipopolysaccharide endotoxin which in turn can cause an inflammatory response by the cow so that she releases prostaglandin $F_{2\alpha}$ **($PGF_{2\alpha}$)**. High enough concentrations of $PGF_{2\alpha}$ in the blood can result in luteolysis and therefore embryo loss. Although mastitis-causing gram positive bacteria do not produce endotoxins, the peptidoglycans comprising their cell wall can elicit an inflammatory response by the cow as well. Cows having mastitis after their first artificial insemination **(AI)** required an extra AI for pregnancy, thus having more days open than those without mastitis (Barker et al., 1998). Incidence of mastitis occurring close to first AI resulted in lower pregnancy rates for those cows compared to cows without such untimely mastitis in the Netherlands (Loeffler et al., 1999). Also the 'risk' of pregnancy (odds ratio) was reduced if cows experienced displaced abomasum (0.25; P = 0.036), retained fetal membranes (RFM) (0.55; P = 0.004), and loss of 1 body condition score **(BCS)** (0.80; P = 0.007) but not milk fever (0.85; P = 0.12) (Loeffler et al., 1999).

Management and nutritional efforts that maintain a healthy immune system may reap benefits for reproduction. The periparturient period is a time of significant stress on the immune system (Goff and Horst, 1997). The nutritional effects on immunity have not received a lot of research attention, although vitamins A (retinol) and E (α-tocopherol) may have received the most. Plasma concentrations of retinol, β-carotene, and α-tocopherol decreased by at least 50% from approximately 4 weeks prepartum to the time of calving, to levels that may be considered below chronic deficiency concentrations (Michal et al., 1994). Additional supplementation around this time period may have benefits for improved immunity.

Vitamin A

Vitamin A is ne0cessary for maintenance of skeletal muscle and epithelial tissue, as well as for normal immune function, vision, growth, and spermatogenesis (NRC, 2001). The 1989 NRC published requirement for vitamin A was based on studies conducted between 1937 and 1957, in which cows showed normal reproductive efficiency until the intake of β-carotene (72 IU of vitamin A) dropped below 0.18 mg/kg of body weight **(BW)** as supplied by prairie grass hay. Incidence of abortions and RFM increased when intakes dropped below that amount. Milk production averaged ~8000 lb in 292 days of lactation. Diets were very fibrous, containing no starchy grains. It is reasonable to assume that today's cows producing 3 to 4 times more milk and consuming lower fiber diets that result in greater ruminal destruction of retinol would require more dietary vitamin A. The new dairy NRC (2001) increased the daily vitamin A requirement from 34.5 to 50 IU/lb of BW for both dry and lactating cows for these reasons, as well as for the potential for improvement in mammary gland health. A 1430 lb cow supplemented at the current recommended

guideline would consume 71,500 IU daily. Clinical signs of a vitamin A deficiency do not appear until plasma concentrations drop below 10 ug/dl; <20 ug/dl may indicate a subclinical deficiency (McDowell, 2000). However plasma concentrations are generally a poor indicator of vitamin A intake because the liver stores vitamin A and supplies vitamin A to the blood stream, carried by retinol binding protein. Relationships between concentrations of plasma retinol and immune status, mammary gland health, or reproduction have been weak (Weiss, 1998).

Vitamin A and immune system

The literature contains only limited documentation of improved immune responses and/or reduced incidence of clinical mastitis due to vitamin A supplementation. Cows supplemented with 120,000 IU/day of vitamin A starting 4 weeks prior to calving date had an improved nonspecific, cellular host defense system than cows given 0 IU/day, as evidenced by increased killing of *S. aureus* by blood polymorphonuclear neutrophils at week 0 and 1 postpartum; however, supplementation did not affect mammary host defense (Michal et al., 1994). In another study in which the control cows were supplemented at 53,000 IU/day from 6 weeks prior to dry off through 2 weeks after dry off, increasing the vitamin A supplementation to 213,000 IU/day had no effect on neutrophil function at week -6, 0, and 2 in relation to time of dry-off (Tjoelker et al., 1990).

Vitamin A and mastitis

In a study involving 326 Canadian Holstein cows, blood samples were collected weekly from 1 week before expected calving date to 1 week postpartum (LeBlanc et al., 2004). Using logistic regression, the authors determined that cows having a 100 ng/ml greater concentration of serum retinol the week before parturition were 2.5 times less likely to have mastitis (n = 23) in the first 30 days postpartum (n = 303 nonmastitic cows). Thirty Finnish herds showed no such relationship between serum vitamin A concentration and the incidence of clinical mastitis, although the mean vitamin A concentration was a good bit higher than that of the Canadian cows (Jukola et al., 1996). Workers at Penn State did not report a significant positive benefit to mammary gland health by increased vitamin A supplementation when the control cows were supplemented also. Increasing the vitamin A intake from 50,000 to 170,000 IU/day from approximately the last 2 weeks of lactation through the first 6 weeks of a new lactation (120 to 140 days total) did not affect the number of new intramammary infections or the cases of clinical mastitis of Holstein cows (Oldham et al., 1991). However, production of 4% fat-corrected milk **(FCM)** was increased by 6.2 lb/day at the higher supplementation rate. All cows in this study had good concentrations of serum retinol even on the day of calving (>34.5 ug/dl).

Vitamin A and reproduction

Vitamin A is clearly present at the ovarian level and in steroidogenesis. Higher vitamin A concentrations are found in non-atretic follicles, and this might indicate a role of vitamin A in follicular development (Schweigert and Zucker, 1988). The synthesis of progesterone was depressed markedly in vitamin-deficient compared to normal rats (Jayaram et al., 1973). It is known that vitamin A influences the Cholesterol Side Chain Cleavage Enzyme (CSCCE) that converts cholesterol to pregnenolone (Ganguly et al., 1980) and also the enzyme Δ^5-3β-hydroxyesteroid dehydrogenase that converts pregnenolone to progesterone (Islabão, 1982). When incubated in vitro with retinol, bovine luteal cells had a 3 to 10 fold increase in progesterone concentration over controls (Talavera and Chew, 1987). Although

based on very limited studies, it appears that supplying vitamin A in amounts much above NRC (2001) recommendations has not benefited reproductive performance of cows bred normally. Increasing supplemental vitamin A (100,000 or 1 million IU/day) to cows (n = 78) the first 120 days postpartum did not affect the number of days to first service (63 days) nor conception rates at first AI service (28%), although the estrus detection rate following prostaglandin treatment was greater for cows fed the higher amount of vitamin A (60 vs. 26%) (Tharnish and Larson, 1992). A follow up study (n = 52) using the same dietary treatments failed to find any reproductive benefit for cows consuming 1 million IU/day nor were circulating progesterone concentrations changed. When cows undergo superovulation, additional vitamin A has proved beneficial. Shaw et al. (1995) reported that vitamin A (retinol palmitate) injection at 1 million IU at the first superovulatory dose of follicle stimulating hormone **(FSH)** increased the number of transferable embryos (5.87 vs. 3.13) in comparison to a control group injected with a placebo solution. The total number of embryos was not affected by vitamin A injection (11.1 vs. 8.2 for vitamin A and control groups, respectively). Amaral (2003) injected four different amounts of vitamin A (0, 500,000, 1,000,000 and 1,500,000 IU of retinol palmitate) into donor nonlactating *Bos indicus* cows (n = 64) grazing brachiaria forage and supplemented with millet silage and concentrate without vitamin A supplementation. Injections were given along with the first superovulatory injection of FSH. The number of viable embryos recovered in the group given vitamin A increased (3.6 vs. 6.1, 6.5 and 6.7 for 0, 500,000, 1,000,000 and 1,500,000 IU of retinol palmitate, respectively). An increase in the number of viable embryos recovered also was reported when supplementing a source of β-carotene to donor nonlactating dairy cows (n = 33) fed a TMR without a vitamin A supplement (Amaral et al., 2001). Nonlactating cows were supplemented with 6.6 lb/day (as-fed) of pumpkin during 20 days before flushing. Cows that consumed pumpkin produced more ($P < 0.02$) viable embryos than the control group (6.4 vs. 5.3). Supplemental β-carotene or animal conversion of β-carotene in pumpkin into vitamin A possibly improved embryo quality. Unfortunately, the vitamin A status of the control cows was not determined in any of these studies.

Summary

Evidence is lacking to support the supplementing of vitamin A above NRC (2001) recommendations in order to reduce the incidence of mastitis and, in turn, improve pregnancy rate. However, superovulated cows may produce a greater number of healthy transferable embryos if injected with vitamin A.

Vitamin E

Vitamin E is a lipid soluble cellular antioxidant having important roles in maintenance of cellular membranes, immunity, and reproduction (NRC, 2001). The form that is most common in feeds and is most biologically active is α-tocopherol. Unlike vitamin A, it is not thought to be degraded by ruminal microorganisms. A specific requirement for vitamin E has not been defined yet because titration studies are lacking. The recommended rate of supplemental vitamin E is 0.73 and 0.36 IU/lb of BW for pregnant dry cows and lactating cows, respectively. A 1430 lb cow supplemented at the recommended guideline of the 2001 Dairy NRC would consume daily ~1000 IU prepartum and ~ 500 IU postpartum. Cows fed fresh forages will require less supplemental vitamin E than this. Unlike plasma retinol concentrations, plasma α-tocopherol concentrations do reflect vitamin E intake. Based on optimizing neutrophil

function and minimizing clinical mastitis, the minimal acceptable concentration of plasma α-tocopherol for the periparturient dairy cow is 3 to 3.5 ug/ml (Weiss, 1998). Cows at later stages of lactation may have a different minimal acceptable concentration, as they may be under less immunological stress. The ratio of α-tocopherol to cholesterol in blood may be a better indicator of a cow's vitamin E status because α-tocopherol is transported by lipoproteins.

Increased supply of vitamin E to cell membranes may improve immune function by protecting neutrophils from oxidative damage following their intracellular killing of ingested bacteria. Neutrophil function in blood was improved in cows 1) fed 500 IU/days for 30 days postpartum compared to unsupplemented cows, 2) fed 3000 IU/day from 8 weeks prepartum to 4 weeks postpartum compared to unsupplemented cows, 3) fed 3000 IU/day from 4 weeks prepartum to 8 weeks postpartum and injected with 5000 IU at 1 week prepartum, and 4) injected with 3000 IU at 10 and 5 days before expected calving in blood collected at calving (supplementing 0 or 1040 IU/day had no effect) as reviewed by Weiss (1998).

Vitamin E & retained fetal membranes

If immune function is improved, then incidence of retained fetal membranes **(RFM)** and mastitis might decline. Indeed, impaired neutrophil function has been reported to occur in cows having RFM (Kimura et al., 2002). A reduction in the incidence of RFM has been a consistent benefit of Se-sufficient cows fed supplemental vitamin E daily during the dry period (1000 IU/day, Miller et al., 1997; 740 IU/day, Harrison et al., 1984) compared to those not supplemented. Supplementation at 2000 IU/day also proved superior to supplementing at 1000 IU/day starting at 14 days prepartum in reducing RFM (Baldi et al., 2000). Supplementing at 1000 IU/day the last 6 weeks prepartum did not reduce RFM, but the amount of vitamin E offered may not have been sufficient, as plasma α-tocopherol only averaged 1.15 ug/ml in the supplemented cows (Campbell and Miller, 1998). A one-time injection of a relatively small amount of vitamin E (700 IU) and 50 mg Se at ~21 days prepartum also reduced RFM (3 versus 10.1%) in a large study (Arechiga et al., 1994) but not in other studies using one injection of similar small amounts (500 to 700 IU) (see Harrison et al., 1984). One larger injection of 3000 IU of vitamin E at ~14 days prepartum reduced RFM (6.4 vs. 12.5%) and metritis (3.9 versus 8.8%) in a 420 cow study (Erskine et al., 1997). Injecting 3000 IU at ~ 7 days prepartum tended to reduce the risk of RFM by ~44% in primiparous but not multiparous cows in a 1142 cow study (LeBlanc et al., 2002). Pregnant heifers may have benefited from the vitamin E injection more than pregnant cows because heifers consume less DM and therefore less vitamin E, they may not receive a vitamin fortified diet in transition, or they may take up vitamin E into tissues better due to less tissue mobilization compared to cows. From this same study but using a subset of cows (n = 138), the authors determined that for every 1 ug/ml increase in serum α-tocopherol prepartum, the risk of RFM decreased by 21%. However, one injection of 3000 IU of tocopherol acetate raised serum α-tocopherol only by 0.4 to 0.5 ug/ml (LeBlanc et al., 2004). In addition, the authors reported that there was no consistent threshold of circulating α-tocopherol that "neatly and repeatedly classifies cows as to risk of RFM." This is not surprising since the cause of RFM is multifactorial, including endocrine, nutrient, and immune factors (Goff and Horst, 1997).

Vitamin E and mastitis

Supplementing vitamin E at 1000

IU/day during the dry period has reduced somatic cell counts **(SCC)**, clinical mastitis, and/or duration of clinical mastitis compared to control cows supplemented at 0 or 100 IU/day as reviewed by Weiss (1998) and Seymour (2001). However, when Se status was suspect (plasma Se concentrations < 50 ng/ml), feeding 1000 IU/day did not improve mammary health. Even when intake of vitamin E was at 1000 IU/d prepartum and 500 or 1000 IU/day postpartum, mammary gland health was improved when intakes of vitamin E were increased to 2000 or 4000 IU/day (Baldi et al., 2000; Weiss et al., 1997). Weiss et al. (1997) reported that cows having a concentration of plasma α-tocopherol of < 3.0 ug/ml at calving were 9.4 times more likely to have clinical mastitis the first 7 days postpartum than those at > 3.0 ug/ml.

Vitamin E and reproduction

Cows and heifers fed 1000 IU/day of vitamin E for only 6 weeks prepartum had fewer days to first observed estrus (42 vs. 62 days), to first AI (62 vs. 72 days), and to pregnancy (113 vs. 145 days) compared to animals receiving no supplemental vitamin E (Campbell and Miller, 1998). Injecting 500 IU of vitamin E and 40 mg of Se reduced RFM (13.3 vs. 30%) and days to first AI (60 vs. 103 days) (Kim et al., 1997). Increasing vitamin E intake from 1000 to 2000 IU/day from 2 weeks prepartum to 1 week postpartum reduced the number of days open (84 vs. 111 days) and the number of AI per conception (1.3 vs. 2.2) (Baldi et al., 2000). Pregnancy rate and concentration of serum α-tocopherol were highly positively correlated in beef heifers. Pregnancy rate was not improved once serum α-tocopherol exceeded 3 ug/ml (Laflamme and Hidiroglou, 1991).

Summary

Cows in good Se status and supplemented with vitamin E at or above the dairy NRC (2001) guidelines show improved immune status and reduced incidence of RFM compared to unsupplemented cows. Giving a one-time injection of 3000 IU at 7 to14 days before expected calving date reduced the incidence of or the risk of RFM, with only heifers benefiting in one study. Supplementing with vitamin E at NRC (2001) rates or at 2 to 4 times the NRC (2001) rates reduced mammary gland infections. Plasma concentrations of α-tocopherol may be a reliable indicator as to whether cows will reap a health or reproductive benefit from supplemental vitamin E.

Phosphorus

Surveys of dairy producers in the U.S. revealed that lactating cow diets contain 15 to 20% excess P based on NRC (2001) requirements. Reasons for this level of feeding include concerns over a potentially low availability of P in feedstuffs and a potential reduced reproductive performance of cows fed diets with lower concentrations of dietary P. Concentrations of dietary P below 0.25% of DM may negatively impact microbial fermentation, which in turn may negatively affect DM intake and body weight. Animals unable to maintain body weight are at risk for low reproductive performance. Studies published prior to 1950 using cattle maintained on pastures deficient in P, and likely other nutrients, reported decreased calf crops. In more recent times, Wisconsin researchers have conducted several long-term studies using graded dietary concentrations of P and measured both productive and reproductive performance. For 308 days, Holstein cows (n = 26) were fed a diet of either 0.31, 0.40, or 0.49% P by increasing the amount of monosodium phosphate in the diet (Wu et al., 2000). The number of days to first estrus and first AI were greatest for cows fed the 0.40% P diet. The number of services per conception by 206 days

in milk increased linearly as dietary P increased. Overall, milk production was not different (24,361 lb average) although cows fed the 0.31% P diet produced less milk during the last third of lactation. In a second study, Holstein cows were fed diets of either 0.31 to 0.38% P (n = 14) or 0.44 to 0.48% P (n = 16) over two consecutive lactation cycles (Wu and Satter, 2000). In year one, dietary P concentration did not influence any productive or reproductive measurement. All cows were pregnant by 230 days in milk. In year 2, cows fed the higher P diet tended to have more days to first estrus and a lower conception rate at first service and at 230 days in milk. Again, milk production and composition were unaffected by diet. In a third Wisconsin study involving far more cows (n = 267), diets of 0.37 and 0.57% P supported similar amounts of milk production and similar conception rates (Lopez et al., 2004). Feeding diets with P concentrations of 0.35 to 0.36% (NRC, 2001) appear sufficient to meet the P requirement. Even if P intake is somewhat deficient during the early days postpartum when DM intake is low, cows are likely able to mobilize P (1.3 to 2.2 lb) from bone to meet a temporary P deficiency and then to replace the bone P when P intake exceeds the P requirement later in lactation.

Summary

Reproductive performance will not be improved by increasing the dietary concentration of P above 0.37 to 0.38% (DM basis).

Excess Dietary Protein Effects

Protein metabolism

Dietary nitrogen is a source of nonprotein nitrogen, amino acids, and peptides for growth of ruminal microorganisms. The utilization of that dietary nitrogen depends heavily on the supply of high energy carbohydrates in the diet. Ruminally degradable protein (**RDP**) that is consumed in greater amounts than can be utilized by the ruminal microorganisms is absorbed through the rumen wall, travels to the liver where it is converted to urea because of its potential toxicity, the urea leaves the liver via the bloodstream, equilibrates with body tissues, and is concentrated in the kidney to be excreted in the urine. Urea also can be produced from ammonia derived from amino acids deaminated by the liver. These amino acids can originate from body tissues, as well as from the diet (ruminally undegradable protein (**RUP**)) and ruminal microbes that reach the small intestine. These amino acids in the circulatory system that are not picked up by the mammary gland or deposited in tissues are taken up the liver and metabolized for energy. Therefore urea concentrations can increase in the animal's system if RDP or RUP is consumed in excess of metabolic need or if dietary energy is deficient to prevent full utilization of RDP by ruminal microbes. Accurate measurement of urea nitrogen in blood (**BUN** or **PUN** for plasma urea nitrogen) and milk (**MUN**) has been used to reflect the status of protein utilization and the protein-energy relationship within the ruminal environment. See Staples and Thatcher (2000) for a discussion of assessing urea status using blood and milk samples.

Urea status

A MUN of 13.5 mg/100 ml is predicted to be a mean value for a cow producing 22,000 lb of milk over a 305-day lactation when fed according the NRC guidelines (Jonker et al., 1998). Swedish workers reported a mean MUN of 13.9 mg/100 ml when cows were fed diets properly balanced for protein and energy (Oltner and Wiktorsson, 1983).

The form of dietary CP (RUP vs. RDP) can greatly influence the degree to which

microbes can incorporate nitrogen and therefore affect urea production by the liver. Roseler et al. (1993) demonstrated how the form of dietary protein can influence MUN concentrations. As the dietary concentrations of CP (~15%) and NE_L (0.68 Mcal/lb) were kept the same but the RDP was overfed and the RUP underfed, the MUN increased from 11.6 to 13.4 mg/100 ml. The PUN increased from 14.8 to 16.5 mg/100 ml. Overfeeding RUP alone (120% of requirement) also elevated MUN to a similar value (14.4 vs. 13.4 mg/100 ml) as that of cows overfed RDP. It is these greater MUN concentrations that may reflect an excessive nitrogen intake that may have a compromising effect on metabolism, specifically reproductive performance.

Urea status and reproductive performance

Elevated concentrations of urea in blood or milk have been associated with reduced reproductive performance of lactating dairy cows. Differing BUN concentrations were created by feeding diets of different CP concentrations and resulting fertility measured (Table 1). In 6 of the 10 studies, conception or pregnancy rates were depressed in the group of animals fed diets of 19 to 21% CP compared to 13 to 17% CP. In a sixth study, Folman et al. (1981), 3 of 20 cows in the high CP group which had been inseminated a minimum of four times were culled prior to pregnancy diagnosis but were counted as pregnant in the final analysis; therefore, the 44% conception rate was an optimum number and could have been as low as 30%. This study too may have reported a significant depression in fertility if the fate of those three cows were known. Although the main effect of diet was not significant, Barton et al. (1996) reported that conception of Jersey cows (84 vs. 17%) was negatively affected by consuming a high CP diet compared to Holstein cows (38 vs. 62%) (diet by breed interaction). Although conception rates were similar, Carroll et al. (1988) reported a tendency (P = 0.17) for days open (72 vs. 82) and services per conception (1.5 vs. 1.8) to be greater for cows fed the high CP diet. Howard et al. (1987) reported no effect of CP intake on reproductive measurements in spite of elevated BUN concentrations.

Diets that were isonitrogenous but oversupplied RDP negatively impacted reproduction (Table 2). Conception rates were depressed or the number of days to first ovulation was greater when cows consumed more RDP, although BUN concentrations did not always differ between treatments.

Others have examined the relationship of BUN to reproductive performance among farms or among cows within a farm. Nine Pennsylvania dairy farms contributed 332 cows to a study examining the relationship between serum urea nitrogen (**SUN**) and conception rate (Ferguson et al., 1993). Most of the herds were fed about a 16.5% CP diet. The SUN concentrations, measured every 2 weeks for each cow, were averaged between 50 and 150 days postpartum. Sixty, 25, and 15% of the cows were classified as having an average SUN value of <14.9, 15 to 19.9, and > 20 mg/100 ml, respectively. The likelihood of conception rate decreased with increasing SUN concentration above 20 mg/100 ml using one type of statistical analysis, but another type of analysis indicated a lowered probability of conception when SUN was >14.9 mg/100 ml. Farms with overall lower conception rates were more sensitive to conception failure due to high SUN values compared to farms with overall higher conception rates.

Diets containing from 17.5 to 19% CP were fed to 160 multiparous cows at the Cornell University farm (Butler et al., 1996). Average PUN on the day of first AI (post 60 days of lactation) was 18.9 $\pm$ 0.3 mg/100 ml.

The pregnancy rate of cows with an above average PUNvalue was lower compared to cows with a below average PUN value (53 vs. 35%). They repeated the study using 155 cows, and only MUN values were determined on the day of AI instead of PUN. The mean MUN value was 22.3 $\pm$ 0.4 mg/100 ml. The mean pregnancy rate of cows having a MUN value of < 19 mg/100 ml was 68% and was greater than the 47% for cows having a MUN > 19 mg/100 ml.

Virgin heifers too have demonstrated a lower first service conception rate when PUN values were elevated by increasing the CP of the diet from 15.5 to 21.8% (Elrod and Butler, 1993). First service conception rates were 82 and 61% for the two groups, respectively. A dividing of the heifers into three groups, based upon whether their PUN values were below (< 9.9), within (9.9 to 16), or above (> 16 mg/100 ml) one standard deviation from the mean, showed conception rate to decrease most dramatically when PUN exceeded 16 mg/100 ml, namely 87.5%, 72.5%, and 42.8%, respectively.

Swedish workers measured the MUN concentrations from bulk tank samples collected weekly over a 4 to 5 month period involving 29 herds producing an average of 17,400 lb of fat-corrected milk **(FCM)** (Gustafsson and Carlsson, 1993). The average MUN was 11.2 $\pm$ 0.2 mg/100 ml. A MUN concentration between 10 to 16 mg/100 ml was associated with the fewest days to first service (~80 days), with days to first service increasing to 128 days when MUN averaged 20 mg/100 ml.

Using DHIA records from Ohio (n = 1249), cows having an average MUN concentration in the months before conception of >15.4 mg/100 ml were at least 1.4 times more likely to not conceive than cows having lower MUN averages (Rajala-Schultz et al., 2001). In another study using cows (n = 1073) managed commercially (Melendez et al., 2000), the MUN concentration within the first 30 days of first AI was not associated with pregnancy. However cows classified as having >17 mg/100 ml MUN were 18 times at higher risk of nonpregnancy than cows with lower MUN when bred during the summer season.

Mechanisms of action of excess protein on reproduction

Several hypotheses have been proposed to explain why overfeeding protein might negatively influence reproductive performance. The uterine environment may be adversely modified by overfeeding protein so that the normal processes leading to fertilization, embryo development, and implantation of the conceptus are hampered. In different studies, the uterine environment of animals overfed CP had elevated concentrations of urea, lowered pH, or lower concentrations K, Mg, and P (Butler, 1998). Because the uterine environment influences embryo development, these changes may compromise normal fertility processes. In other words, cows may be conceiving equally well when fed high CP diets, but the embryos are not surviving. Early embryonic mortality was suspected in Holstein heifers (n = 80) that were fed 21.8% compared to 15.5% CP diets (Elrod and Bulter, 1993). Of the 16 heifers fed the high CP diet that did not conceive to first service, seven heifers demonstrated extended interestrus intervals of 26 to 36 days, whereas the seven control heifers that did not conceive had normal interestrus intervals of 18 to 22 days. Further work in this area is needed to test this hypothesis.

Another hypothesis to explain the negative impact of high concentrations of systemic nitrogen on reproductive performance states that the energy costs of detoxifying large amounts of ammonia to urea may aggravate

an existing energy shortage postpartum such that metabolic attention is diverted away from ovarian activity. Those energy costs of ammonia detoxification are rarely observed in reduced milk production by cows fed the higher CP diets, possibly because of homeorhesis. However, increased loss of body weight is not an unusual response of cows fed greater amounts of unutilized nitrogen. In just one example, approximately 110 lb of BW were lost during the first 28 days postpartum by cows fed diets of 15.7% RDP compared with only 46 lb during the first 21 days postpartum by cows fed diets of 11.1% RDP (Garcia-Bojalil et al., 1998a). The greater loss of BW by cows fed greater amounts of CP may reflect a greater reliance on body tissue reserves to maintain milk production because of greater energy expenditure for ammonia detoxification. Indeed, these cows fed a diet of 15.7% RDP without inert fat (Megalac®, Church and Dwight Co., Princeton, NJ) had 17 more days to first service, fewer corpora lutea **(CL)**, and less accumulated plasma progesterone the first 50 days postpartum than cows fed diets of 11.1% RDP. The supply of additional energy to diets in excess of RDP corrected the situation. The inclusion of inert fat at 2.2% of dietary DM into the high RDP diet shortened the time to first service by 6 days, increased the number of CL, and alleviated plasma progesterone depression caused by feeding high RDP alone (RDP by fat interaction) (Garcia et al., 1998b).

Liver function may be compromised by exposure to excess ammonia. Defects include a reduction in the capacity of the liver to synthesize glucose from propionate and a reduced ability to detoxify ammonia to urea when the triglyceride content of the liver is elevated.

Lastly, excess dietary CP may inhibit fertility by suppression of the immune system by some nitrogenous compound that reduces the cow's response to an antigenic stressor (Barton et al., 1996). Primiparous cows recovering from uterine infections experienced more days to first ovulation (39 vs. 18 days) when fed a 20 vs. 13% CP diet (Carroll et al., 1988). Likewise, cows fed a high CP diet (20 vs. 13%) tended to increase days open when they had health problems compared to healthy cows as determined using survival analysis (Barton et al., 1996).

Summary

Both MUN and BUN can potentially serve as indicators of a diet formulated properly for the correct ratio and amount of protein and energy as well as the correct proportions of RDP and RUP. Based upon the current literature, cows fed a well formulated diet would be expected to have a MUN value between approximately 11.5 and 14 mg/100 ml. Values greater than these suggest that dietary nitrogen is being used inefficiently and an adjustment in dietary protein and/or energy is likely warranted. Cows fed CP or RDP in significant excess of need have often, but not always, demonstrated reduced reproductive performance. This has included reduced conception, more days open, or delayed ovulation accompanied, in some cases, by lower plasma progesterone concentrations, greater loss or slower gain of body weight, and decreased pH and concentrations of K, Mg, and P in the uterus. Concentrations of BUN or MUN of >16 to 17 mg/100 ml for cows and virgin heifers may indicate that the animal is at risk of reduced reproductive performance. Cows that experience health disorders or are bred in the warm season may be at greater risk of reproductive harm when diets containing excessively high CP or RDP are fed. Great attention should be given to practice excellent reproductive management skills on farm and to formulate and feed appropriate amounts of nitrogen in order to minimize potential negative effects of feeding high CP diets on fertility. The mechanism(s) by which excess dietary nitrogen negatively affects fertility are reviewed in the paper and continues to be studied.

Supplemental Fat Feeding

Supplementing with some sources of fat to lactating dairy cows has improved reproductive performance. In several studies, lactating cows fed a basal diet containing whole cottonseed (~9% C18:2) and further supplemented with Ca salts of palm oil (**CaPO**) (~8% C18:2) experienced a better rate of conception or pregnancy than cows fed the diet containing only whole cottonseeds (Staples et al., 1998). Lactating cows fed tallow (4.3% C18:2) at 3% of dietary DM tended to have a better conception rate by 98 days in milk than cows not fed tallow (Son et al., 1996). Grazing dairy cows supplemented with soybean oil soapstock (53% C18:2) at ~2% of dietary DM experienced a greater pregnancy rate than controls (62.5 vs. 22.2%), whereas those fed fat and housed in a free stall barn had lower pregnancy rates than controls (0 vs. 22.2%) (Boken, 2001). Primiparous beef heifers also have experienced greater pregnancy rates (94, 90, 91, and 79%, respectively) from being fed rolled and cracked safflower seeds, soybeans, or sunflower seeds, all high in C18:2 concentration (Bellows, 1999). The inclusion of fish meal in the diet also has stimulated fertility in several studies (n = 4) (Staples et al., 1998). The oils in the fish are hypothesized to be responsible for this positive response, hence their inclusion in the current discussion. What accounts for this improved fertility of cows supplemented with fat?

How might the feeding of additional fat improve fertility?

Some have suggested that the feeding of additional energy in the form of fat reduces the cow's negative energy status so that she returns to estrus earlier after calving and therefore conceives sooner. However, the energy status of cows supplemented with fat is unchanged most of the time because of a nonsignificant depression in feed intake and/or an increase in milk production (Table 3; Staples et al., 1998). In fact, dairy cows fed tallow at 3% of dietary DM had a greater pregnancy rate despite having a more negative calculated mean net energy status from weeks 2 to 12 postpartum compared to controls (Son et al., 1996).

A second hypothesis is that cows fed fat have higher circulating concentrations of progesterone, a hormone necessary for the implantation and nutrition of the newly formed embryo. Progesterone is called the hormone of pregnancy; that is, progesterone is continually synthesized during pregnancy. The CL formed by the ovulated follicle remains on the ovary throughout pregnancy and is responsible for synthesizing progesterone. Increased concentrations of plasma progesterone have been associated with improved conception rates of lactating ruminants (Butler et al., 1996). A number of studies have reported that dairy cows fed supplemental fat (tallow, CaPO, prilled fatty acids, or whole cottonseeds) had elevated concentrations of blood progesterone (Staples et al., 1998). This may result from a reduced clearance of progesterone from the blood or an increased production by larger or a more productive CL. Feeding fat often increases the size of the dominant follicle (Staples et al., 1998). In addition, concentrations of progesterone were higher in follicular fluid of ruminants fed supplemental fat (Staples et al., 1998). In summary, fat supplementation can increase the concentration of fat, cholesterol, and progesterone in blood and ovarian structures of ruminants as well as increase the size of ovulating follicles. Improved fertility may result from more progesterone being available to improve embryo survival and health of fat-fed cows.

A third explanation of improved fertility

of cows supplemented with fat is that specific individual long chain fatty acids found in some fats inhibit the production or release of prostaglandin $F_{2\alpha}$ ($PGF_{2\alpha}$) by the uterus. This prevents the regression of the corpus luteum on the ovary so that the newly formed embryo survives. The omega-3 long chain, polyunsaturated fatty acids may exert their effect in this way; namely linolenic acid (**C18:3**), eicosapentaenoic acid (**EPA, C20:5**), and docosahexaenoic acid (**DHA, C22:6**). All three fatty acids have a double bond located between the third and fourth carbon counting from the methyl end of the molecule, thus are classified as omega-3 fatty acids. These latter two fatty acids are found in marine products, such as algae, fish meal, fish oil, and some seafood byproducts. Linolenic acid is the main fatty acid found in some vegetable oils such as linseed and in pasture forages.

Linolenic acid may have been responsible for the improvement in conception rate (87.5 vs. 50.0%) of lactating dairy cows (n = 35) fed formaldehyde-treated whole flaxseed (17% of dietary DM) compared to those fed CaPO (5.6% of dietary DM) from 9 to 19 weeks postpartum (Petit et al., 2001). Supplementing diets of lactating dairy cows with fish meal has improved conception rates (Staples et al., 1998). First service conception rate tended to be greater (P = 0.14) for lactating primiparous beef cows (n = 82) fed fish meal compared to corn gluten meal (75.6 vs. 61.5%) (Bonnette et al., 2001). Serum progesterone concentrations after insemination were similar between the two groups of cows.

The synthesis of $PGF_{2\alpha}$ is from arachidonic acid (C20:4) and is regulated by the key enzyme, prostaglandin endoperoxide synthase (**PGHS**) (Figure 1). The feeding of C20:5 may aid in the suppression of synthesis of $PGF_{2\alpha}$ by the uterus by competing for PGHS. Dihomo-g-linolenic acid also can compete for PGHS when it is converted to the series one prostaglandins. Although C22:6 is not a substrate for PGHS, it is a strong inhibitor of PGHS activity. Therefore when intake of C18:3, C20:4, or C22:5 increases, conversion of C20:4 to $PGF_{2\alpha}$ can be reduced, thus potentially increasing the chances of preserving the life of a newly formed embryo. In addition, the increased presence of C20:5 and C22:6 can inhibit the synthesis of C20:4 from C18:2 by inhibiting the desaturation and elongation enzymes required for that conversion (Figure 1). Linolenic acid also can compete with C18:2 for the desaturase enzymes so that more C20:5 and less C20:4 are synthesized (Figure 1). In addition, the omega-3 fatty acids can displace C20:4 in the phospholipids of cell membranes, thus reducing availability of C20:4. Therefore increasing the dietary intake of the omega-3 fatty acids can potentially reduce the production of $PGF_{2\alpha}$. Evidence supporting this mechanism is a slower regression of the CL in cows fed fish meal (Burke et al., 1997) and a reduced response of the uterus to secrete $PGF_{2\alpha}$ by lactating dairy cows fed fish meal (Mattos et al., 2002) and by periparturient dairy cows fed fish oil (Mattos et al., 2004). If the omega-3 fatty acids are performing as described, embryo survival should be increased. Holstein cows (n = 141) were allotted to one of three dietary treatments initiated at calving (Petit and Twagiramungu, 2002). Diets were isonitrogenous, isoenergetic, and isolipidic. Diets contained whole flaxseed, CaPO, or micronized soybeans. Flaxseeds are ~32% oil of which 57% is C18:3, 14% is C18:2, and 18% is C18:1. The diameter of the CL of the cows fed flaxseed was larger than that of cows fed soybeans (19.7 vs.16.9 mm) but not larger than that of cows fed CaPO (17.5 mm). Embryo mortality from day 30 to 50 after AI tended to be lower (P < 0.11) when cows were fed flaxseed (0%) compared to CaPO (15.4%) or soybeans (13.6%).

A fourth reason offered is that supplemental fats are alleviating an essential fatty acid (**EFA**) deficiency (linoleic acid [**C18:2**] and C18:3) of the modern high-producing dairy cow. Deficiencies of EFA have reduced reproductive performance of nonruminants. Using the recent fat sub-model developed for use in the CPM-Dairy model, Sanchez and Block (2002) suggested that the amount of C18:2 excreted in 100 lb of milk daily exceeds the post ruminal uptake from typical diets. Therefore, fat sources that supply additional EFA may minimize the need to mobilize EFA from tissues, thus protecting their functional integrity. According to the scientific literature dealing with human and lab animal nutrition, a ratio of C20:3 to C20:4 in tissues/serum that exceeds 0.4 is indicative of a C18:2 deficiency or an imbalance of C18:2 to C18:3. If the ratio of C20:3 to C20:5 exceeds 0.4, a deficiency of C18:3 is suspected. The rational behind this ratio is that the synthesis of C20:3 n-9 from oleic acid increases when C18:2 or C18:3 are deficient. It might be productive if these same ratios could be relevant to identify situations, if any, in which supplemental EFA would benefit the bovine.

Lastly, an improved fertilization rate and embryo quality may also result when lactating cows are supplemented with select fat sources. Dairy cows supplemented with a calcium salt blend of linoleic acid and monoenoic trans fatty acids or a calcium salt of palm oil (Bioproducts, Inc., Fairlawn, OH) from 25 days before calving through ~55 days postpartum were timed AI and flushed 5 days after AI with recovered structures evaluated (Santos et al., 2004). Cows fed the linoleic acid and monoenoic trans fatty acids tended to have (P = 0.11) a greater fertilization rate (87 vs. 73%), had more accessory sperm per structure collected (34 vs. 21), and tended to have (P = 0.06) a greater proportion of embryos classified as high quality (73 vs. 51%). In an accompanying study, conception rate at first AI was greater for cows fed the linoleic and trans acid salt (38.9 vs. 25.9%).

Sources of fat supplements

Only calcium salts of long chain fatty acids and fish meal have been evaluated in repeated studies for their reproductive effects, both having improved pregnancy or conception rates in a limited number of studies. The unique fatty acids in fish meal may be responsible for enhanced fertility. Animal tallow, flaxseed, safflower seeds, soybeans, sunflower seeds, and oil originating from soybeans have proven beneficial for ruminants in even more limited work. Obviously, more studies are needed with these fat sources. If linoleic acid is a limiting fatty acid postruminally, then fat sources containing high concentrations of this fatty acid (e.g. soybeans and Megalac-R, Church and Dwight Co., Inc., Princeton, NJ), would be a good choice. Soybeans appear to deliver more linoleic acid to the small intestine than cottonseeds. Roasting of soybeans may be an effective way to reducing biohydrogenation in the rumen, thus increasing the delivery of EFA to the small intestine for absorption.

Summary

Evidence is accumulating that the design and delivery of supplemental unsaturated fatty acids to the lower gut for absorption (specifically linoleic acid, linolenic acid, EPA, and DHA) may target reproductive tissues to improve reproductive function and fertility. Improvement in pregnancy may be associated with improved embryo survival due to increased production and/or decreased clearance of progesterone as well as the suppression of uterine prostaglandin secretion by omega-3 fatty acids. Further work is needed to determine if the modern high-producing dairy cow is in a negative EFA balance.

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Table 1. Conception or pregnancy rates **(CR)** and BUN of lactating dairy cows or virgin heifers fed diets of moderate or elevated crude protein **(CP)** concentration.

Reference	No. Animal	13 to 17% CP diets		19 to 21% CP diets	
		CR, %	BUN, mg/100 ml	CR, %	BUN, mg/100 ml
Jordan and Swanson, 1979	30	53[a]	---	40[b]	18
Folman et al., 1981	39	56	9	44	15
Kaim et al., 1983	250	79[a]	9	65[b]	17
Howard et al., 1987	109	87	~15	85	~25
Carroll et al., 1988[2]	57	64	10	56	24
Bruckental et al., 1989	139	65[a]	25	52[b]	32
Canfield et al., 1990[2]	65	48[a]	12	31[b]	19
Elrod and Butler, 1993[1,2]	80	82[a]	~14	61[b]	~24
Barton et al., 1996[2]	64	41	9	44	21
McCormick et al., 1999	119	75[a]	20	53[b]	25
Average		65	14	53	22

[ab]Means in the same row with different superscripts differ, P < 0.05.
[1]Virgin heifers only.
[2]First service.

Table 2. Reproductive performance of lactating dairy cows fed diets of high crude protein **(CP)** content with moderate or elevated concentrations of ruminally degradable protein **(RDP)**.[1]

Reference	Diet CP, %	RDP, % CP	BUN, mg/100 ml	Reproductive measure
Garcia-Bojalil et al., 1998b	20.5	54	17	25 days to 1st ovulation[a]
	20.7	76	22	39 days to 1st ovulation[b]
Figueroa et al., 1992	20.0	60	20	34 days to 1st ovulation[a]
	20.0	65	21	50 days to 1st ovulation[b]
Bruckental et al., 1989	21.6	FM replaces	~28	72% pregnancy rate[a]
	21.6	some SBM	~33	52% pregnancy rate[b]
Carroll et al., 1994	20.8	61	23	71% conception 1st AI[c]
	20.7	67	23	68% conception 1st AI[c]
Westwood et al., 1998	19.3	63	---	lower conception at 1st AI
	19.3	85	---	for high RDP diet

[1]AI = artificial insemination, BUN = blood urea nitrogen, FM = fish meal, and SBM = soybean meal.
[ab]Means with different superscripts within an experiment are different, P < 0.05.
[c]A diet by location interaction; cows fed the low RDP diet had greater conception (P = 0.04) when fed using a feed bunk line but lower conception when fed using Calan gate feeders.

Table 3. Effect of fat on performance factors related to energy status in studies reporting improved fertility due to feeding of tallow (Son et al., 1996) or calcium salts of long chain fatty acids (all other

Reference	DM intake lb/day	Fat corrected milk, lb/day	Body weight or energy status **(ES)**
Son et al., 1996	↓2.6	↑1.3	More negative ES
Sklan et al., 1991	↓0.2	↑3.7	↑ loss of weight
Scott et al., 1995	[1]N.R.	↑2.9	No change
Garcia-Bojalil et al., 1998a	↓0.2	↑3.5	No change
Sklan et al., 1989	N.R.	↑3.1	↑ loss, followed by↑weight

[1]N.R. = not reported.

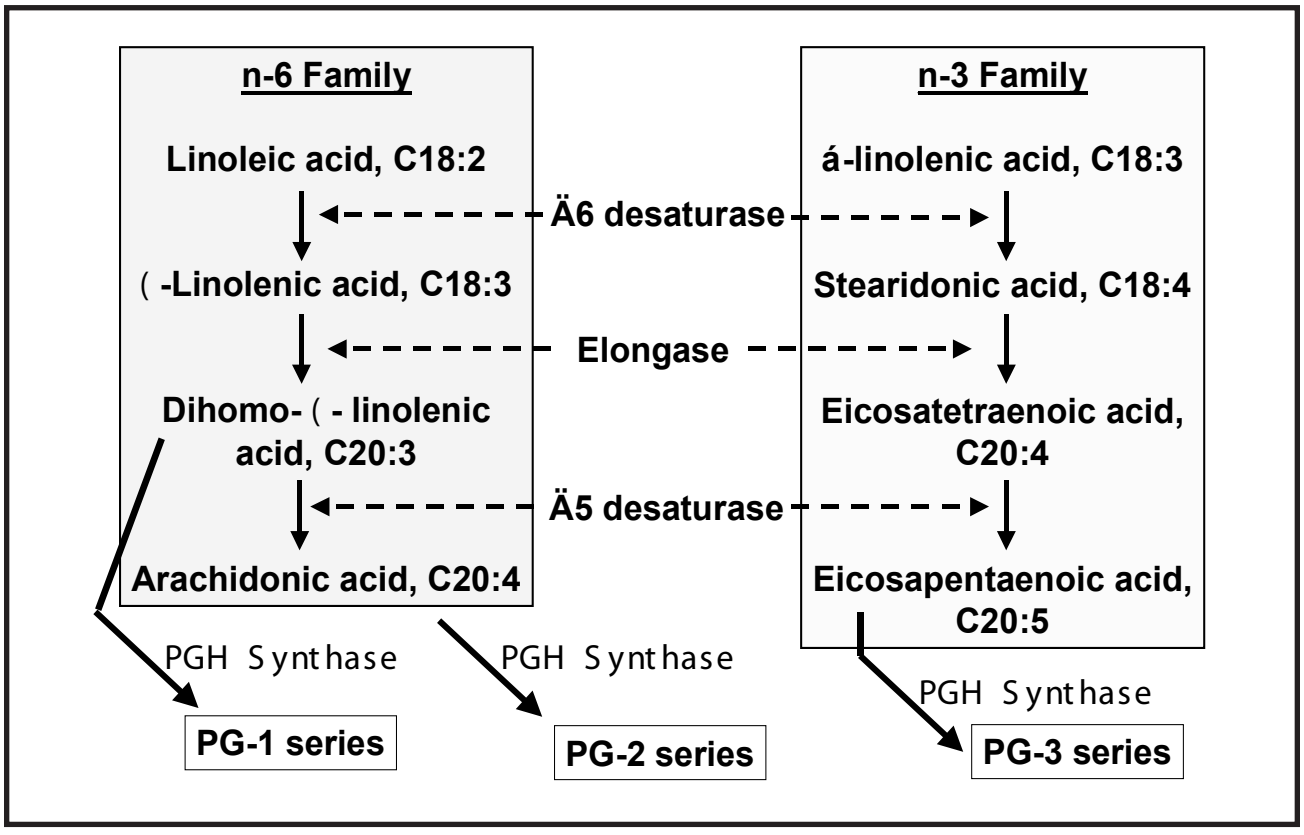

Figure 1. Synthesis of the various prostaglandin **(PG)** series from fatty acid precurors (PGH = prostaglandin endoperoxide).

Dietary Approaches to Keeping Calves Healthy

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Introduction

Calf disease particularly diarrhea and respiratory disease has significant effects on the profitability of every calf raising enterprise. Calf raisers, including dairy farmers, veal growers, calf ranchers and others, all deal with calves that are particularly susceptible to disease and then exposed to disease-causing pathogens (especially viruses and bacteria) when they are transported from farm to farm. Underlying most of these strategies is the underlying assumption that most calves will begin life with inadequate passive immunity. Studies continue to show that >50% of shipped calves (calves that leave one farm to be raised at another) arrive at the final facility with <10 g/L of immunoglobulin G **(IgG)** in serum within the first few days of life. Therefore, many calf raisers have begun looking for means of supplementing the immune system until it is strong enough to protect the calf from pathogens in the environment. Traditionally, we have relied on the use of antibiotics to reduce the effects of disease in calves. It is still quite common (in some parts of the U.S.) to include chlortetracycline or oxytetracycline/neomycin in the milk replacer and to aggressively treat outbreaks of respiratory disease or diarrhea with one or more antibiotic preparations.

We assume that the availability of antibiotics for subtherapeutic treatment (i.e., feeding) will be much more limited in the future. Therefore, alternatives to feeding antibiotics are required. It is important to note the difference between feeding antibiotics to improve growth and feed efficiency (subtherapeutic) and the treatment of disease. Antibiotics will continue to be available to treat disease. However, their availability may be more limited.

Traditionally, most commercial milk replacers **(CMR)** in certain areas of the U.S. have contained antibiotics (**AB**) to prevent or treat bacterial scours (Heinrichs et al., 1995). However, use of AB in CMR has recently been criticized due to increasing evidence that such AB use may contribute to increased transfer of antimicrobial resistance to pathogens of medical importance. Although the efficacy of AB in CMR applications has been established (Morrill et al., 1977; Quigley et al., 1997; Tomkins and Jaster, 1991), a need exists for viable alternatives to AB in the diet of young calves.

We evaluated the use of oxytetracycline/neomycin in milk replacers with a group of 120 purchased bull calves in 2001 (Quigley, unpublished). Calves were assigned randomly to receive experimental CMR (Table 1) containing 0 or 200 g/ton (0.22 mg/kg) of oxytetracycline plus 400 g/ton of neomycin base (0.44 mg/kg). All CMR were formulated to contain 22% CP, 20% fat, 0.8% Ca, and 0.7% P (air-dry basis) and to meet or exceed NRC (2001) requirements for vitamins and minerals.

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Calves were fed CMR twice daily at approximately 0700 and 1600 h using individual nipple bottles. Calves were offered 454 g/day of CMR reconstituted in 3.8 L of water during weeks 1 to 8. The CMR were mixed in hot water (approximately 50°C) to disperse fat. Cool water was then added to bring temperature to approximately 39°C and the appropriate DM prior to feeding. Commercial textured calf starter (**CS**; Cargill Herd Builder, Cargill, Inc., Minnetonka, MN) was offered once daily for ad libitum consumption, and feed refusals were measured daily. Water was offered once daily for ad libitum consumption. Refusals of water were measured, and water intake was assumed to equal water offered minus water refused. No hay was fed. Hutches were bedded with straw throughout the study.

Data in Table 1 show that the inclusion of antibiotics in CMR improved animal performance. This is particularly interesting because overall mortality was very low in the study (2 calves in each treatment) and overall morbidity (number of veterinary treatments) was also quite low. Nonetheless, calves fed the diet containing antibiotics grew faster, were heavier at 56 days of the study, consumed more calf starter, and were more efficient than calves fed control CMR.

We have to balance the benefits of including antibiotics in the diets of animals with the potential harm that widespread use of antibiotics might cause to others. If the use of antibiotics can spread antibiotic resistance to other pathogens (including important medical pathogens), then it is in everyone's best interest to limit or eliminate the unnecessary use of these drugs. In many parts of the world, subtherapeutic antibiotic use has been restricted or eliminated. Other legislatures (including those in the United States) are considering significant restrictions as well. Therefore, producers are facing the loss of a significant management tool with the restriction in use of antibiotics.

It is in this context that researchers have been looking for alternatives to antibiotics and new methods of feeding calves to reduce the potential for calves to get sick. What is a reasonable strategy in this effort? Well, consider that there are two primary sites of infection in young calves enteric and respiratory. Other systems of the animal (reproductive, mammary, etc.) are not usually major sites of infection and disease in young calves. Considering enteric and respiratory disease, the most common source of disease is enteric infection. This is also the site where dietary intervention is most effective. Therefore, our focus will be on feeding practices to minimize the risk of enteric disease in calves.

Of course, proper nutrition is essential in keeping calves healthy. Formulation of diets to provide sufficient amounts of protein (including ruminally available and escape protein), energy (as fat and carbohydrates), vitamins, minerals, and water is essential. However, in our current context, we will be focusing on "non-nutritional" or "extra-nutritional" strategies. These concepts must be incorporated into a feeding program <u>in addition</u> to the proper nutrition that is essential to the young animal.

Compounds that can be fed and have a non-nutritional effect on an animal have been called "nutraceuticals" or "functional foods". There is considerable debate in the regulatory community regarding the proper classification of these compounds. Are they foods? Are they drugs? There is a lot of confusion about this point and the Food and Drug Administration **(FDA)** has attempted to clarify the differences as it relates to human and animal "nutraceuticals". With the passing of the "DSHEA" (dietary supplement health and education act), there is greater confusion, because dietary supplements

that are sold for people with many claims related to health cannot be sold for use in animals for the same purposes.

The FDA has taken a strong stand related to the promotion and sale of nutraceuticals for animals. The following is an excerpt from an FDA publication that describes the position of FDA related to the use of "nutraceuticals" for animals. The specific references are to pets, but they are relevant to all animals. For the complete FDA publication, go to http://www.fda.gov/cvm/index/fdavet/1999/jan.html.

> "Nutritional supplements for pets have been available for many years. These are products that provide a source of a recognized essential nutrient, such as calcium or vitamin A, and are intended to augment and ensure nutritional completeness of the diet. Labeling for nutritional supplements must follow the same rules as for other pet foods. If it claims to be a vitamin or mineral supplement, the label must bear guarantees for each vitamin or mineral in the product.
>
> "Dietary supplements" describe a much broader range of products. Some provide essential nutrients, such as vitamins and minerals, but others contain substances that are not recognized as essential for the intended species (for example, vitamin C for dogs and omega-3 fatty acids for cats). Herbs, plant or organ extracts, enzymes, and a host of other substances are also often marketed as dietary supplements. The market for dietary supplements was boosted by passage of DSHEA. This law changed the way FDA regulated these products. Briefly, it said that FDA could not call a substance a "drug" or "food additive" if it met the definition for a dietary supplement and was not already regulated as a drug or food additive. Thus, it shifted the burden of the manufacturer of having to prove a product was safe before it went on the market to the FDA having to prove it was unsafe before it could be removed. This prompted a sizable increase in the number and range of dietary supplements available on the market today.

It must be noted that DSHEA only applies to human products, not pet products. Thus, some of the substances allowed for sale as human dietary supplements may not be legally permitted to be sold for animals. There is good reason for this, though. Although some of the supplements, such as herbal products, may have "thousands of years of history of safe use," this does not include history of use in animals. It is well known that animals may react very differently to substances than people, and even small doses can cause adverse effects. For example, aspirin and chocolate that are used by people every day without ill effect, can be toxic to pets and even cause death. Therefore, since it's not known what the true effects an herb or other supplement may have on pets, it's safest not to allow marketing for that use.

The term "nutraceuticals" was coined to describe the increasing number of products offered for the prevention or treatment of disease but marketed under the guise of dietary supplements. The promise of a "safe" and "natural" remedy for disease is very appealing. However, since the product has not undergone the same testing for safety and efficacy as required for approved drugs, it's

impossible to know whether the product works at all or is even unsafe.

Clearly, the FDA is taking a position that "nutraceuticals" considers that if claims are made to change "form or function", then the product is a drug. Most, if not all of the "nutraceuticals" sold today that make claims to improve animal health, reduce disease, etc. are in violation of these rules. The FDA has published several articles related to their position on "nutraceuticals" for example in the Nov/Dec 2000 issue of FDA Veterinarian (http://www.fda.gov/cvm/index/fdavet/2000/november.pdf) and some information on regulatory activities in the March/April 2001 issue of FDA Veterinarian (http://www.fda.gov/cvm/index/fdavet/2001/Mar_Apr.pdf).

There are many classes of "nutraceuticals" available. Many are popular as human dietary supplements, for example St. John's Wort, ginseng, and condroitin . However, we will limit this discussion to those products/compounds that may have some utility in reducing the effects of disease in calves. Briefly, we can categorize these into:

- functional proteins
  - iron binding antimicrobial proteins (lactoferrin and transferrin)
  - immunoglobulins
- probiotics
- immune "stimulants"
- oligosaccharides
- yeast and yeast culture
- others

There are many different other classes of compounds that may be considered "nutraceuticals" that will not be considered here, as they are not thought to be related to enteric disease.

To achieve the goal of reducing enteric disease, any compound must possess several attributes:

- it must survive processing, storage, and handling of animal feeds
- it must not be degraded by temperatures typical of storage and feeding
- it must survive the rumen and/or abomasum of the animal (the rumen and abomasum if fed in dry feed; abomasum if fed in the milk or milk replacer)
- it must not be degraded by intestinal enzymes
- it must act while in the intestinal tract

Functional Proteins

Most nutritionists view proteins simply as sources of amino acids. This traditional view assumes that proteins are consumed by the animal and the proteins are digested by stomach acid and intestinal enzymes to their component amino acids, which are then absorbed into the bloodstream. However, some proteins will retain biological activity in the animal after being consumed by the animal. These *functional proteins* have the ability to elicit a physiological response in the animal. Functional proteins may partially resist digestion or functional protein fragments are produced during the digestion process. Functional proteins can be obtained from either animal or vegetable sources. Indeed, some functional proteins (e.g., trypsin inhibitors in soybeans) are deleterious to producers and must be destroyed prior to feeding. There are several classes of functional proteins that act to reduce the effects of microbial challenge in the animal. These include iron binding proteins, immunoglobulins, defensins, bacteriocins, and others.

The methods of collection and processing of functional proteins is extremely important to

maintaining functionality. Proteins have been used as a source of amino acids for many years. In the past, most proteins were dried using high temperatures with little consideration to the value (i.e., digestibility) of the amino acids. Improvements in processing resulted in improved digestibility of protein, but there was considerable variation in protein quality due to variation in drying temperatures and length of time which the protein was heated (Goedeken et al., 1990; Knabe et al., 1989). More recently, spray-drying technologies have been introduced to the feed industry. This method of drying reduces the effects of heat and time and maintains the concentration of bioactive proteins in the products.

Iron binding antimicrobial proteins

Iron is an essential nutrient for growth. However, free iron in the body may promote the production of free radicals, which can result in tissue damage. Therefore, the body utilizes several different kinds of iron carrying proteins to provide a mechanism for transporting iron while simultaneously keeping it from causing damage. Iron is also an essential nutrient for many different kinds of bacteria. If iron were removed from the bacterial environment, then growth of the bacteria might be impaired. Indeed, research has been conducted with two different iron binding compounds, lactoferrin and transferrin, to determine if they can contribute to the animal's immune system and possibly replacing AB.

Lactoferrin **(LF)** is an iron-binding glycoprotein found in milk with a molecular weight of 80 kD. Lactoferrin may serve as an antimicrobial in the gut of the animal (Arnold et al., 1977; Shin et al., 1998) and as a regulator of the immune system (Rejman et al.,1992; Smith and Oliver, 1981). The antimicrobial activities of LF may be especially effective against enteric pathogens such as *E. coli* (Shin et al., 1998) and others (Arnold et al., 1977). In January 2002, the USDA approved activated lactoferrin as an antimicrobial protein to be applied on fresh meat to reduce the growth of important disease causing pathogens, including *E. coli* O157:H7.

Joslin et al. (2002) evaluated the addition of LF to CMR (and colostrum) in calves housed in individual pens at the University of New Hampshire Experiment Station. Calves were fed 0, 1, or 10 g/day of purified LF in the milk replacer. Intakes of CMR and starter, BW, gain, and fecal scores were measured during the 56-day study.

The authors reported improved average daily gain **(ADG)** and starter DM intake (Figure 1) when calves were supplemented with 1 or 10 g of LF in the CMR. Improvements in BW gain and starter intake were particularly evident during the latter weeks of the study. The authors suggest that calves were healthier, and consequently, consumed more starter DM, which improved growth. Unfortunately however, there were only seven calves per treatment, which makes firm conclusions difficult based on the small number of animals. Further, although the authors hypothesize that calves were healthier, fecal scores measured during the study did not differ among treatments (2.51, 2.46, and 2.52 on a scale of 1 = normal to 5 = severe diarrhea, respectively) and the number of days the calves had diarrhea (fecal score > 3) also did not differ statistically. Based on these data, the question of whether LF can contribute to animal health and potentially reduce the effects of an enteric challenge (i.e., replace AB) have not been completely addressed and more research is required.

Transferrin **(TF)** is an iron-binding protein in blood that performs a similar function in blood as LF in milk. Transferrin has been proposed as a method of reducing growth of

pathogenic bacteria (Brock, 1989; Fettman and Rollins, 1985); however, no on-farm trials have been conducted with TF in calf milk replacers. In vitro work conducted in our laboratory indicates that apo-TF can reduce growth of pathogenic bacteria, including *Salmonella typhimurium* and *E. coli*, by up to 50%.

Antimicrobial peptides

Other antimicrobial peptides that may be used to reduce the risk of enteric infections include lysozyme, lactoperoxidase, bacteriosins, and defensins. These peptides kill pathogens by direct killing of bacteria and viruses. To date, no studies have evaluated these antimicrobial peptides in diets of calves.

Immunoglobulins

Introduction. The use of immunoglobulins **(Ig)** to reduce the effects of pathogenic challenge has been recognized for hundreds of years. To understand the role of Ig in replacing AB, it is important to understand that the intestinal tract is the largest immunological organ in the body. The total area of these mucosal surfaces, which cover these tube-like tissues, are at least two hundred times larger than those of skin (Takahashi and Kiyono, 1999). The large amount of lymphoid tissue (primarily as Peyer's patches) in the gut also contributes to the immunological capability of the intestine. These tissues appear to be particularly important in enteric disease caused by viruses and bacteria (Brodersen and Kelling, 1999; Frost et al., 1997). Therefore, in addition to providing critical digestive functions, the intestine must also prevent diseases from entering the body.

The gastrointestinal tract is constantly exposed to insults consumed by the animal. These may include pathogenic organisms, toxins, noxious chemicals, physical insults (e.g., hardware disease), and many others. Organs in the gastrointestinal tract have many methods to deal with these insults, including secretion of digestive enzymes and acid, harboring of commensal organisms, and other methods (Kruzel et al., 1998). Of particular interest, however, is the presence of Ig in the intestines. The second component involves functional immunological elements found in the mucosal and submucosal compartments, e.g., gut associated lymphoid tissue. When gut integrity is disrupted by invasive pathogens or by trauma, a myriad of pro-inflammatory mediators are released from cells in the gut wall that exert actions in the tissue or gut lumen. Immunoglobulin is an important defense mechanism in overall immune response in the intestine and production of Ig by gut associated lymphoid tissue is a critical function of these tissues.

Traditionally, the only Ig considered important in the intestine was IgA, which is produced by epithelial cells. Indeed, researchers continue to focus on production of intestinal IgA as a means of controlling disease (Coffin et al., 1999; Sagodira et al., 1999). However, other recent evidence suggests that IgG may also play an important role in reducing the risk of disease in animals. The two primary sources of IgG in the gut is through secretion of IgG from the blood into the intestine and oral consumption of IgG from milk or colostrum (lacteal secretions), blood, or eggs.

Movement of circulating IgG into the gut. Research done at Washington State University investigated the movement of circulating IgG into the intestinal tract and the role of IgG in reducing effects of microbial challenge (Besser et al., 1988a,b). The researchers conducted two studies to determine the metabolic fate of IgG that entered the bloodstream. In the first study, calves were injected with a radioactive (^{125}I)

labeled IgG directly into the blood. The calves (n = 24) were colostrum deprived and obtained from a commercial U.S. dairy. The excretion of the radioactive label was then monitored over time by collecting urine and fecal samples and determining the amount of radiation they contained. The excretion of total radiation and the total radiation still bound to protein (an estimate of the "intact" IgG) were measured.

An average of 2.52% of the ^{125}I was excreted in the urine every day (Table 2). Most of this was not bound to protein (only about 3% of urinary excretion), indicating that the IgG excreted in urine had been previously catabolized. Also, 1.5% of injected ^{125}I was excreted by way of the feces. Most of this (82%) was still bound to protein, indicating that these IgG were not degraded prior to excretion in the feces. The total excretion of ^{125}I was 4.02% per day of the amount injected. Regression analysis indicated that the half-life of the injected ^{125}I containing IgG was 17.9 days.

Calves were euthanized and the amount of ^{125}I was determined in various compartments of the intestine to directly estimate the amount of IgG that moved from the circulation into the intestine. The total values corresponded to a daily transfer of 2.60% of the total infused ^{125}I into the gastrointestinal tract. Most of this IgG appears to be secreted into the intestine as intact IgG, but a portion apparently is degraded by intestinal enzymes. The authors estimated that if a calf were to consume and absorb 100 g of IgG from maternal colostrum within the first 24 hours, it would subsequently secrete 1 to 4 grams of IgG back into the intestine daily for the first two weeks of life.

In a second experiment, Besser et al. (1988b) fed newborn calves colostrum containing antibodies against a specific strain of rotavirus. Dry cows were immunized with a vaccine against the rotavirus at 6 and 3 weeks prior to expected calving to produce colostrum containing the specific antibody. The amounts of specific antibody were then measured in the blood and gastrointestinal contents following sacrifice at 5 or 10 days of age.

The correlation between serum rotavirus antibody and intestinal rotavirus antibody (Figure 2) showed a close correlation. This means that calves: 1) absorbed the specific antibody from the colostrum consumed within the first 24 hours, 2) the specific antibodies then moved from the circulation into the lumen of the intestine, and 3) the movement of specific antibodies into the intestine occurred in proportion to concentrations in the blood.

The value of intestinal IgG. Many bacteria and viruses that infect calves are enteric typically causing intestinal damage and signs of disease (diarrhea and dehydration). Immunoglobulins in the intestine could assist the animal to mount an effective immune response when they attach to the antigenic binding sites on the specific pathogen. Therefore, movement of IgG from the circulation into the intestinal lumen would be one way to provide immunity in response to the pathogens that infect the animal by the fecal-oral route.

To determine if there is any value to circulating IgG in dealing with intestinal pathogens, Besser et al. (1988b) injected calves subcutaneously with 1.25 liters of whey extracted from the colostrum of cows immunized against rotavirus or colostrum from non-immunized cows. The control group was fed colostrum from non-immunized cows. These calves were then challenged with enteropathogenic strain of rotavirus at 72 and 96 hours after birth.

Administration of IgG by subcutaneous injection protected calves against rotavirus

infection (Table 3). Calves treated with subcutaneous "immune" whey (whey containing rotavirus antibody) had higher serum antibody titers against rotavirus and were more protected against oral rotavirus challenge than calves that were injected with "non-immune" whey. Presumably, the mode of action for the immune whey was via movement of the IgG from the circulation into the intestinal lumen, where the rotavirus was present. It is important to note that these calves were fed no colostrum, so the only source of antibody was through subcutaneous injection.

Ward et al. (1996) measured serum levels of rotavirus specific maternally derived antibodies in neonatal pigs. Pigs were grouped into non-detectable, low, or high serum titers. Pigs were then challenged with virulent rotavirus at 3 days of age and monitored for infection and disease. All inoculated pigs shed rotavirus and developed diarrhea, and pigs with highest levels of circulating antibody to rotavirus developed less severe diarrhea and shed rotavirus for fewer days than pigs with lower antibody titers. The researchers concluded that circulating maternal antibody plays a significant role in mitigating clinical disease and movement of antibodies from the circulation into the lumen of the intestine is important in this response.

These studies indicate that:

- Ig in the intestine play an active role in the resistance to pathogenic organisms that infect calves via the oral route, such as rotavirus.
- Ig in the intestine are sufficiently resistant to digestion to provide immune response. Studies have documented the relative resistance of IgG to proteolytic degradation in the gut.
- A major source of IgG in the intestine of newborn calves is from circulating IgG that are absorbed from ingestion of colostrum within the first 24 hours.
- Larger concentrations of IgG in the serum generally produce larger concentrations of IgG in the lumen of the intestine.

Reduced digestibility of Ig. Immunoglobulins are more resistant to proteolysis than many other proteins. This is necessary for IgG to provide local response in the intestine of the animal. Roos et al. (1995) reported that the recoveries of N of ingested IgG and IgM still immunologically active were 19 ± 3% and 19 ± 4%, respectively, in human patients consuming ^{15}N labeled preparations of Ig. According to the data of Roos et al., the ileal digestibility of IgG in healthy humans was 79%. Interestingly, much of the immunological activity was associated with the $F(ab')_2$ fragments, which are produced by pepsin and trypsin activity on IgG. The $F(ab')_2$ fragments contain a molecular weight of ~100 kDa.

IgG from milk/colostrum. The role of IgG in milk and colostrum in supporting the health of young calves is very well defined. Dairy professionals have long recommended feeding transition milk (which contains from 2 to 4 g/100 ml of total IgG) to "bathe" the gut and reduce the effects of enteric challenge. The role of colostrum or milk derived antibody (which is a combination of IgA and IgG) has been evaluated in many species.

Ebina (1996) reported that colostrum from cows hyperimmunized against human rotavirus MO strain contained neutralizing antibody to four different G serotypes of human rotavirus. The colostrum was effective in protecting suckling mice against rotavirus infection. Further, purified IgG obtained from colostrum protected against infection with the homologous virus. After randomly grouping 20 infants from a baby care center, 10 infants received 20 ml of colostrum for 2 weeks and 10 control infants received none. Rotavirus-

associated diarrhea developed in 7 of the 10 infants in the control group. None of the three infants in the group daily receiving the colostrum had such symptoms, and one of three infants in the group receiving treatment, every other day developed rotavirus-induced diarrhea. Oral administration of rotavirus-antibody colostrum seems to be an effective and safe means of preventing diarrhea caused by human rotavirus infection. Recently, the immunized cows were boosted by reinjection of 4 serotypes of human rotavirus into a superficial cervical lymph node two weeks after delivery, resulting in mass production of cow's milk containing a high-titered antibody to human rotavirus.

Fowler et al. (1995) obtained colostrum from cows immunized against rotavirus during the dry period. Feeding colostrum to calves for 14 days after birth reduced shedding of rotavirus after oral challenge and improved fecal scores and rate of body weight **(BW)** gain. Other researchers (Drew, 1994) have reported similar results. Clearly, there is a compelling reason to explore the potential for supplementation of liquid feeds with colostrum.

Challenges with commercial use of colostrum/milk derived antibodies are: limited production of colostrum, a lack of facilities to process colostrum, very low concentrations of Ig in whole milk, expensive processes needed to extract Ig from milk, and competition with human IgG markets. Products utilizing milk/colostrum IgG are available for use as colostrum supplements, but no products are currently available for continued feeding as a source of intestinal IgG.

IgG from plasma. The utilization of plasma in diets of young ruminants has been evaluated scientifically and on the farm. As early as the late 1800's, blood has been utilized in dietary formulations to replace cows' milk, for both its nutritional value as well as improved health of calves. The advantages of IgG from plasma are their availability, low cost, and ease of collection and processing. Whole blood (primarily beef, pork, or poultry) is collected from government inspected abattoirs, centrifuged to remove cellular components (red and white blood cells, and platelets), and the resulting plasma is then spray-dried to produce a light-tan powder. Spray-dried animal plasma **(SDAP)** contains about 78% CP and contains approximately 16% IgG. Remaining nutrients in plasma include moisture (9%) and ash (10%). Plasma is not a significant source of fat or carbohydrate.

The value of the functional proteins in SDAP was first recognized in young pigs in the 1990's (Gatnau and Zimmerman, 1990, 1992; Hansen et al., 1993; Kats et al., 1994; Sohn et al., 1991). These studies reported dramatic improvements in intake, BW gain, and efficiency when pigs were fed diets containing SDAP. Subsequent experiments reported that the response was primarily associated with the IgG fraction, although others indicated a beneficial effect of other fractions of plasma. Today, nearly 90% of starter diets fed to early weaned pigs in the U.S. contain SDAP. The rapid acceptance of SDAP in pig diets occurred even though the cost of the overall diets increased significantly.

The value of SDAP in the diets of herd replacement calves has been evaluated experimentally. Morrill et al. (1995) reported improved BW gain in calves fed plasma (25% of protein) compared to control (whey protein concentrate). All diets in this study were medicated with neomycin/oxytetracycline. Animals in this study were housed on a commercial calf ranch in Kansas. All calves were purchased and transported to the research facility. Amount of stress in these calves was significant, as was shown by loss of BW for the

first two weeks of the study. Body weight gains (Figure 3) approached 700 g/day by week 5, then were depressed with the outbreak of disease (Salmonella infection) on the farm. Under these conditions, plasma (bovine or porcine) resulted in significantly greater BW at 6 weeks of age compared to calves fed control. By the end of 6 weeks, calves fed milk replacer containing plasma had consumed 9.13 lb more calf starter than calves on control.

Data by Quigley and Bernard (1996) showed no significant effect of bovine plasma (25% of protein) on animal growth, intake, or efficiency. Mean feed efficiency in the study was 469 and 442 g BW gain/kg of DM intake for calves fed control and plasma containing milk replacers, respectively. Mean BW gains from 0 to 56 days of age were 523 and 469 g/day, respectively. Animals in this study were derived from dairy farms, raised under excellent management conditions, and exposed to little stress. Rates of BW gain in this study were greater than the study by Morrill et al. (1995) and were indicative of excellent management conditions.

Quigley et al. (2002) reported the effects of feeding SDAP or a product containing bovine serum, fructooligosaccharides, and minerals/vitamins (Gammulin®, APC, Inc.) in two studies utilizing 240 Holstein bull calves purchased from sale barns and dairy farms. Calves were usually within one week of age and in various stages of failure of passive transfer. In Experiment 1, calves fed the additive containing bovine serum tended to have fewer days with diarrhea, lower use of electrolytes, and improved BW gain from days 29 to 56 (Table 4). Addition of SDAP to milk replacer did not influence any parameter measured. In Experiment 2, calves fed the additive containing bovine serum or milk replacer containing SDAP had lower mortality (4.4 vs. 20%) and tended to have improved fecal scores and fewer days with scours (Table 5). Antibiotic use was lower when calves were fed the additive. Indices of enteric health (incidence of scours and treatment with antibiotics and electrolytes) were improved when plasma was added to milk replacer throughout the milk feeding period or as an additive during the first 15 days of the milk feeding period, when calves were most susceptible to enteric pathogens. The primary difference between Experiments 1 and 2 was the overall level of stress. Calves purchased in Experiment 1 were purchased from more dairy farms than sale barns and the experiment was conducted at an optimal time of the year (i.e., weather closest to the thermoneutral zone), CMR contained all milk protein, and there was a general lack of enteric challenge. Conversely, Experiment 2 was conducted during a cold period of the year, the calves were fed CMR containing soy protein and an outbreak of enteric and respiratory pathogens occurred during the trial. Generally, these data suggest that calves fed SDAP whether as SDAP in the CMR or as an additive such as Gammulin will respond to the products, particularly when the overall level of challenge is significant.

Quigley and Wolfe (2003) also recently reported that bovine or porcine derived SDAP added to CMR. Experimental milk replacers were formulated to contain whey protein concentrate **(WPC)** as the primary protein source or WPC plus 5% spray-dried bovine plasma **(SDBP)** or spray-dried porcine plasma **(SDPP)**. The SDPP was heated to remove heat insoluble materials and provide products with similar IgG content. Calves were also fed commercial calf starter and water for ad libitum consumption. Intake, change in BW, feed efficiency, morbidity, and mortality were determined. Mortality was 10, 3, and 2 in calves fed WPC, SDBP, and SDPP treatments, respectively (Table 6). Morbidity, measured as the number of days that calves had diarrhea, was reduced by 30% when SDBP, or

SDPP were fed. Calves had diarrhea for 6.9, 3.9 and 4.7 days during the 42-day study when fed CMR containing WPC, SDBP, and SDPP, respectively. Fecal scores tended ($P < 0.10$) to be reduced and feed efficiency tended to be improved when SDBP or SDPP were fed. Mean intakes of total DM during the 42-day study were greater when calves were fed SDBP or SDPP and were 661, 710, and 684 g/day for calves fed WPC, SDBP and SDPP, respectively. Mean BW gains from d 0 to 42 were 231, 261 and 218 g/day, respectively. Calves fed SDPP tended ($P < 0.10$) to have lower BW gain during the first 28 days of the study. However, difference in daily BW gain from day 1 to 28 was only 39 g/days. Inclusion of SDBP or SDPP in milk replacer reduced morbidity and mortality of milk-fed dairy calves.

Researchers at Virginia Tech (Mowry, 2001) recently compared CMR containing WPC versus WPC plus 4% of the total protein as NutraPro (APC, Inc. Ankeny, IA). Holstein and Jersey calves (n = 78) were fed milk replacers between June and December, 2000 and were fed for 28 days. Bull and heifer calves were used. There was no difference in survival, growth, intake, or health of calves fed either WPC or NutraPro in this study. Calves were raised under excellent management and had minimal stress. Mean DM intakes were 32.3 and 32.6 lb during the 28 day study for calves fed WPC and NutraPro, respectively ($P > 0.10$). Mean BW gain during the trial were 193 and 174 g/day for calves fed WPC and NutraPro, respectively ($P > 0.10$).

The use of SDAP to reduce the effects of enteric challenges has been evaluated by several researchers. Quigley and Drew (2000) fed 21 Holstein bull calves fed CMR containing no additives, bovine serum, or neomycin/oxytetracycline for 21 days. Calves were colostrum deprived and were challenged with *E. coli* on day 3. Health, mortality, intake, and BW gain were improved when either SDAP or AB were included in the CMR. Arthington et al. (2002) challenged 12 colostrum deprived, purchased Holstein bull calves (approximately 21 days of age) with coronavirus and measured intake, fecal scores, and recovery from the challenge. Calves fed bovine serum recovered more quickly than control calves the authors concluded that the addition of bovine serum increased the rate of recovery of calves, including improved intake and fecal scores.

Finally, Hunt et al. (2002) fed 24 Holstein bull calves milk replacer supplemented with bovine serum or soy protein. Calves were orally infected with a *Cryptosporidium parvum* (10^8 oocysts) at day 8 of life. Health, intake, intestinal integrity, and oocyst shedding was measured for 10 days. Cryptosporidiosis induced diarrhea lasting more than 9 days and produced a 25% increase in intestinal permeability, a 33% decrease in villous surface area, and a 40% reduction in mucosal lactase specific activity. Animals receiving bovine serum had lower peak diarrheal volume and intestinal permeability (-33%), fewer oocysts shed, intestinal crypts were significantly deeper, and villous surface area returned to normal by 9 days after infection (all $P < 0.05$).

IgG from eggs. Another source of IgG used in animal agriculture is chicken IgY. The IgY is similar to IgG and layers can be hyperimmunized against enteric pathogens (e.g., rotavirus) to produce specific IgY in their eggs. The eggs can then be processed to remove the white (most IgY is found in yolks) and spray-dried to produce a product containing specific antibodies. Commercially available products are available to provide IgY as a source of antibodies prior to gut closure (in the first 24 hours of life) or in a post-gut closure application (as a source of IgG to bathe the gut).

German researchers (Erhard et al., 1997) reported that newborn calves fed chicken egg IgY in the first day of life (20 g of egg powder containing 15 mg/g of IgY) absorbed the IgY and the half-life of the IgY was approximately 5 days. Due to the short half-life of heterologous Ig, the researchers recommended that egg powder should be fed after the first 48 hours of life. The researchers also concluded "*Most important for the prophylactic effect of specific antibodies on infectious diarrhea is not their systemic but their local intestinal availability*".

Ikemori et al. (1997) fed dairy calves CMR supplemented with IgG from bovine colostrum or IgY from spray-dried eggs. Both the cows and birds were vaccinated to produce antibodies against bovine coronavirus. One day after feeding CMR plus experimental products (colostrum was fed at three different doses and egg powder at two doses), calves were orally challenged with bovine coronavirus (109 TCID50). All calves fed no supplemental product developed severe diarrhea and died. Calves fed the egg or colostrum survived, except calves fed the low levels of colostrum. These data suggest that specific antibodies can in indeed protect animals against specific challenges, if the specific challenges on the farm are known.

However, egg yolk antibodies are prone to variability of results under field conditions. Kuroki et al. (1997) conducted three field trials using egg yolk IgY from layers hyperimmunized against bovine rotavirus. In only one of the three trials was there an improvement in rates of mortality and growth rate. The authors concluded that the high health status of calves and low overall challenge in the two studies was responsible for the lack of response.

Immunoglobulins are important to the health, growth, and profitability of dairy calves. It is important that calves are fed sufficient Ig within the first 24 hours of life. These research trials indicated above show that Ig (especially IgG) play an active role in all areas of the body including the intestine, where many pathogens cause disease. The use of IgG from milk/colostrum, eggs, and plasma is a scientifically sound approach to replacing AB in animal diets. A tremendous body of research indicates the value of these proteins in reducing the effects of microbial challenge.

Probiotics

Intestinal bacteria are an integral component of the intestinal immune system. Intestinal homeostasis relies upon the equilibrium between absorption (nutrients and ions), secretion (ions and IgA), and barrier capacity to pathogens and macromolecules of the digestive epithelium. The intestine, particularly the large intestine, is inhabited by a diverse population of bacteria that perform a variety of functions which contributes to many of these functions. When this homeostatic control is disturbed, chronic inflammation, diarrhea, and disease may occur. A normal intestinal bacterial flora is critical to maintaining health. A key part of their function is to "out compete" the pathogenic bacteria and keep them from becoming established in the gut. When an animal is exposed to significant stress, it is possible for the growth of these normal enteric bacteria to become impaired. This allows for the growth of potential pathogens, thereby increasing the risk of disease.

The theory related to the usefulness of probiotic bacteria is simple the balance of the intestine becomes upset due to some insult. Growth of normal "commensal" bacteria (particularly lactic acid bacteria) are impaired. By providing an exogenous source of bacteria, it is possible that these exogenous bacteria can become established in the gut, thereby reducing

the chance for pathogens to become established. Probiotic products are relatively inexpensive and readily available; therefore, they are included in many different types and kinds of combination products (e.g., Donovan et al., 2002).

Research with probiotics added to diets of young calves have been equivocal. In some experiments, improvements in animal performance have been reported, in others, no effect of the inclusion of probiotics has been reported. It is probable that, like other potential AB replacements, effects are dependent on environmental conditions. In addition, the selection of specific bacteria may be important. Bacteria typical to the intestine (especially *Lactobacilli* and *Bifidobacterium*) have shown improved responses compared to other bacteria (e.g., *Bacillus subtillus*).

Abe et al. (1995) reported improved performance (decreased scour scores and improved growth) when probiotic bacteria (*Lactobacillus acidophilus* and *Bifidobacterium pseudolongum*) were provided. On the other hand, Harp et al. (1996) reported that feeding probiotics to calves challenged with *Cryptosporidium parvum* had no effects on fecal scores or oocyst shedding in dairy calves. Morrill et al. (1995) also reported no effect of adding probiotics on health or growth of calves. Some researchers have suggested that probiotics may reduce the shedding of zoonotic pathogens, such as *E. coli* 0157H7 (Ohya et al., 2000; Zhao et al., 1998).

Probiotics are often misused on the farm. Because probiotics are living bacteria, they must be handled carefully to maintain viability. The expiration date is very important to ensure viability. In addition, storage temperatures can influence the viability of the bacteria. Finally, it is important to remember that probiotics are bacteria adding probiotics to medicated milk replacers will defeat the purpose of including the probiotic in the first place!

Immune Stimulants

A novel approach to increasing the resistance of animals to disease is to increase the animal's immune response. This approach is termed "immunotherapy" or "immunomodulation". There are several products that, when administered to animals (usually by injection), will non-specifically stimulate the animal's immune system and prepare it to meet the challenges of any type of enteric infection. One such product, ImmunoBoost® (Bioniche Animal Health USA, Inc., Bogart, GA), is advertised as a USDA approved immune stimulant. Results of the company's technical evaluations in a challenge study with 22 Holstein bull calves is available at http://www.vetrepharm.com/immuno/techrepr.htm. Kirk et al. (1998) evaluated this product on a large California calf ranch using 200 newborn Holstein bull calves that were fed either control CMR without or with an IV injection of the test product. Calves used in the study were those that were purchased and transported to the calf ranch. Calves were enrolled when they showed clinical signs of sickness (diarrhea, depression, and anorexia). Calves were monitored for five days. There was no effect of the product on any clinical score or in the number of calves that were clinically ill. The authors indicated that the stress on the animals was significant colostrum deprived calves purchased and transported, and the study was conducted in the summer when the ambient temperature often exceeded 40^{o}C (105^{0}F). However, such stressors are not unusual in many parts of the world, and such stressors are often imposed to increase the differences between treatments.

The idea of immune stimulants is interesting "jump start" the immune system so it can react to the inevitable pathogenic challenges.

However, this is a costly strategy. Up regulating the immune response will increase energy and protein utilization. If pro-inflammatory cytokines (IL-1β, IL-6, and TNF-α) increase in response to immune stimulants, energy and protein metabolism may be affected and appetite can be suppressed. Maybe a better approach is to eliminate or reduce the challenges in the first place, so that the immune system is not challenged at all.

Muscato et al. (2002) recently reported the effects of feeding autoclaved rumen fluid to young milk-fed dairy calves. Calves were fed 8 ml of rumen fluid daily to weaning; these calves gained more BW and had fewer scours than controls not receiving rumen fluid. The reason for improved response is not clear, but could potentially be due to the presence of antibacterial proteins used by bacteria to inhibit the growth of others.

Oligosaccharides

Oligosaccharides are a class of carbohydrates that are not absorbed or digested in the small intestine of man and animals and thus reach the colon unaltered. In the colon, oligosaccharides are readily fermented by the intestinal microflora. This may result in changes in this flora, thereby increasing the number of (potential) beneficial microorganisms, while repressing the number of (potential) harmful bacteria. This possible change in the intestinal flora may be beneficial to the health of man and animals. In addition, the production of volatile fatty acids by bacteria fermenting oligosaccharides in animals may improve energy efficiency and alter (improve) intestinal morphology.

Several classes of oligosaccharides are found in nature — fructooligosaccharides, mannanoligosaccharides, galactooligosaccharides, glucooligosaccharides, and others. Others are produced chemically and are used as functional foods or prebiotics. These oligosaccharides are available for inclusion in milk replacer or dry feed diets. Most commonly available oligosaccharides are fructooligosaccharide **(FOS)** and mannanoligosaccharide **(MOS)**. Products are available and have been tested in a wide number of animals species, including calves. However, few data are available in peer-reviewed journals. Fairchild et al. (2001) reported improved health and growth of poultry when challenged with E. coli and fed Bio-Mos (Alltech, Inc., Nicholasville, KY). Another potential product includes galactosyl-lactose, which has been shown to reduce scours and improve growth in calves (Quigley et al., 1997).

Oligosaccharides have been added to calf milk replacers to reduce the potential growth of enteric pathogens and to promote the growth of "beneficial" bacteria. While data with milk-fed calves are generally scarce, results in other species (pigs, humans, and pets) suggest that inclusion of oligosaccharides can alter populations of bacteria and improve or stabilize enteric health of calves.

Other Products

A number of other ingredients/products are available that provide data to suggest that they can replace AB. Results of some of these trials are listed below.

Garlic and derivatives

Allicin (thio-2-propene-1-sulfinic acid S-allyl ester), a component of garlic, inhibits growth of bacteria by binding to the enzyme, alcohol dehydrogenase, and pathogenic microorganisms such as *Thermoanerobium brockii* (Rabinkov et al., 1998). Allicin may also have antioxidant effects. Some researchers have reported that allicin can reduce the effects

of fungal and viral diseases (Josling, 2001; Weber et al., 1992). A product containing FOS, allicin, and probiotic organisms (Enteroguard®; Pharmax Biologicals, Inc., W. Des Moines, IA) was evaluated (Donovan et al., 2002) in milk-fed calves (n = 45) fed CMR containing the experimental product or AB (neomycin and oxytetracycline) for five weeks. Calves were born and raised on an experimental farm and were fed colostrum immediately after birth. They were not transported. The authors reported no differences in fecal scores, incidence of diarrhea, or electrolyte treatments when either treatment was fed. Unfortunately, this trial did not utilize a negative control, so it is not possible to know if the lack of difference between the experimental product and AB was because there was no response to the AB. Since calves had adequate passive transfer (minimum total serum protein > 5.1 g/dl) and were not exposed to challenges such as transport or movement through a sale barn, it is possible that the level of challenge in the study was insufficient to observe a difference between the experimental product and antibiotic treatment.

Olson et al. (1998) also evaluated an allicin-based product in calves challenged with *Cryptosporidium parvum*. Calves were dairy calves fed colostrum and not transported. A total of 24 calves were used in the study. Calves were fed 3.8 L (4 quarts)/day of reconstituted milk replacer and had ad libitum access to starter and water. On arrival, 20 calves were orally inoculated with 1.5 x 10^6 *C. parvum* oocysts. Fecal scores were monitored for the next 21 days. There was no effect of the product on fecal scores or BW changes in calves to 21 days.

Essential oils

Essential oils are compounds of plants that are known to provide aromatic (odor) characteristics to plants and are thought to serve as attractants, among other potential purposes. However, the actual role of many of these compounds is not well understood. Many essential oils, however, have been shown experimentally to reduce or inhibit the growth of bacteria and viruses. Therefore, they have and are being evaluated as potential replacements for antimicrobials. To date, no published studies are available evaluating essential oils in reducing effects of disease in young calves.

Summary

A number of viable alternatives exist for replacing AB use in animal diets. The use of functional proteins, oligosaccharides, probiotics, and essential oils have all been tested alone or in combination with other ingredients. It is likely that combination products will be most effective. It is important to remember that each category of product has special requirements for processing, storage, handling, and feeding to maximize the response. Our management will have to change and adapt to these new requirements.

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Table 1. Least squares means of animal performance (Quigley, unpublished)[1].

	Treatments[2]			
	Control	Medicated	SE	P[2]
N				
Begin	60	60	…	…
End	58	58	…	…
Mortality, %	3.3	3.3	2.4	NS
BW, kg				
day 0	44.9	44.5	0.5	NS
day 28	49.1	50.8	0.7	0.10
day 56	68.8	73.5	1.3	0.01
ADG, g/day				
days 0-28	149	221	20	0.01
days 29-56	699	813	28	0.01
days 0-56	424	517	22	0.01
DMI, g/day				
CMR[4]	460	461	1	NS
Starter[4,5]	543	674	36	0.01
ADG:DMI, g/kg[4]	340	394	16	0.02

[1]SE = standard error, NS = not significant, BW = body weight, ADG = average daily gain, DMI = dry matter intake, and CMR = commercial milk replacer.
[2]Treatments: Control = no additives; Medicated = CMR containing oxytetracycline + neomycin.
[3]P = Probability of a significant effect of CMR formulation.
[4]Significant effect of week ($P < 0.01$).
[5]Significant week x CMR interaction ($P < 0.01$).

Table 2. Excretion of ^{125}I-labelled immunoglobulin G **(IgG)** in the urine and feces of calves intravenously injected with ^{125}I-labelled IgG (Besser et al., 1988a).

	^{125}I Excretion (%/day)	
Item	Total	Protein bound
Urine	2.52	0.08
Feces	1.50	1.23
Urine + feces	4.02	1.31
Moved to GIT[1]	2.60	---

[1]GI = gastrointestinal tract.

Table 3. Effects of subcutaneous injection of immune whey [containing rotavirus antibody **(Ab)**] versus non-immune whey (not containing rotavirus Ab) on response to disease challenge with oral rotavirus (Besser et al., 1988b).

Item	Immune Whey	Non-Immune Whey
Rotavirus Ab titer (1/log2)	14.85	9.10
Calves infected, %	20.0	100.0
Incubation time (hr)	72.0	32.0
Duration time (hr)	64.0	135.0
Days with diarrhea	0.10	2.83

Table 4. Least squares means of animal performance, Experiment 1 (Quigley et al., 2002).

	Treatment[1]					Contrasts[2]		
	P-A-	P-A+	P+A-	P+A+	SE	P	A	I
N								
Begin	30	30	30	30	…	…	…	…
End	29	30	30	30	…	…	…	…
Mortality, %	3.3	0	0	0	0	…	…	…
IgG, g/L	9.0	10.3	8.5	11.1	1.0	NS	0.06	NS
Hematocrit, %	35.0	35.3	36.0	34.9	1.4	NS	NS	NS
Age, days	8.8	8.9	9.1	9.0	0.8	NS	NS	NS
Fecal scores[3]	1.6	1.6	1.6	1.6	0.03	NS	NS	NS
Scours, days[3]	6.6	4.9	7.3	6.1	0.9	NS	0.09	NS
Electrolytes, days[3]	2.0	1.6	3.0	1.4	0.6	NS	0.10	NS
Antibiotics, days	1.1	0.9	1.3	0.4	0.4	NS	NS	NS

[1]Treatment: P = Commercial milk replacer containing 0 (-) or 20% (+) of CP as spray-dried bovine plasma; A = addition of placebo (-) or supplement (+) containing bovine immunoglobulin and fructooligosaccharide. SE = standard error.
[2]Contrasts: P = effects of P- vs. P+; A = effects of A- vs. A+; I = interaction of P and A; NS = not significant.
[3]Significant effect of week ($P < 0.01$).

Table 5. Least squares means of animal performance, Experiment 2 (Quigley et al., 2002).

	Treatments[1]					Contrasts[2]		
	P-A-	P-A+	P+A-	P+A+	SE	P	A	I
N								
Begin	30	30	30	30	---	---	---	---
End	24	29	29	28	---	---		
		---	---					
Mortality, %	20.0	3.3	3.3	6.7	5.0	NS	NS	0.05
IgG, g/L	8.6	9.3	7.5	10.1	1.1	NS	NS	NS
Hematocrit, %	33.4	32.9	34.1	32.4	1.2	NS	NS	NS
Plasma protein, g/L	55.4	55.6	54.5	58.6	1.3	NS	0.11	NS
Fecal scores[3]	1.49	1.44	1.47	1.45	0.03	NS	0.06	0.08
Scours, days[3]	5.0	3.5	4.7	4.0	0.6	NS	0.02	0.07
Electrolytes, days[3]	2.2	1.4	1.6	1.4	0.4	NS	NS	NS

[1]Treatments: Commercial milk replacer containing 0% (P-) or 4% (P+) spray-dried bovine plasma; A = addition of 0 (-) or 30 to 60 (+) g/day of additive containing bovine immunoglobulin and fructooligosaccharide for the first 15 days. SE = standard error.
[2]Contrasts: P = main effect of P; A = main effect of A; I = interaction of P and A; NS = not significant.

Table 6. Least squares means of animal performance of calves fed experimental commerical milk replacers (Quigley et al., 2002).

	Treatments[1]				Contrasts[2]	
	WPC	SDBP	SDPP	SEM	1	2
N						
Begin	40	40	40	---	---	---
End	30	37	38	---	---	---
Mortality, %	25.0	7.5	5.0	5.1	0.003	NS
IgG, g/L	11.9	11.9	10.8	1.1	NS	NS
Hematocrit, %	35.4	34.2	32.2	1.1	NS	NS
Plasma protein, g/dl	5.79	5.81	5.79	0.13	NS	NS
Age on day 0, days	4.4	5.0	4.6	0.2	0.09	NS
Fecal scores[3]	1.67	1.58	1.61	0.03	0.06	NS
Scours, days[3]	6.36	3.89	4.69	0.54	0.009	NS
Electrolytes, days[3]	2.77	1.85	2.37	0.36	NS	NS
Antibiotics, days[3,4]	2.31	1.42	2.15	0.41	NS	NS

[1]Treatments: WPC = calf milk replacer containing all-milk ingredients; SDBP = calf milk replacer containing spray-dried bovine plasma; and SDPP = calf milk replacer containing spray-dried porcine plasma. SEM = standard error of mean.
[2]Contrasts: 1= WPC vs. (SDBP + SDPP); 2 = SDBP vs. SDPP; NS = $P > 0.10$.
[3]Significant effect of week ($P < 0.0001$).
[4]Significant week × treatment interaction ($P < 0.05$).

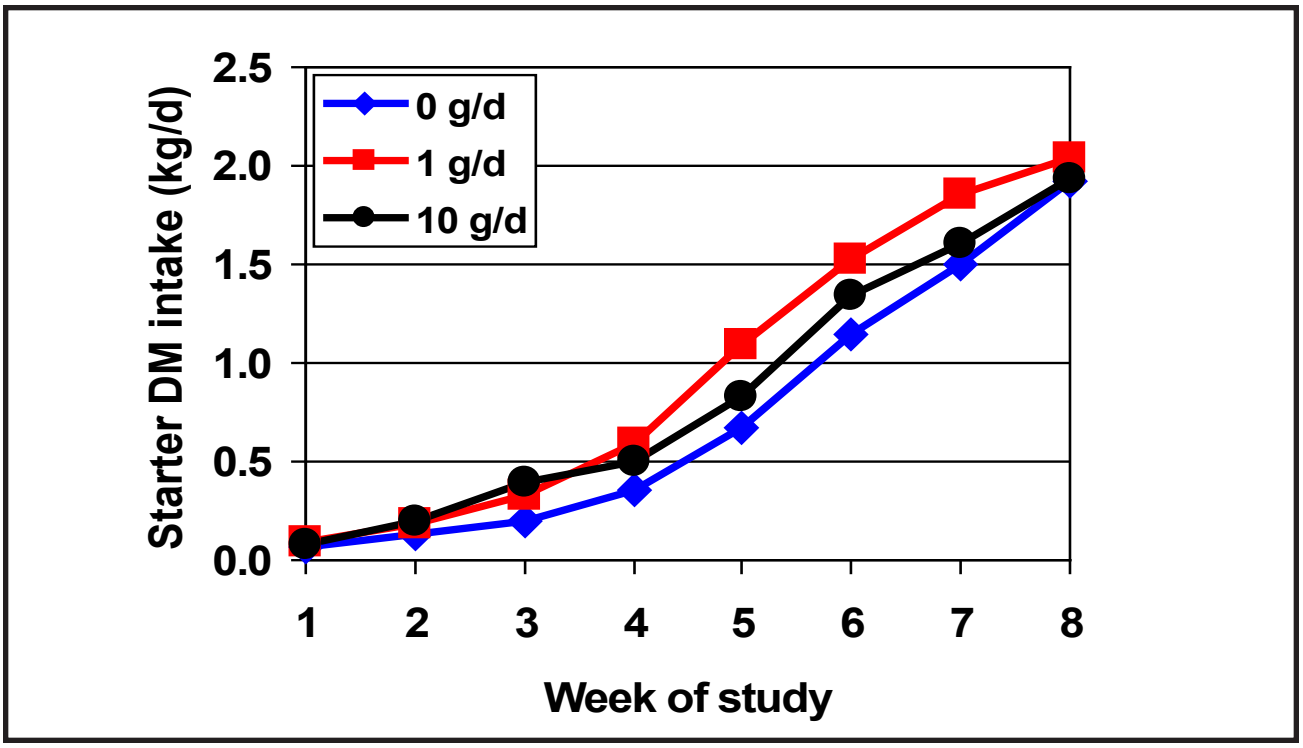

Figure 1. Starter DM intake in calves fed 0, 1 or 10 g/day of lactoferrin. Adapted from Joslin et al., 2002.

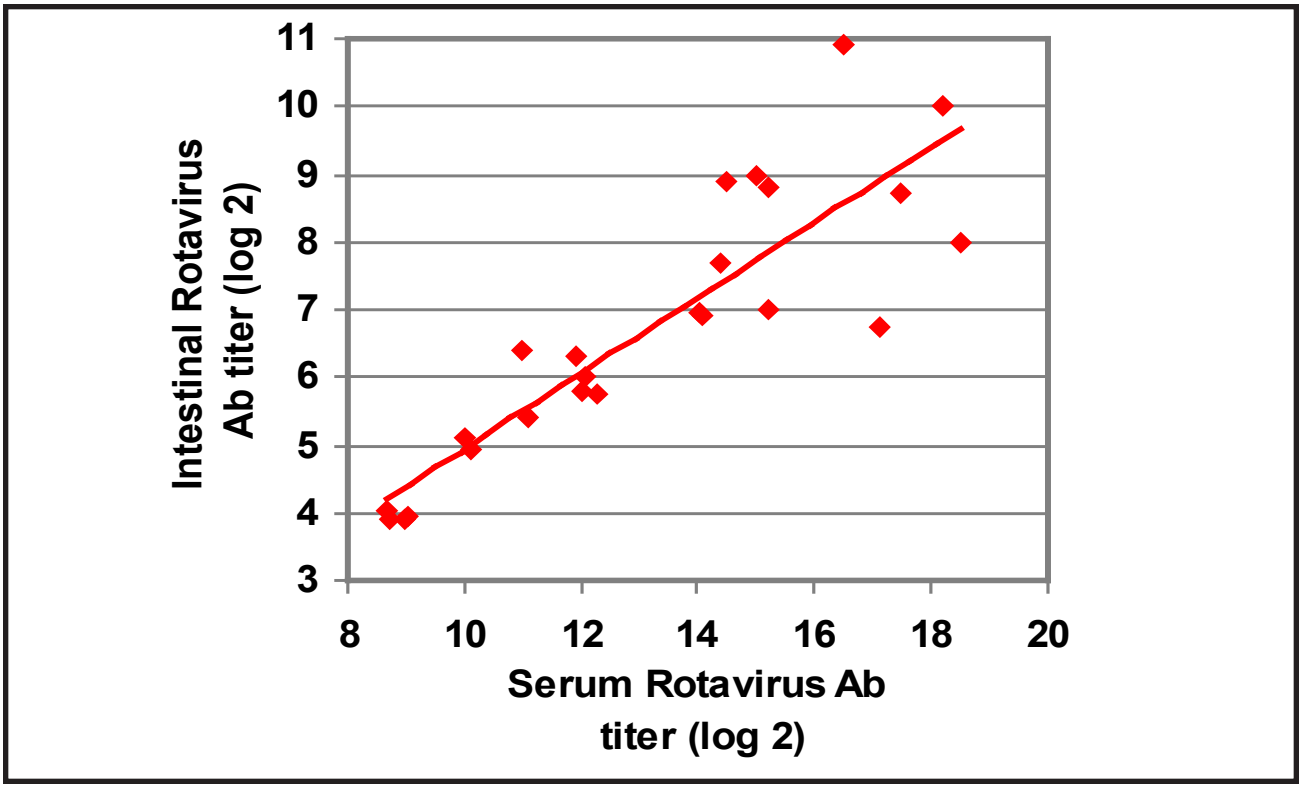

Figure 2. Relationship of serum and intestinal rotavirus antibody titers (Besser et al., 1988b).

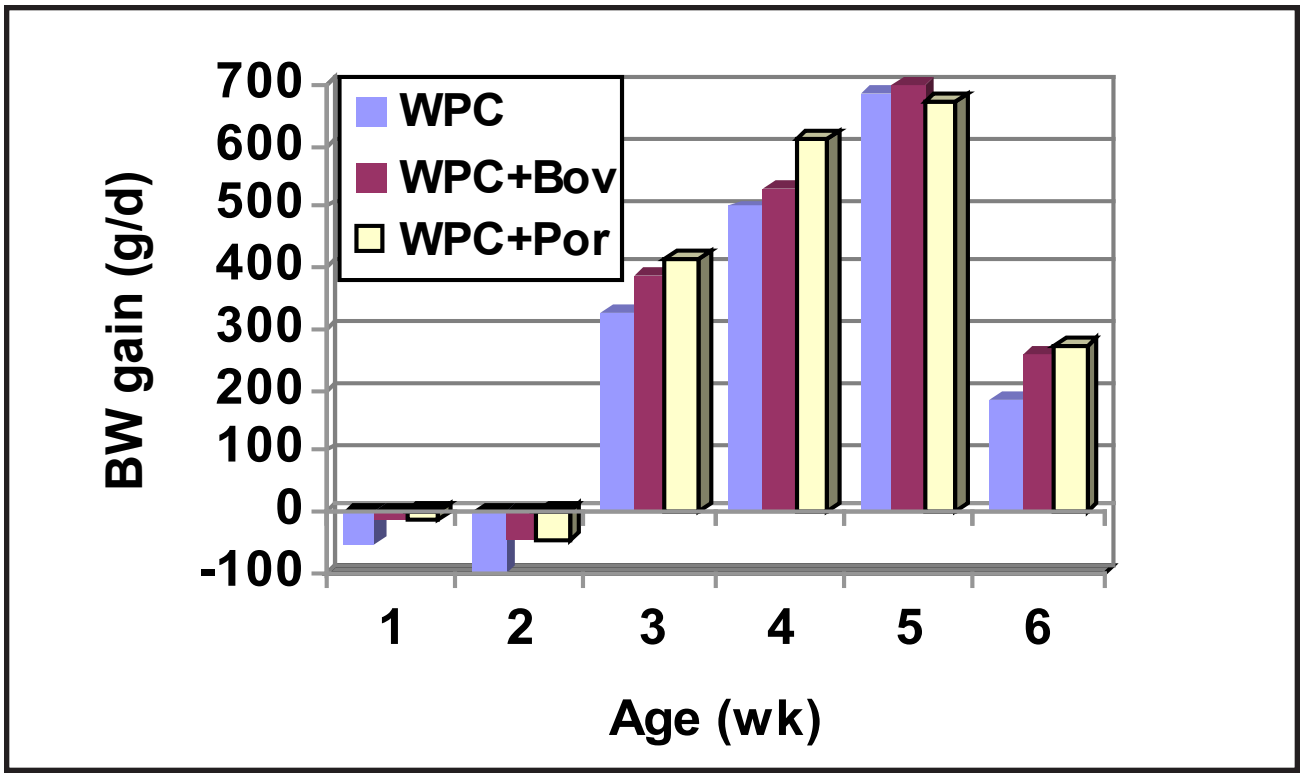

Figure 3. Body weight gain in calves fed milk replacer containing whey protein concentrate **(WPC)**, and bovine **(Bov)** or porcine **(Por)** plasma (Morrill et al. 1995).

How Fast Should Heifers Grow?

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Abstract

A strong heifer rearing program is critical to produce animals at first calving that have well-developed mammary glands capable of producing at the animal's genetic potential and that have sufficient body size and body condition capable of high feed intake and delivery of nutrients to the mammary gland. Weight gains more rapid than 2.0 lb/day before puberty generally decrease development of the mammary gland and subsequent milk production. Feeding more protein when heifers are grown rapidly will reduce the risk for impaired mammary development and is probably worth the added expense when trying to achieve postpartum body weights **(BW)** of ~1250 lb and calving at 22 to 24 months of age. Although calving earlier than 22 months will decrease the costs of raising heifers, heifers fed to achieve rapid gains before puberty are at risk for impaired mammary development and decreased profitability.

Introduction

In 1998, I wrote and presented a paper at the Tri-State Dairy Nutrition Conference on heifer growth entitled, "Heifer Growth: Truth or Consequences." My conclusion was that prepubertal heifers fed high energy diets that promote BW gains greater than 2.0 lb/day are at risk for impaired mammary development. The purpose of the current report is to give an update on the state of our knowledge on heifer growth. Along with brief summaries of the 1998 paper, I will present relevant work published in the last six years, and then conclude with current recommendations. As you will discover, the last six years haven't changed my recommendations much. I am willing to condone faster growth for calves younger than 2 months, and to accept growth rates slightly above 2 lb/day for heifers between 2 and 10 months, but I still disagree with targets for an average calving age earlier than 22 months and average growth rates faster than 2.1 lb/day for the duration of the prepubertal period. In this paper, I will give my side of the debate, but I admit that I do not have all the answers. While I base my ideas on research, my conclusions are my interpretation of that research. Furthermore, I appreciate opposing views, as debate is a healthy thing and promotes critical thinking. Finally, I acknowledge that those who promote rapid gains are, like me, interested in the well being of the dairy industry.

Why Try to Speed up Heifers?

In 1993, Heinrichs estimated the cost of raising Holstein heifers to first calving at 24 months to be about $1200, or ~15 to 20% of the total costs for a dairy enterprise consisting of cows and replacement heifers; if anything, the projected cost is now higher. Therefore, many consultants have focused on trying to

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decrease the cost of raising heifers as a means to increase farm profitability. One way to decrease these costs is to "accelerate" the growth and breeding of heifers so they calve earlier; some have suggested age at first calving as early as 20 months. However, accelerated growth can also decrease future milk yield, and level of milk production is a major determinant of profitability of lactating cows (VandeHaar, 1998). Level of milk production of a cow is determined by the 1) the ability of the mammary gland to produce milk, 2) the ability of the cow to provide the mammary gland with nutrients, and 3) the ability of the farmer to manage and care for the cow. The ability of the mammary gland to produce milk is largely dependent on its content of milk-secreting cells, which are found in the mammary "parenchymal" tissue (Tucker, 1987). The number of milk-secreting cells is determined by genetics and by the environment during mammary development, especially during the rapid mammary growth that occurs before and during the time of puberty, between 3 and 10 months of age (Sinha and Tucker, 1969). A sound heifer rearing program is critical to produce animals at first calving that have well-developed mammary glands capable of producing to the animal's genetic potential, and that have the body size and condition capable of high feed intake and delivery of nutrients to the mammary gland. Calving heifers as early as 20 months requires a body growth rate faster than 2 lb/day or body size at calving below 1250 lb. Both rapid gains and small size at calving can decrease subsequent milk production (Hoffman, 1997; Sejrsen and Purup, 1997). Thus, the decreased heifer-rearing costs associated with early calving must be weighed against the potential losses in milk income over the productive lifetime of the cow.

Desired Body Weight and Condition Score at Calving

Most studies examining the relationship between body size at calving and subsequent milk yield have made conclusions using correlations. I summarized these studies in 1998 and estimated that the optimal BW after calving is ~1250 lb for Holstein heifers (about 90% of mature BW for other breeds), that the optimal body condition score is 3.0 to 3.5, and that the optimal withers height is 54 to 56 inches for Holstein heifers at calving. In 1998, I stated that the effect of BW at calving on subsequent productivity has never been determined definitively in a "cause and effect" study. I was wrong. In 1986, Lin et al. reported a study using 500 heifers (Holstein, Ayrshire, and Holstein x Ayrshire) randomly assigned for breeding eligibility at 11.5 or 15 months. The heifers bred early calved at 23 months compared to 26 months for the delayed heifers; they also weighed 100 lb less at calving and produced 600 lb less milk. Given that the heifers in both groups were fed for standard growth rates and that there is no evidence to suggest that 23 months is too early for calving, the lower milk yield of early bred heifers was likely due to their lower weight at calving. Most correlation studies are consistent with this finding a 100 lb lower body weight at calving can be expected to result in ~700 lb less milk in the lactation

Effect of Nutrition on Growth, Mammary Development, and Milk Yield

To achieve a body weight of 1250 lb after calving, heifers must weigh ~1400 lb before calving, and they must gain an average of 1.8 lb/day if they are to calve at 24 months. If calving at 20 months is desired, then average gains must be 2.1 lb/day. Gains in the first 2 months are typically slower (I will discuss accelerated calf growth later in the paper), so gains after 2 or 3 months must be even faster to achieve the target BW. The period after 3 months of age and before puberty (8 to 10 months) is a critical time in mammary development.

During this time, the mammary parenchyma rapidly expands into the mammary fat pad like a head of broccoli and forms the daughter cells, which are the foundation for later mammary development. The number of parenchymal cells present at puberty partly dictates the number of milk-secreting cells that will be present during lactation. Growth of the mammary gland slows down shortly after puberty, and after breeding, high energy diets and rapid gains have little effect on subsequent milk production if calving occurs at optimal body size and moderate body condition (Grummer et al., 1995; Hoffman et al., 1996; Sejrsen et al., 1982; Valentine et al., 1987).

Multiple university studies have shown that mammary development and future milk production are impaired when heifers are fed diets that promote BW gains greater than 2.2 lb/day during the critical prepubertal phase of mammary growth. For example, Sejrsen et al (1982) fed heifers at high or low intake of an energy-dense diet to gain 2.8 or 1.4 lb/day from 7 months of age to 700 lb of BW and found that heifers fed for high energy intakes had 32% less mammary parenchymal DNA than those grown slowly. In 2000, we reported results from a study in which 70 heifers were fed either a high energy and high protein diet [1.27 Mcal/lb of metabolizable energy **(ME)**, 20% CP, and 75% grain) or a low energy diet (90% poor quality forage) from 4 months of age until confirmation of pregnancy (Radcliff et al., 2000). Heifers were eligible for breeding at 800 lb. Standard heifers grew at 1.8 lb/day during treatments, were first bred at 14.0 months, and calved at 23.6 months. Rapidly-grown heifers grew at 2.5 lb/day during treatments, were first bred at 10.9 months, and calved at 20.7 months. After breeding, all heifers were fed the same diet. Heifers calved at similar BW, body height, and body condition score. After calving, heifers were fed a similar diet and milked 2X per day; bST was not used. Milk production on a 305-day basis was 19,000 lb for control heifers. Rapidly-grown heifers produced 12% less milk (10% less on an energy-corrected basis) in their first lactation than did control heifers. In our study, 40 of the heifers were at the MSU campus farm, but 30 were at the Kellogg Biological Station **(KBS)**. We observed a trend for a treatment x location interaction ($P = 0.08$). Milk production was decreased only 4% on campus but decreased 23% at KBS; perhaps this difference was related to the fact that cows at the campus dairy were in tie-stalls, whereas those at KBS were in loose, free-stall housing. Heifers fed the high diet also tended to have more feet and leg problems.

In addition, there are at least three other published university studies with prepubertal growth rates of >2.2 lb/day (Gardner et al., 1977; Little and Kay, 1979; Peri et al., 1993). All three demonstrated that heifers fed high energy to promote rapid growth before puberty produced less milk as cows (18% less, 52% less, and 16% less, respectively). In the studies of Gardner et al. (1977) and Little and Kay (1979), rapidly-grown heifers calved at 20 and 19 months, respectively, and in Peri et al. (1993), heifers calved at 26 months. Consistent with this, Lammers et al. (1999) found that feeding a high energy diet that promoted gains of 2.2 lb/day before puberty resulted in 4% less fat-corrected milk than feeding a low energy diet that promoted a gain of 1.6 lb/day; in their study, rapidly-grown heifers calved at 23 months. I hypothesize that if Lammers et al. (1999) had bred heifers earlier or grown them slightly faster, the decrease in milk production would have been more pronounced. This decrease in mammary development is difficult to demonstrate on commercial farms when heifers are all fed the same diet and no control group is used for comparison. Rapid growth does not cause an apparent reduction in udder size in the live animal (the parenchyma is only part of the

udder). Moreover, milk production occurs at least one year later, and it is affected by several other factors, including genetics, environment, feeding, and management during the time around calving and lactation.

The relationship between prepubertal growth rates and mammary development is complicated by the fact that heifers will grow fast for one of two reasons. When heifers are fed ad libitum and grown in a good environment, feeding a diet high in energy density will result in faster BW gains. Along with faster gains, the heifers also will become fatter, and as research has shown, average gains greater than 2.2 lb/day will reduce subsequent milk production at least 10%. However, within a group of heifers, some will grow faster than others, and we found that these fast growing heifers are actually the leanest in the group. We also reported that heifers naturally grow faster than herdmates (when fed and managed the same) do not have less mammary parenchyma or produce less milk once they become cows (Silva et al., 2002b). In fact, when we searched for factors during the prepubertal period that might explain variation in mammary development or subsequent milk yield, body condition score was the only consistently significant factor. In other words, heifers with the genetic predisposition to gain fat will likely produce less milk as cows. However, the fact that some heifers naturally grow faster than others and produce as much milk as the slower growers once they become cows does not indicate that it is okay to feed all heifers for rapid growth.

Van Amburgh et al. (1998) found that rapid prepubertal growth (2.1 lb/day) significantly decreased milk yield 5%, but many other factors affected milk yield as well. Thus, they found that the correlation between prepubertal growth rate and first lactation milk yield among 270 heifers was very low (r = 0.2). More recently, Smith and Van Amburgh (2002) reported on a study to examine effects of different dietary fat sources fed to prepubertal heifers on subsequent milk production. All heifers were grown on an intensive feeding management system from birth to first calving, with targets of first calving at 22 months and postcalving BW of 1210 lb. In the study, prepubertal dietary treatment had no effect on milk yield. On average, however, heifers calved at 22.0 months of age and produced 25,000 lb of milk in their first lactation (heifers were given bST, but I don't know whether milking was 2X or 3X). This production level is impressive for the first lactation and indicates that a target of 22 months is probably reasonable when heifers are grown in an intensified management system from birth to first calving. Because the heifers were eligible for breeding at 750 lb, the faster growing heifers were bred at a younger age than the slower growing heifers and the age at first calving ranged considerably. The authors then categorized animals into three groups according to age at first calving to examine relationships between calving age and milk production. The average age at first calving for the 19 heifers categorized as early calvers was 20.2 months, compared to 24.2 months for the 19 heifers categorized as late calvers (after 23 months). Compared to the late calvers, early calvers had faster prepubertal daily gains (2.16 vs. 1.96 lb/day) and were smaller at calving (1180 vs. 1310 lb after calving). Interestingly, the early calvers produced as much fat-corrected milk as those that calved later. The authors noted that the heifers produced 88% as much milk as the mature cattle in the herd. Thus, they argued that a systematic approach to intensified calf and heifer management, beginning at birth, seems to allow heifers to achieve lower ages at first calving with little or no loss in milk production. According to the paper, the authors currently are conducting a study to determine if this intensified system does in fact result in as much milk as conventional slower-growth systems

by directly comparing the two systems using a cause and effect experimental approach.

This retrospective analysis is certainly interesting, because according to current thought, the faster prepubertal gain and lighter BW at calving of their early calving heifers should have resulted in less milk. However, I believe it is important that these relationships not be interpreted to indicate that a target age for first calving at 20.2 months has no impact on milk yield. In my opinion, caution is warranted until experiments are reported using a cause and effect philosophy; in other words, if heifers are randomly assigned for early vs. late breeding so that they calve at 20 vs. 24 months, will the two groups produce the same amount of milk? The fact that heifers with a genetic predisposition toward faster growth (and thus earlier breeding) produce as much milk as herdmates does not mean that all heifers can be managed for rapid growth and early calving without loss of milk production. Perhaps, heifers that naturally grow faster may be the heifers with the highest growth hormone concentrations, the greatest lean to fat ratios before puberty, the greatest appetites, or the best health, and these same heifers may give more milk as cows. Furthermore, perhaps these early calving heifers would have produced more milk if they had been managed to grow a little slower and calve a little later! The fact remains that every published study in a peer-reviewed journal in which heifers were purposely grown faster than 2.0 lb/day or purposely calved earlier than 21 months has resulted in less milk production than the respective controls for the study (although in some studies, the decrease was not statistically significant). Until such a study has been published, the conclusion cannot be avoided that heifers grown more rapidly than 2.0 lb/day are at high risk for decreased milk yield in first lactation.

Diet Composition/Source of Calories

The responses to diets promoting rapid body gains (>2.0 lb/day) vary considerably. Decreases in parenchymal DNA with rapid growth range from no change in some studies to as much as 50% in others. Decreases in milk production with rapid growth vary from 5 to 50%. In 1998, I postulated that some of this variation in the response to prepubertal diet was due to the ratio of protein to energy in the diet. Using all available published literature, I examined the relationship between mammary development or milk yield and the dietary protein to energy ratio that was used to achieve rapid gains in excess of 2.0 lb/day. My analysis gave indirect evidence that increasing the dietary protein of prepubertal diets might allow growth as rapid as 2.1 lb/day without impairing mammary development. This analysis was consistent with work of Pirlo et al. (1997), who fed high energy prepubertal diets with high or low protein to Friesian heifers for moderate rates of gain. Diets were 62 vs. 50 g of CP/Mcal of ME from 220 to 440 lb BW and 49 vs. 40 from 440 to 660 lb, respectively. Heifers grew ~1.8 lb/day. Compared to a control group fed low energy diets, heifers fed high energy with low protein tended to produce 15% less milk protein as cows, but those fed high energy with high protein produced as much as controls.

Since 1998, two papers have been published directly examining effects of dietary protein on mammary development in heifers grown rapidly. Lammers and Heinrichs (2000) reported that feeding 61 compared with 46 g of CP/Mcal of ME to Holstein heifers from 6 to 12 months of age increased the rate at which the teats elongated. The study was complicated by the fact that heifers fed higher protein also grew slightly faster (2.4 vs 2.2 lb/day). More importantly, however, teat length likely is not a very good measure of mammary development,

and the high protein heifers had shorter teats initially, and still had shorter teats at the end of the treatment period. There is no question that teat length does increase as heifers grow, but in our laboratory, we found no correlation between teat length and mass of mammary parenchyma. So whether or not protein alters mammary development was still unanswered.

Meanwhile, we also were conducting a study to examine the effects of the protein to energy ratio on mammary development (Whitlock et al., 2002). In our study, 54 Holstein heifers were fed high energy diets containing a low, standard, or high protein to energy ratio from 3.5 months of age until slaughter at ~9 months of age, which was ~46 days after puberty. The diets were fed ad libitum as TMR with 40% alfalfa haylage and 60% grain and contained 1.30 Mcal/lb of ME. The low, standard, and high protein treatements were calculated to contain 37, 41, and 44 g of metabolizable protein / Mcal of ME and 48, 57, and 66 g of CP / Mcal of ME, respectively. This range in CP:ME was similar to what we had found in the literature, and we hypothesized that the low protein diet would impair mammary development, and thus we would understand why the published responses to high energy diets prepartum varies so much. Onset of puberty was carefully monitored by palpation. Estrous was managed with prostaglandin $F_{2\alpha}$ after detection of the first corpus luteum, so that each heifer was killed 7 to 12 days after her fourth estrus. This protocol minimized variation in mammary tissue due to changes in ovarian steroids. Heifers fed low, standard, and high protein gained 2.5, 2.6, and 2.6 lb/day, respectively. Dietary protein did not affect age or BW of heifers at puberty or slaughter, wither height gain, or carcass composition. Average mammary parenchymal DNA content for heifers on low, standard, and high protein diets was 595, 619, and 670 mg /100 kg of BW, respectively, and was not significantly different. Thus, these data did not support our initial hypothesis. However, the timing for the onset of puberty varied considerably; for heifers that attained puberty early, those fed low protein had 33% less parenchymal DNA than those fed high protein even though their body growth and carcass composition were not compromised (Figure 1). We concluded that dietary protein does not have a major effect on mammary development of rapidly grown prepubertal heifers (as we expected), provided protein is adequate for normal body growth. However, the low protein diet did impair mammary development in animals that achieved puberty early, even though their body growth and carcass composition were not compromised. Therefore, we suggested that feeding low protein diets increases the risk of impaired mammary development when heifers are fed for rapid growth.

In 2001, the National Research Council published a new version of the Nutrient Requirements for Dairy Cattle. For heifers, the required protein to energy ratio is greater for heifers fed for faster gains and decreases as heifers age. In addition, the new program uses a reasonable approach to predicting microbial protein yield for heifers so that heifer diets now require reasonable amounts of rumen undegradable protein. In my opinion, the new guidelines are consistent with feeding protein for optimal mammary development.

In the last five years, two studies were reported that examined effects of fat. Smith and Van Amburgh (2002) found no effect of feeding high conjugated linoleic acid **(CLA)** or high fat diets compared with an isocaloric low fat diet to prepubertal heifers on subsequent milk yield in the first lactation. Thibault et al. (2003) found no effect of feeding a high soybean oil

grain mix to heifers from 2 to 6 months of age on mammary development or subsequent milk yield; however, heifers in both the high oil and control groups were fed to restrict gains, and daily gains averaged 1.8 lb/day. New data has also been published regarding the effects of stair-step heifer raising programs on subsequent milk production (Ford and Park, 2001). The study had only 12 heifers, but the authors found that feeding for slow growth (1.3 lb/day) from 6 to 9 months, followed by rapid growth (2.1 lb/day) from 9 to 11 months and two more slow and fast phases, resulted in 21% more milk in the first lactation and 15% more in the second lactation. In light of recent work with calves (discussed later), we are currently testing the hypothesis that short periods of rapid growth may actually benefit mammary development in contrast to the negative effects of long periods of rapid growth.

Possible Mechanism for the Effect of Diet on Mammary Development

The fact that feeding for rapid growth decreases subsequent milk production has been known for 85 years. At one time, the theory for this relationship was that rapid growth was associated with too much fat deposition in the udder (Swanson, 1960). Later the predominant view was that the fat itself was not the problem, but rather that high energy intake caused hormonal changes, such as decreased serum growth hormone, that reduced mammary development (Sejrsen et al., 1982). Recently, we found that even when heifers are fed the same diet, those that are the fattest around the time of puberty have the least mammary parenchymal tissue (Silva et al., 2002b). Thus, excess body fat, whether due to diet or genetics, is associated with less mammary parenchyma. In addition, parenchymal tissue from heifers fed for rapid growth contains more adipocytes than that from heifers fed for slow growth (Capuco et al., 1995), and mammary extracts from rapidly grown, compared to slowly grown, heifers are less mitogenic for cultured bovine mammary epithelial cells (Weber et al., 1999). Finally, in support of the idea that accumulation of fat is detrimental to optimal mammary development, McFadden and Cockrell (1993) observed a decrease in proliferation of bovine mammary epithelial cells when they were co-incubated with bovine adipose tissue. These results indicated that bovine adipose tissue might secrete a compound that inhibits proliferation of mammary cells. The fact that body fat is inversely related to mammary development and that adipose tissue impairs mammary cell proliferation in vitro led us to investigate the possibility that leptin, a hormone produced by adipose tissue, is at least partly responsible for the effect of high energy intake on mammary development.

Leptin is a promising candidate for mediating the effects of diet on mammary development. It is produced by adipocytes and acts as a metabolic signal for body fatness (Houseknecht et al., 1998). Increased body fatness increases blood leptin concentrations in cattle (Ehrhardt et al., 2000). Furthermore, high energy diets increase blood leptin concentrations in sheep, independent of effects on body fatness (Blache et al., 2000), and calves fed for rapid rates of gain have elevated leptin concentrations before changes in body fat are noticeable (Block et al., 2003; Brown et al., 2002). In addition, leptin is produced locally in the mammary gland by both fat cells and epithelial cells; based on data showing that insulin and insulin-like growth factor-I increase leptin mRNA in cultured mammary epithelial cells, it seems possible that rapid gains also may increase leptin synthesis within the gland (Smith and Sheffield, 2002). A primary physiological role for leptin is to act on the hypothalamus to decrease feed intake (Houseknecht et al., 1998). But leptin

receptors are found outside the hypothalamus, and numerous effects of leptin on other tissues have been demonstrated (Houseknecht et al., 1998).

We first found that leptin reduces the proliferation of bovine mammary epithelial cells in culture (Silva et al., 2002a). Next, we also observed that leptin inhibited mammary cell proliferation in vivo (Silva et al., 2003). Twelve prepubertal dairy heifers were given intramammary infusions of insulin-like growth factor-I (IGF-I; a stimulator of mammary cell proliferation) and leptin. With this protocol, each mammary quarter served as a separate experimental unit. After 7 days of treatment, the percentage of epithelial cells that were undergoing mitosis was increased 60% by 0.01 mg/day of IGF-I per quarter and decreased 40% by 0.1 mg of leptin per quarter per day (Figure 2). Much remains to be done to understand the possible role of leptin in mammary development, but because both high energy intake and obesity increase blood leptin concentrations, our research to date supports the hypothesis that leptin may be partly responsible for the effect of energy intake and body fatness on mammary development. Thus, we suggest that the accumulation of fat before puberty may be just as important, or perhaps more important, than the actual BW gain of a heifer in considering the role of diet in mammary development. If so, trying to feed heifers to maximize lean growth, while minimizing fat growth, might benefit lifetime productivity. However, until new studies prove that excess fattening is in fact the reason that rapidly-grown heifers produce less milk, I discourage rates of gain faster than 2.0 lb/day even if the heifers do not gain excessive body fat. Growth that is too fast and associated with too much body fat gain most commonly occurs on farms when heifers are fed diets high in corn silage, especially if protein supplementation is inadequate.

Another possible mechanism for the effect of prepubertal diet on mammary development is that high energy diets decrease the age for the onset of puberty by 1 to 2 months. The onset of puberty and the associated changes in circulating sex steroids are likely the signals that slow down the rapid mammary development of young heifers. A shorter prepubertal period may be another reason for the decreased mass of mammary parenchymal tissue at puberty.

Effect of Heifer Feeding Program on Lifetime Profitability

Although the cost of raising a heifer to first calving is not trivial, it is substantially less than the gross income generated from subsequent milk sales. Thus, in developing a cost-effective heifer rearing program, one must weigh the costs of heifer rearing versus the potential impact on net income of the animal after calving. While the costs to raise a heifer vary widely across farms and management systems, these costs can be partitioned into costs that remain relative constant despite faster growth rates (e.g, breeding and vaccines), costs that will change as a function of growth rate (feed), and costs that will change as a constant function of days in the heifer enterprise (e.g., labor, facilities). As heifers grow faster, the percentage of feed used for maintenance declines, so accelerated growth systems require fewer feed calories to achieve the target BW at first calving. However, faster growth rates may require better quality feeds that cost more per unit of energy consumed. This cost differential would depend on the price of grains relative to forages, and the availabililty and cost of high quality forages relative to low quality forages. If feed for accelerated growth is more expensive per unit of energy, the savings in total calories for early calving may be offset by the higher feed costs per day.

In 2001, Wolf and VandeHaar assessed the value of accelerated growth programs. We estimated feed costs for confined heifer programs with first calving at 20 or 24 months. To do this, we balanced several rations for different growth rates at various stages of growth. We assumed that costs before weaning were the same. Results are shown in Table 1. Under a scenario with low feed prices, the least cost ration resulted in $19 more costs for the 24 month program. A scenario with higher feed prices resulted in a $16 difference. If the accelerated growth program requires a higher level of protein, as NRC (2001) and most nutritionists recommend (for this example, I assumed 61 instead of 58 g CP/ Mcal of ME), the feed costs are only $7 lower in total for the accelerated growth program. We also estimated yardage costs, which included labor, facilities, and overhead. On the low end, yardage costs were estimated at $0.30/day (a common value for beef feedlots). On the high end, yardage costs were estimated at $1.02/day, based on an analysis of Michigan farms by Harsh et al. (2000). Total potential cost savings for accelerated growth is estimated to be in the range of $43 to $143 per heifer (Table 2). Of course, the actual cost savings will be specific to an individual operation, but yardage costs likely are more important than feed costs in making decisions about early calving. A shortage of heifer space relative to the space for lactating cows would effectively increase yardage costs and push decisions toward earlier breeding. We did not consider the possibility of grazing for heifers, but the availability of pasture (which typicially is low cost per Mcal of energy) could result in a large savings in feed costs, even if it reduced growth rates and delayed first calving until 24 months. Furthermore, yardage costs are often, but not always, less for a grazing system.

Next, we must consider the value of the milk lost due to accelerated growth programs. All experiments to date comparing a rapid growth diet to a low growth diet have found decreased milk production, anywhere from 4 to 50% for studies in which rapid growth was defined as greater than 2.0 lb/day. In my 1998 TriState paper, I gave a detailed analysis of the value of lost milk using the concept of marginal profits. My economist friends have convinced me that I did not use the word "marginal" correctly in that analysis. So, rather than get bogged down in the lingo of economics, I will compare the economics of heifer programs to the decisions that one uses in considering the use of bST. It takes 16 doses to treat a cow with bST, starting at 70 days in milk and continuing every 14 days until the last injection at 294 days. The cost of bST is at least $6 per dose or $96 for 16 doses. Assuming that a cow produces 75% of her saleable milk after 70 days, and that bST increases milk yield 15%, then the total increase in saleable milk per lactation would be 11.25%. So for nearly $100 in supplies plus additional labor costs, the return is ~11% in milk income. For a cow producing 20,000 lb of milk without bST, 11% is an extra 2200 lb. If the payback on bST is 2:1, the increased milk, after considering additional feed and other variable costs, must be worth $192/2200 lb, or 8.7 ¢/lb.

According to our earlier cost analysis, the cost of delaying calving by 4 months is $43 to $143. Almost all nutritionists agree that first calving at 22 months is achievable with reasonable growth rates. Thus, the cost of delaying calving from 20 months to 22 months would be half of our projections, or between $22 and $72. Based on most published and controlled studies (heifers fed different diets to achieve fast or slow growth), the return in milk income to delaying calving past 21 months is expected to be 5 to 15%. Is spending an extra $22 to $72 on a heifer worth getting an extra 1000 to 3000 lb of milk from her one year later, which according to my bST comparison must

be worth $87 to $260? Moreover, as mentioned earlier, the cost for delayed calving might be even lower in some grazing systems.

Accelerated Growth Programs for Calves

In recent years, accelerated growth programs for calves have become popular. However, the effect of these programs on mammary development is not clear. Although the amount of mammary growth before 3 months of age is small on an actual basis, the fractional growth rate of mammary parenchyma is quite high early in life. For example, we found that mammary parenchymal mass increased 500% between 8 and 14 weeks, while at the same time, carcass mass increased only 10 to 70% (Brown et al., 2002). Any factor that alters mammary growth this early in life might have a substantial impact on subsequent milk production.

Calves that were allowed to suckle from a cow or drink whole milk from birth to 6 weeks of age grew faster (2.0 vs. 1.3 lb/day) and produced just as much, if not more, milk in their first lactation than calves that were restricted-fed (Bar-Peled et al., 1997; Foldager and Krohn, 1994). These studies led to the proposition that heifer calves can be grown at rapid rates of gain until they are 3 months old without impairing future milk production. However, neither study examined the impact of feeding milk replacer to achieve rapid gains. Anecdotal evidence suggested that calves could be fed a high protein milk replacer to achieve gains as fast as 3 lb/day without excess body fat deposition, but effects of these replacers on mammary development were not known.

We conducted an experiment to determine if increasing energy and protein intake in heifer calves less than 14 wk of age would alter mammary development (Brown et al., 2002). In a 2x2 factorial arrangement of treatments, Holstein heifer calves (n = 53) were fed diets for low or high gains from 2 to 8 weeks and from 8 to 14 weeks of age. The low gain calves were fed standard milk replacer at 1.2% of BW (21.3% CP and 21.3% fat) and calf starter at restricted intake (20.5% CP). The high gain calves were fed a high protein milk replacer at 2% of BW (30.3% CP and 15.9% fat) and a high protein calf starter (25% CP) free-choice. Low gain calves grew at 0.9 lb/day from 2 to 8 weeks and 0.9 lb/day from 8 to 14 weeks of age. High gain calves grew at 1.5 lb/day from 2 to 8 weeks and 2.4 lb/day from 8 to 14 weeks of age. Calves were weaned at 7 weeks of age and slaughtered at 14 weeks of age. Calves fed the high gain diet from 2 to 8 weeks had twice as much mammary parenchymal DNA (per unit of BW) as calves fed the low gain diet. Calves on the high gain diet were also more efficient at converting feed to gain in both periods. We are currently conducting a follow-up study in which calves on an accelerated versus traditional milk program will be evaluated through their first lactation; preliminary data indicates that the heifers are attaining breeding size at an earlier age. However, the cost of feeding this high protein milk replacer at a higher rate was expensive, costing ~$40 more than the conventional milk replacer program. Moreover, the gain in BW at weaning was only ~22 lb, which is ~2 weeks of growth with a conventional program. It is difficult to justify spending $40 to decrease the age at calving by 2 weeks; based on our earlier analysis, the savings in yardage will be $4 to 10 and the savings in feed will be $10 to 15. However, if the increased cost of the accelerated calf program results in decreased mortality, or improved growth efficiency later in life, or increased milk production as a cow, then the program may be economically beneficial. In addition, most studies examining possible benefits of accelerated calf programs use calves fed standard milk replacer at low rates of intake and, in some cases, restricted grain as well. We

do not know whether high protein milk replacer is necessary for the response, whether the same response would be observed with increased grain intake, and whether growth rates faster than 1.5 lb/day would also increase mammary growth.

Recommendations

1. Heifers grown faster than 2.0 lb/day will likely produce less milk as cows, especially if they are fed inadequate protein. Current NRC (2001) recommendations for protein relative to energy are adequate and need not be exceeded. Targets for heifers are in Table 3.

2. Accelerated growth programs require excellent reproductive management and excellent nutritional management after breeding. The breeding pen should either have a lower energy diet or methods should be in place to ensure conception occurs soon after breeding eligibility and therefore minimize variation among heifers. Rapidly-grown heifers often grow slower than expected after breeding. Unless they are fed and managed to maintain high rates of gain, they will likely calve at lighter weights than control heifers and produce even less milk during lactation. Heifers that were bred late may gain too much body fat when fed high energy diets throughout gestation.

3. For most well-managed, intensive-feeding operations, the most profitable age for first calving is likely 22 to 24 months. First calving at greater than 24 months will likely reduce profitability, unless feed or fixed costs are unusually low, as may be the case for heifers grown on pasture. Decreasing the age at first calving to less than 22 months may increase profits if milk production is not impaired, but all experiments to date have shown impaired milk production. Thus, in my opinion, early calving is risky.

4. Pasture generally has a very low cost per Mcal of ME. Even in pasture systems, however, gains of 1.8 lb/day are attainable through intensive-grazing or grain supplementation, and 22 to 24 months may be most profitable.

5. Accelerated milk programs for calves do not seem to impair mammary development, and in fact may benefit it. However, they are expensive, and unless they promote health or later milk production, do not seem economically beneficial.

6. Under good environmental conditions and management, dairy heifers usually will grow considerably faster than expected when fed a TMR free choice. If you balance a diet for 1.8 lb/day, the heifers may very likely grow at 2.3 lb/day. Thus, to achieve goals for heifers, growth should be monitored on at least 10% of the heifers. The resulting measurements should be compared to tables of recommended weights and heights.

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Table 1. Feed cost estimates for confined heifer programs (Wolf and VandeHaar, 2001).

	24 month[1] (total cost)	20 month [2](total cost)	Difference
Low feed price[3]	$511	$492	$19
High feed price[4]	$646	$630	$16
High protein[5]	---	$504	$ 7

[1]The total energy required for 24 month age at first calving was 12,605 Mcal of metabolizable energy **(ME)**.
[2]The total energy required for 20 month age at first calving was 11,482 Mcal of ME.
[3]Low feed price rations were balanced for least cost using $2.20/bu for corn and $22/ton for corn silage.
[4]High feed price rations were balanced for least cost using $4/bu for corn and $33/ton for corn silage.
[5]High protein rations used the low feed prices, but the 20-month program was balanced for 61

Table 2. Total potential cost savings ($ per heifer) for 20 compared to 24 month age at first calving (Wolf and VandeHaar, 2001).

	Feed cost difference	
	High	Low
Yardage difference		
High	$143	$131
Low	$55	$43

Table 3. Targets for rearing heifers in intensive management conditions.

Age at first breeding	13 to 15 months
Body weight at first breeding	800 to 850 lb
Age at first calving	22 to 24 months
Body weight after calving	1250 lb
Withers height at calving	56 inches
Body condition score at calving	3.0 to 3.5
Growth rate from 3 to 10 months of age	1.7 to 2.0 lb/day

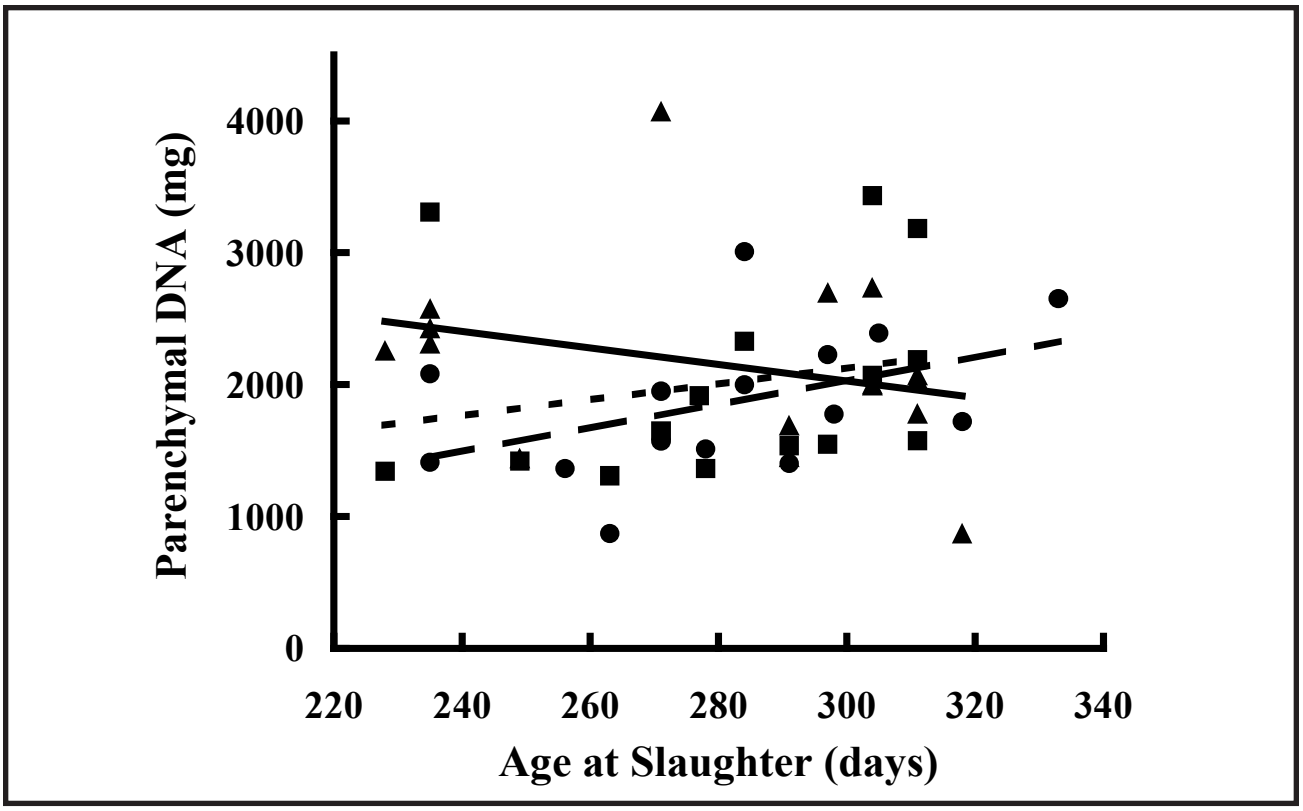

Figure 1. Partial regression lines of total mammary parenchymal DNA against age at slaughter for each dietary treatment: low protein (__ __ __, slope=9.0, *P* = 0.17), standard protein (**.....** , slope=6.0, *P* = 0.36), and high protein (_____ , slope=-6.2, *P*=0.24) (Whitlock et al., 2002). Also plotted are individual heifer values for heifers fed low protein (n = 15, circles), standard protein (n = 15, squares), and high protein (n = 16, triangles).

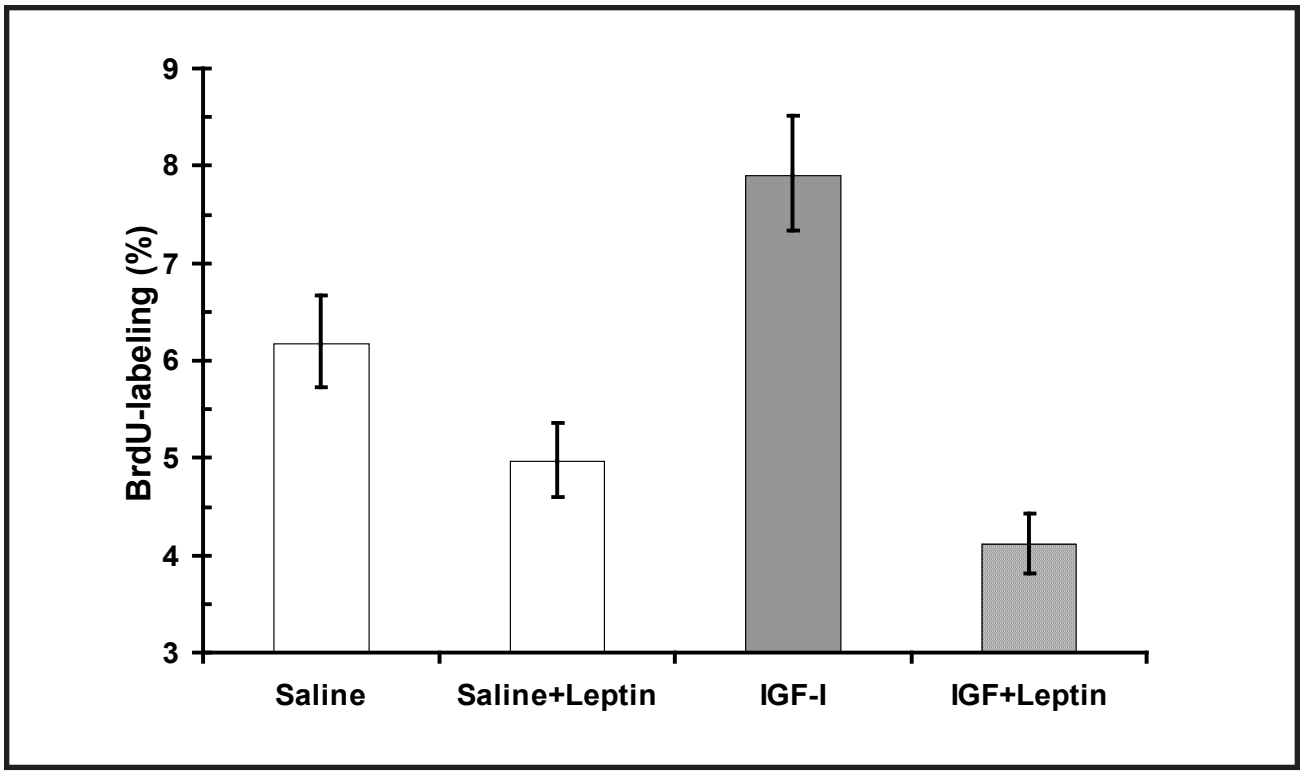

Figure 2. Effects of intramammary infusion of leptin and insulin-like growth factor-I (IGF-I) on proliferation of mammary epithelial cells in prepubertal heifers as measured with bromodeoxyuridine-(BrdU) labeling (Silva et al., 2003).

Straw in Rations for Dairy Cows

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Abstract

With the strategy to provide adequate effective fiber in diets for dairy cattle and yet use a source that promotes the formation of a rumen mat and requires low inclusion rates for target effective fiber concentrations, straw is being added to rations on many US dairy farms. Wheat and barley are the most common sources of straw. Data on feeding dry and lactating cows straw at low inclusion rates are very limited; most of the data available is from high inclusion rates. High feeding rates are likely to decrease intake, total tract digestibility, and animal performance. In some situations, feeding straw at low inclusion rates may be beneficial by causing positive associative effects in the rumen, especially in low forage diets. If straw if to be fed, typical inclusion rates should be 2 to 8% of the ration and it must be chopped or particle size adequately reduced in the TMR mixer to minimize the potential for sorting by cows.

Introduction

Fiber is very important for dairy cattle to maintain rumen heath and optimize rumen microbial efficiency. The primary source of effective fiber fed to dairy cattle is forages, especially corn silage, various legumes (alfalfa being the most prevalent), and various grasses; however, several nonforage fiber sources are available to provide some effective fiber and to dilute starch from the ration. Dietary indexes for effective fiber include concentrations of forage, neutral detergent fiber **(NDF)**, acid detergent fiber **(ADF)**, and forage NDF **(FNDF)** (Table 1); however, dietary concentration of forage is not very relevant because quality of the forage is not included. Total dietary NDF can be inflated with the use of nonforage fiber sources, thus FNDF is commonly used as a reference for effective fiber. With higher concentrations of forage NDF, more nonfiber carbohydrates (**NFC**) can be tolerated (NRC, 2001), and thus the FNDF:NFC is a useful monitor (Table 1). With the increased use of nonforage fiber sources, increased milk yield by cows, and more comprehensive nutrition models, more fine tuning of carbohydrate concentrations from many different ingredient sources is being practiced.

With the strategy to provide adequate effective fiber in diets for dairy cattle and yet use a source that promotes the formation of a rumen mat and requires low inclusion rates for target effective fiber concentrations, straw is being added to rations on many US dairy farms. For example, three of the six farms surveyed and reported by Shaver and Kaiser (2004) elsewhere in this Proceedings fed straw two farms to both the dry and lactating cows and one farm to only the dry cows. Most of this straw is chopped and then added to total mixed rations **(TMR)** or directly added to a TMR mixer with hay handling features. A lot of research has been conducted over the years on alkaline treatment of straw to increase its digestibility (therefore

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energy value); however, most of the straw used on dairy farms today is untreated. Thus, the focus of this paper will be on the feeding of untreated straw to dry and lactating dairy cows.

Straw is a byproduct of cereal grain production; therefore, the availability of straw from different cereal grains is dependent on the production of the grain. In the US, about 68.3, 10.2, 6.7, 2.3 million tons of wheat, rice, barley, and oats, respectively, are produced annually (Eastridge and Firkins, 2002). Therefore, wheat straw is the most readily available and only limited amounts of oat straw are available. Based on the nutritional value (discussed later) and proximity of supply to dairy farms, limited amounts of rice straw are fed and barley is the second most commonly fed straw. The focus of this paper is to review the composition of straw and the ramifications for feeding it to dry and lactating dairy cows at low inclusion rates as a source of effective fiber.

Composition of Straw

The NRC (2001) only provides the composition of only wheat straw (Table 2). Most of the nutrient variables for wheat straw in the NRC (2001) have many observations which provide confidence in the data. Straw is low in crude protein (**CP**), with rice straw likely being lower in CP than wheat or barley straw. Bourquin and Fahey (1994) separated wheat straw into leaf and stem; the leaf was of higher quality than the stem (74.0 versus 83.5% NDF, 53.5 versus 58.9% ADF, 6.5 versus 8.9% lignin, and 13 versus 8.2% ash, respectively). The NDF exceeds 70%, ADF is about 50%, hemicellulose about 24 to 27%, and lignin is $\geq$ 7%. Therefore, the hemicellouse concentration is similar to grasses, but the lignin concentration similar to alfalfa. Rice straw is very high in ash and is of lower nutritional quality than wheat or barley straw. The in situ DM digestibility at 48 hours is low, with wheat and barley straw being somewhat similar. However, G. Varga (unpublished; Penn State University, University Park) noted considerable more variation in situ digestibility within wheat straw (36.9% $\pm$ 5.2 at 48 hours) than barley straw (34.3% $\pm$ 2.4 at 48 hours). Some of the variation in wheat straw may be caused by different varieties and harvesting methods to affect the ratio of leaf to stem. Overall, the nutritional value of straw is low and provides structural carbohydrates as effective fiber.

Dry Cow Diets

Published data are limited on the feeding of straw to dry cows at low inclusions that are common in the field (e.g. 5 to 10% of the dietary DM). Data with feeding straw exclusively to close-up dry cows are apparently unavailable. Dewhurst et al. (2000) compared the feeding of a 60:40 mixture of grass silage and barley straw to all grass silage or grass silage plus 1.1 lb/day of concentrate (Table 3). Diet had no affect on ruminal pH and volatile fatty acids. Apparent rumen digestibilities of DM and NDF for the diet with straw were lower than for the other two diets. The DM intakes for the entire period, at week 5 prepartum, and at week 1 prepartum were lower for the diet containing the straw. Change in DM intake from week 5 to 1 prepartum was less for the diet containing straw, but because of lower dietary energy concentration and lower DM intakes, cows fed straw lost body weight (**BW**) within the same time period, whereas cows on the other two treatments gained BW. Rabelo et al. (2001) fed cows prepartum a high forage diet, a high energy diet without straw, and high energy diet with straw (grain source not reported) as a effective fiber source (Table 3). The DM intakes were similar to among treatments, but total tract digestibilities of DM and NDF were lower for the high energy diet with straw than the high energy diet without straw. Ruminal concentration of propionate

was highest and the acetate:propionate ratio the lowest (2.6 versus 3.0 to 3.2) for the high energy diet with straw because of the high concentration of NFC (52.2% concentrates). McNamara et al. (2003) fed dry cows four weeks perpartum diets of 75% grass silage and 25% barley straw ad libitum, ad libitum grass silage, or grass silage plus 6.6 lb/day of concentrate. The DM intake prepartum was lower for the cows fed straw and postpartum DM intake was lower for cows fed straw prepartum compared to cows fed grass silage plus concentrates (more similar to ration used today for close-up dry cows) (Table 3). Milk yield during the first eight weeks of lactation was less for cows fed straw prepartum.

Based on the three studies above, feeding 4 to 7.5 lb/day of straw in a diet for dry cows can limit nutrient intake and digestibility and may affect performance of cows after calving. However, the feeding of 1 to 3 lb/cow/day as is practiced in the field may have little impact on intake and digestibility if the diets are adequately balanced for nutrients and to support rumen heath.

Lactating Cow Diets

Similar to the feeding of straw to dry cows, data are limited on the feeding of straw at low inclusion rates to lactating cows. In Trial 1, Brown et al. (1990) fed chopped alfalfa hay versus chopped straw at about 23% of the ration. The DM intakes were similar, but milk yield was low for both treatments (Table 4). Because the diets were not balanced for similar concentrations of fiber, the straw diet resulted in a higher milk fat percentage and lower concentration of ruminal propionate. In another trial, Brown et al. (1990) compared the feeding of chopped alfalfa hay, long alfalfa hay, and chopped straw. Again, because diets were not balanced for similar concentrations of fiber, concentrations of ruminal acetate were higher and ruminal propionate were lower for the diet with chopped straw. Poore et al. (1991) investigated the substitution of chopped wheat straw for alfalfa hay in diets consisting of flaked sorghum grain as the major concentrate ingredient. Diets contained similar concentrations of NDF (30 to 32%) and forage FNDF ranged from 20 to 23% (Table 4). As the proportion of straw increased in the diets to provide 30% dietary NDF, the level of concentrates increased in the ration because less straw was needed than alfalfa to provide the target NDF and concentration of starch was allowed to increase along with increasing straw levels. Thus, starch was about 30% for the diet with the highest level of straw. The DM intake and milk yield were not significantly affected by the substitution of straw for alfalfa hay, but the efficiency of milk yield (fat-corrected milk yield/DM intake) decreased with increasing concentration of straw. The proportion of ruminal acetate decreased and propionate increased with increasing straw concentration, to the extent that the acetate:propionate ratio was < 2 with 28% straw in the diet. Greater than 10% straw in the diet resulted in decreased DM and NDF digestibilities.

In a study just completed in our laboratory (Bucci et al., 2004), different sources of NDF for lactating cows were compared. Diets were formulated to contain: 17% FNDF with corn silage and alfalfa hay, 17% FNDF with corn silage and grass hay, 17% FNDF with corn silage and straw, and 12.8% FNDF with corn silage and 10% whole cottonseed. Corn silage was held constant at 35.7% of the ration. The DM intake was similar among the treatments (Table 5), but milk yield was lowest for cows fed the straw (overall milk yield was low because of using cannulated cows in late lactation). Ruminal pH, acetate, and propionate were similar among the three forage sources compared. Total tract digestibilites of DM and NDF were higher for the diet with straw than the diets with grass hay and cottonseed. The straw may have slowed

down the rate of particulate matter passage from the rumen, thus possibly increasing ruminal fiber digestion. Relative to the cottonseed diet, the straw may have resulted in positive associative effects in the rumen. The diet with alfalfa hay provided at the same level of NDF as for the straw resulted similar observations as for diet with straw.

High inclusion rates of straw in diets for lactating cows can cause decreased DM intake (likely due to slow rate of passage and rumen fill), decreased total tract digestibility of DM (low quality forage), and decreased milk yield and efficiency of milk yield (reduced supply of nutrients). Inclusion at less than 10% of the ration, straw will likely have no negatively affects on animal performance if the diet is well balanced for carbohydrate fractions, but in some situations, straw may even be beneficial by causing positive associative effects in the rumen, especially in low forage diets. High quality forages also can be fed at higher levels to achieve targeted fiber levels to support optimal rumen fermentation.

Summary

Feeding straw as a source of effective fiber is being practiced commonly in the dairy industry. Data from published studies on the low inclusion rates are limited, but of the data available, straw should not be fed at high inclusion rates. High feeding rates are likely to decrease intake, total tract digestibility, and animal performance. In some situations, feeding straw at low inclusion rates may be beneficial by causing positive associative effects in the rumen, especially in low forage diets. Some general considerations are:

1) The grain type, grain hybrid, and harvesting methods may affect composition of the straw and thus how it behaves in the rumen.

2) Straw is a low quality forage and may be expensive relative to the nutrients in typical high quality forages fed to dairy cattle: straw may typically cost $60 to 100/ton depending on the dairy farm's location relative to the area where the cereal grain is grown and bale size; the value can be as high as $155/ton [calculated based from St-Pierre, (2004)] because of the high concentration of effective fiber (about 60, 30, and 10% of value from effective fiber, energy, and protein, respectively).

3) If straw if to be fed, typical inclusion rates should be 2 to 8% of the ration.

4) Chopping the straw adds costs to a low quality feed, but it must be chopped or particle size adequately reduced in the TMR mixer to minimize the potential for sorting by cows.

5) Some herbicides and insecticides approved for application to cereal grain may restrict the use of the straw as animal feed.

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Table 1. Dietary factors for balancing carbohydrates in diets for lactating dairy cows (Eastridge,

Dietary Component[1,2]	General Guideline	Comments
Forage, % of DM	40 to 60	Not a good indicator because forage quality, total NDF, NFC degradability, and particle sizes are unknown
NDF, % of DM	26 to 28 minimum	Source of NDF unknown
ADF, % of DM	19 to 21 minimum	Excludes hemicellulose, which varies among forage species
FNDF, % of DM	16 to 21 minimum	Good indicator of effective fiber
NFC, % of DM	35 to 42	Methods of calculations often differ
Starch, % of DM	25 to 35	Often unavailable

[1]DM = dry matter, NDF = neutral detergent fiber, ADF = acid detergent fiber, FNDF = forage NDF, and NFC = nonfiber carbohydrates.
[2]Particle size of forage, grain, and TMR also must be evaluated.

Table 2. Chemical composition and digestibility of straw from different cereal grains.

Item[1]	Wheat[2]	Wheat[3]	Barley[4]	Rice[5]	Oat[6]
DM, %	92.7 (131)[7]	87.9 (2)	89.4 (3)	--	--
In situ DM digestibility, %					
24 hours	--	24.1 (5)	20.9 (3)	--	--
48 hours	--	36.9 (5)	34.3 (3)	--	--
CP, %	4.8 (161)	4.3 (3)	4.8 (3)	3.7 (1)	--
NDICP, %	2.1 (8)	--	--	--	--
ADICP, %	1.4 (8)	2.0 (1)	--	--	--
RUP, % of CP	77.4 (2)	--	--	--	--
RUP digestibility, %	65.0 (2)	--	--	--	--
Fat, %	1.6 (37)	--	--	--	--
NDF, %	73.0 (107)	79.1 (4)	83.4 (3)	67.9 (1)[8]	88.2 (1)
ADF, %	49.4 (109)	51.5 (4)	51.7 (3)	41.5 (1)[8]	61.3[9]
Hemicellulose, %[10]	23.6	27.6	31.7	26.4	26.9 (1)
Lignin, %	8.8 (9)	7.3 (4)	6.7 (1)	--	10.2 (1)
NE_L-3X, Mcal/lb	0.37	--	--	--	--
Ash, %	7.6 (64)	6.9 (3)	5.7 (3)	16.2 (1)	—
Ca, %	0.31 (137)	--	--	--	--
P, %	0.10 (134)	--	--	--	--
Mg, %	0.14 (123)	--	--	--	--
K, %	1.55 (125)	--	--	--	--
Na, %	0.12 (91)	--	--	--	--
Cl, %	0.60 (8)	--	--	--	--
S, %	0.11 (41)	--	--	--	--
Cu, ppm	6 (120)	--	--	--	--
Fe, ppm	172 (121)	--	--	--	--
Mn, ppm	67 (69)	--	--	--	--
Zn, ppm	16 (116)	--	--	--	--

[1]DM = Dry matter, CP = crude protein, NDICP = neutral detergent insoluble crude protein, ADICP = acid detergent insoluble crude protein, RUP = rumen undegraded protein, NDF = neutral detergent fiber, ADF = acid detergent fiber, and NE_L-3X = net energy for lactation at three times maintenance.
[2]Taken from NRC (2001).
[3]Taken from Friggens et al. (1998), Haddad et al. (1995, 1998), and G. Varga (Penn State University, University Park; unpublished).
[4]Taken from Dewhurst et al. (2000), McNamara et al. (2003), Okine et al. (1993), and G. Varga (Penn State University, University Park; unpublished).
[5]Taken from Crocker et al. (1998) and Grimaud et al. (1999).
[6]Taken from Jung et al. (1992).
[7]Mean (number of observations).
[8]Ash-free basis.
[9]Calculated by NDF minus hemicellulose.
[10]Calculated by NDF minus ADF, except for oat straw.

Table 3. Straw fed prepartum to dairy cows.[1]

Dewhurst et al., 2000[2] (6 weeks prepartum)				Rabelo et al., 2001 (~13 weeks prepartum)				McNamara et al., 2003 (4 weeks prepartum)			
Item	60% GS, 40% BS	GS	GS, 1.1 lb/day CGM	Item	LE	HE	HES	Item	75% GS, 25% BS	GS	GS, 6.6lb/day grain
Rumen				Ration				Prepartum			
pH	6.61	6.61	6.54	Alfalfa silage	49.5	33.6	14.7	DM intake, lb/day	16.3[a]	17.8[b]	21.8[c]
Acetate, mol/ 100 mol	67.3	65.0	64.2	Corn silage	42.2	28.7	12.7	BWC, lb/day	0.48	0.22	1.19
Propionate, mol/100 mol	21.8	20.0	21.2	Straw, chopped	---	---	20.4	BCS change	-0.09[a]	0.01[ab]	0.12[b]
DM intake, lb/day				Concentrates	8.3	37.7	52.2	Postpartum (8 weeks; 8.8 or 17.7 lb/day of grain)			
Overall	15.8	23.8	22.8	CP, %	14.0	13.9	13.5	DM intake, lb/day	29.7[a]	30.4[ab]	31.2[b]
5 weeks prepartum	20.3	27.7	27.0	NDF, %	39.2	34.6	35.8	Milk, lb/day	53.0[a]	57.6[b]	62.0[b]
1 week prepartum	17.1	20.7	20.5	NFC, %	33.6	39.5	40.5	BWC, lb/day	0.40[a]	0.22[a]	-1.28[b]
Change week 5 to 1	-3.2	-7.0	-6.5	DM intake, lb/day	31.5	35.6	35.4	BCS change	0.02[a]	0.06[a]	-.0.26[b]
BWC week 5 to 1, lb	-7.9	22.9	46.6	Apparent total tract digestibility, %							
Apparent rumen digestibility, %				DM[3]	53.1	56.5	55.5				
DM	31.6	42.2	42.7	NDF[4]	38.2	42.9	39.2				
NDF	43.6	54.6	55.0	Rumen							
				pH	6.4	6.1	6.1				
				Acetate, mM	78.0	78.7	77.3				
				Propionate, mM[3]	24.6	26.3	29.8				

[1]GS = Grass silage, BS = barley straw, CGM = corn gluten meal, LE = low energy, HE = high energy, and HES = high energy with straw, DM = dry matter, BWC = body weight change, BCS = body condition score, NDF = neutral detergent fiber, and NFC = nonfiber carbohydrates.

[2]Minimal effects on subsequent lactation.

[3]LE versus HE and HES differ, and HE versus HES differ, $P < 0.05$.

[4]LE versus HE and HES differ, and HE versus HES differ, $P < 0.10$.

[abc]Means in the same row with different superscripts differ, $P < 0.05$.

Table 4. Straw fed postpartum to dairy cows.[1]

Brown et al., 1990						Poore et al., 1991				
	Trail 1			Trail 2			Wheat straw:Alfalfa Hay			
Item	Alfalfa	Straw	Control	Long alfalfa	Wheat straw	Item	0:3	1:2	2:1	3:0
Ration						Ration				
Alfalfa hay, long	22.8	23.1	23.4	46.7	23.1	Alfalfa hay	49.0	31.4	15.1	---
Alfalfa hay, chopped	22.8	---	23.4	---	---	Straw, chopped	---	10.1	19.4	28.0
Straw, chopped	---	23.5	---	---	23.6	Concentrates	51.0	58.5	65.5	72.0
Concentrates	54.4	53.4	53.2	53.3	53.3	CP	17.6	17.6	17.2	17.4
CP	15.9	15.1	17.4	17.5	16.9	NDF	30.4	31.3	31.9	30.9
ADF	22.7	28.2	18.2	18.2	23.9	FNDF	22.0	22.8	21.2	20.4
DM intake, lb/day	39.6	40.7	38.1	36.5	40.4	Starch	25.6	26.7	28.3	29.9
BWC, lb/day	0.0	0.1	-0.3	-0.3	-0.2	DM intake, lb/day	49.5	51.3	52.6	49.5
Milk, lb/day	59.4	61.8	56.8	47.7	55.9	Milk, lb/day	84.5	86.9	86.7	79.6
Milk Fat, %	2.4[a]	3.2[b]	2.9[ab]	2.6[a]	3.3[b]	Milk fat, %[c]	3.22	3.00	2.94	2.60
Milk protein, %	2.8	2.8	2.9[a]	3.2[b]	3.0[a]	Milk protein, %[c]	2.81	2.87	2.93	3.00
Rumen						FCM/ DM intake, lb/lb[c]	1.60	1.54	1.53	1.39
Acetate, mol/100 mol	43.9	47.0	59.5[a]	56.7[a]	65.9[b]	BWC, lb/day	0.99	1.23	1.96	1.94
Propionate,mol/100 mol	31.4[a]	26.0[b]	25.1[a]	26.6[a]	19.1[b]	BCS change	0.08	-0.04	0.0	0.13
						Rumen				
						Acetate, mol/100 mol[c]	64.1	59.9	59.3	57.3
						Propionate, mol/100 mol[c]	21.7	25.1	27.1	29.8
						Apparent total tract digestibility, %				
						OM[d]	67.2	69.1	68.0	63.5
						NDF[d]	43.5	45.4	40.7	31.2

[1]CP = Crude protein, ADF = acid detergent fiber, DM = dry matter, NDF = neutral detergent fiber, FNDF = forage NDF, OM = organic matter, FCM = fat-corrected milk, BWC = body weight change, and BCS = body condition score.

[ab]Means in the same row within a trial with difference superscripts differ ($P < 0.05$).

[c]Linear effect ($P < 0.05$).

[d]Quadratic effect ($P < 0.05$).

Table 5. Different effective fiber sources for lactating cows (Bucci et al., 2004).[1]

Item	Alfalfa Hay	Grass Hay	Wheat Straw	Cottonseed
Ration, % of DM				
Corn silage	35.7	35.7	35.7	35.7
Alfalfa hay	11.7	--	--	--
Grass hay		7.02	--	--
Wheat straw	--	--	5.22	--
Cottonseed	--	--	--	10.0
Concentrate[2]	52.6	57.3	59.1	54.3
NDF	39.3	39.5	39.4	39.5
DM intake, lb/day	52.0	53.5	56.1	55.4
Milk, lb/day	50.0^{ab}	51.6^{a}	47.6^{b}	52.8^{a}
Milk fat, %	4.11	4.20	4.48	4.33
Milk protein, %	3.51	3.47	3.62	3.55
Rumen				
pH	6.25	6.29	6.31	6.15
Acetate, mol/100 mol	63.9^{a}	63.4^{a}	63.5^{a}	61.6^{b}
Propionate, mol/100 mol	20.3^{a}	20.7^{a}	20.6^{a}	22.4^{b}
Apparent total tract digestibility, %				
DM	65.4^{cde}	61.9^{ce}	67.9^{d}	63.9^{e}
NDF	57.7^{ce}	50.6^{d}	59.2^{e}	52.8^{cd}

[1]DM = Dry matter, CP = crude protein, and NDF = neutral detergent fiber.
[2]Soyhulls were added to all diets to maintain nonfiber carbohydrates at about 35%.
[ab]Means in the same row with different superscripts differ ($P < 0.05$).
[cde]Means in the same row with different superscripts differ ($P < 0.10$).

Changes in Cereal Grain Byproducts for Dairy Cattle

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Abstract

Changes in grain consumption patterns by consumers, along with changes in energy production and export policies, have impacted the availability and prices of cereal grain byproducts. As more corn goes toward bio-fuel production, we will likely see an increase in corn price and a larger supply of corn byproducts. This increasing supply of corn byproducts will replace larger portions of conventional dairy feeds. Ration formulation skills will need to be honed as we look toward maximum inclusion rates for some byproducts. This paper will review the changes that are occurring with cereal grain byproduct supply, quality control issues, and use of an array of cereal grain byproducts in dairy rations.

Introduction

Feed by-products by definition are products that have value as an animal feed and are obtained during the processing of a commodity in which human food, fiber, or alcohol is produced. Byproduct feeds can come from plant or animal origin. The Feedstuffs Reference Issue and Buyers Guide lists analyses for nearly 400 byproducts and unusual feedstuffs (Feedstuffs, 2003). This paper will focus on the main byproducts from cereal grain origin that are commonly used in dairy ration formulations. Changes in energy production, environmental regulations, export regulations, human dietary demand, and value added to the dairy ration are all factors affecting how and why we might include cereal byproducts in dairy cow rations. The main cereal grain that produces the vast amount of byproducts used in US dairy rations is corn. Byproducts include corn gluten feed (wet and dry), corn distillers grain with solubles (wet and dry), hominy feed, and corn gluten meal. To a lesser degree, small grain cereal byproducts, such as brewers grain (wet and dry) and wheat middlings that are derived from barley and wheat, respectively, are used in dairy ration formulations. Food industry waste products of cereal grain origin, that traditionally were disposed of, are being modified into useful dairy feeds. Bakery waste meal is one example. All of these products can have value in the dairy ration provided that they are properly identified, handled, priced effectively, and that their nutrients are well defined and characterized for today's complex dairy ration formulation programs.

Production and Distribution Statistics

Yearly change in cereal byproducts and US population from 1990 to 1999 are displayed in Table 1.

As evidenced in Table 1, the supply of barley and wheat-based byproducts is shrinking. There has been a dramatic increase in the

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production of corn-based byproducts. This is primarily a consequence of the development and growth of the bio-fuel industry and the corn dry milling process resulting in an increase in distillery-based byproducts. The corn sweetener industry has also continued its growth. Byproducts of the corn wet milling industry have continued to gain tonnage. Table 2 illustrates the ranking of the top 10 states from highest to lowest for milking cow numbers and for total byproduct tonnage. California, Wisconsin, New York, Pennsylvania and Minnesota have approximately 50% of the total milking cows in the US. California and Wisconsin alone have over 30% of the total number of milking cows. It is apparent from these data (Fadel and Asmus, 2003) that only two of the top ten dairy states (Minnesota and Ohio) are also in the top 10 for total byproduct production. Many factors impact the siting of a dairy production facility. Attractive milk markets and low feed costs are two of the more important ones. The large quantity of cereal grain byproducts produced in the North Central region of the US will continue as an attractant for siting new dairy farms in this region.

Main Cereal Grain Byproducts

Table 3 provides a comparison of the 1989 NRC (National Research Council, 1989) published analyses of select nutrients to the 2001 NRC (National Research Council, 2001) analyses of those same select nutrients for the main cereal grain byproducts. The main differences with this select group of cereal byproducts was an adjustment upward on the energy density of brewers grain and a downward adjustment on the energy density of corn gluten feed, distillers grains with solubles and hominy feed, as well as, a correction on the fiber content of hominy feed. Belyea et. al. (1989) discussed the variation in composition of byproduct feeds and concluded that use of book values for balancing dairy diets containing significant quantities of byproduct feeds "could lead to nutritional problems and testing should be encouraged". Byproduct feeds are produced by a number of physical (grinding and milling), chemical (sodium hydroxide and sulfuric acid), and biological (fermentation) processes. Type and age of equipment, quality of grain processed, and discretionary blending of byproducts can result in considerable variation among processors for the same byproduct. A dairy nutritionist accountable for animal performance must recognize the potential for variation in cereal grain byproduct composition, especially across different processors. Testing and characterizing the composition of byproducts specifically available to dairy clients will allow more accurate diet formulation, especially advanced formulations that require accurate protein and carbohydrate fraction inputs.

Corn Distillers Grain

The livestock industry and the feed industry that supports it is in a position to take advantage of a large and rapidly growing supply of corn by-products from biofuel production. There are two methods used to produce ethanol from corn. They are commonly referred to as wet milling and dry milling. Dry mills are significantly less expensive to build and are by far the more common source of ethanol production. From 1980 to 2000, the tonnage of distillers grains increased ten fold from 320 thousand metric tons to 3.5 million metric tons. Distillers grain production is expected to double again by 2005 to 7 million metric tons. To put this in perspective, if the present national dairy herd of 9.1 million cows were expected to consume all of the distillers grain produced in 2005, each cow would need to consume 5.5 lb/head/day over a 305-day lactation to balance this supply.

Distillers grain and condensed distillers

solubles that result from the dry milling process are available in both wet and dry forms. At most dry corn milling production facilities, the condensed distillers solubles are added back to the distillers grain to produce wet distillers grains with solubles **(WDGS)**. The WDGS can be dried and become dried distillers grains with solubles **(DDGS)**. The DDGS is available for feed manufacturers and dealers. It can also be sold directly to livestock producers. It is financially more attractive for distilleries to market WDGS without having to dry it. The typical customer base for WDGS are users within a 100-mile radius of the production facility. Drying and transportation cost savings are normally passed on to the livestock producer. Everyone is a winner. The ethanol plant achieves more efficient energy conversion from each bushel of corn and the livestock producer realizes greater income over feed costs.

Nutrient composition of distillers grains with solubles and feeding practices

Mean DDGS nutrient composition values from a survey of eight Midwestern fuel ethanol plants (Harty et al., 1998) compare favorably with the analyses reported in the NRC (2001). The corn fermentation process results in a near total removal of soluble carbohydrate from the starch laden corn-kernel. This removal creates a three-fold increase in the concentration of the primary components that are left behind which include protein, fat, and fiber. This process also enhances the digestibility of the fiber fraction. The moderate fat content and highly digestible fiber fraction classify distillers grains with solubles **(DGS)** as a high energy feedstuff. Wet and dried DGS are excellent sources of ruminally undegraded protein and are rich in the amino acid methionine which is the first limiting or co-limiting amino acid for milk production. Similar to other corn proteins, DGS is a poor source of lysine, the other important amino acid for milk production. Many in the industry suggest that dairy producers are able to feed up to a maximum of 20% of the ration dry matter **(DM)** as DGS (Schroeder, 2003b). Hutjens (2003) suggests half this amount as a conservative upper limit, mainly because of the high oil content, which is primarily comprised of unsaturated fatty acids. Unlike soybeans or cottonseeds, the oil in DGS is free oil and is not contained in an oil seed. This free oil can reduce fiber digestion and lower milk fat percentage. Considerable personal experience with DGS supports the Illinois recommendation of not exceeding 0.50 lb of free oil in dairy rations. The DGS that I formulate into dairy rations is typically 11 to 12% fat. I limit the inclusion rate to 8 to 9% of the total ration DM. This limitation does not apply to non-lactating classes of dairy livestock. Most dairy nutritionists also consider the amino acid composition of the protein fraction and balance for protein quality. Using the 2001 NRC Dairy Model or the CPM (Cornell-Penn-Miner) Model allows nutritionists to formulate for a 3:1 ratio of lysine to methionine from the rumen undergradable and microbial protein sources. Because of the high methionine content of DGS and the concomitant deficiency in lysine, it is important to evaluate protein quality with one of these methods when feeding an aggressive rate of DGS. The WDGS ranges from 65% distillers grains and 35% condensed solubles to 50% distillers grains and 50% of condensed solubles. This is typically contingent on the portion of product leaving the distillery as dried product (Kaiser, 2003). Because of this factor alone, WDGS can vary from 30 to 40% DM and the fat and protein fractions may vary significantly between distilleries. Market conditions may also impact the amount of condensed solubles added back to the distillers grain. Establishing lines of communication with the wet cake manager at a distillery along with routine testing of the WDGS are necessary components to avoid the pitfalls of WDGS use.

Corn Gluten Feed

Contrary to distillers grain production from the dry milling of corn, corn gluten feed **(CGF)** results from the wet corn milling process. Corn wet milling plants are often very large and complex, representing hundreds of millions of dollars of investment and employing hundreds of people. Plants that grind 6000 tons/day of corn and produce 1200 to 1400 tons/day of CGF are commonplace (Lewis, 2003). As recently as the early 1990's, over 90% of the total US production of CGF was exported, with most going to Europe as a consequence of their grain policies. Because of the strong export value for CGF, most processors were not aggressive in the domestic market until recently. Over the past 5 years, more CGF has stayed in the US market. Western corn belt processors move wet product via truck to local users. Processors further East move dry CGF pellets to the animal dense areas of the Texas Panhandle and California (Lewis, 2003). The mind set of the corn wet miller is changing as they attempt to sell more CGF into the domestic market. The Atlantic Ocean has typically insulated the processor from the customer. Ocean going vessels carrying 100,000 ton payloads to the Amsterdam/Rotterdam market allowed more flexibility for blending distressed product compared to truckload quantities going to a nearby dairy farm in the US. Customer feedback is more direct in the domestic market, and the processor is becoming much more cognizant of quality control.

Nutrient composition of corn gluten feed and feeding practices

The CGF is a relatively high fiber, medium energy, and medium crude protein byproduct. After the corn is wet milled, the bran is mixed with the steep liquor that has been condensed via centrifugation in a ratio of about 2 parts bran and 1 part condensed steep liquor. This product then leaves the plant at 40 to 45% DM as wet corn gluten feed **(WCGF)** or it is flash dried to 90% DM and often pelleted to be sold as dry corn gluten feed **(DCGF)** pellets. The energy value of WCGF is 92 to 95% of the energy value of shelled corn (Firkins et al., 1985). The WCGF tends to have a slight advantage over DCGF, most likely due to problems associated with the drying process and an increase in acid detergent insoluble nitrogen caused by overheating. The corn bran fraction of CGF adds digestible fiber to the ration. The steep liquor fraction of CGF has a very high ruminal nitrogen degradability. Schroeder (2003a) reported that WCGF can replace 15 to 30% of the dietary DM (replacing both forage and concentrate) in lactation rations, with an optimum rate for maximum milk yield of 18.6% of dietary DM. Milk urea nitrogen content was significantly elevated when more than 15% of the dietary DM came from WCGF. Diet formulation must account for metabolizable protein and rumen degradable protein fractions when feeding CGF. Also at high inclusion rates, dietary phosphorus and sulfur become excessive. Environmentally friendly nutrition is gaining attention and could become a limiting factor for CGF inclusion in the future.

Brewers Grains

Brewers grains **(BG)** are residues of grains used to produce beer. These residues are marketed as wet brewers grain **(WBG)** or as dried brewers grain **(DBG)**. The BG are primarily of barley origin but can also include corn, wheat, and rice. The Beer Institute (2004) reports that U.S. beer consumption has gradually declined since 1990. Meanwhile, craft brewers or small specialty brewers have increased in popularity, suggesting that the major breweries with drying capabilities have less tonnage of byproduct available. The vast majority of BG is still derived from the major breweries; however,

it is not uncommon to find small quantities of WBG available in nearly every US city with populations of 50,000 or greater.

Nutrient composition of brewers grain and feeding practices

Brewers grains contain about 23% crude protein and are high in digestible fiber. Due to the fibrous nature of BG and medium energy content, this byproduct makes an attractive dairy ingredient to replace some forage and offset heavy starch loads coming from corn silage or corn grain. The moisture content of WBG ranges from 65 to 75%. The DBG handles more easily than WBG; however, drying increases the cost of the BG. Several researchers have studied the feeding value of BG for dairy cows. Inclusion rates up to 20% of the ration DM have shown to be effective (Davis et al., 1983; Hoffman and Armantano, 1988). Dhiman et al. (2003) reported that the relative nutritive values of WBG and DBG were the same for lactating cows when fed at 15% of the ration DM.

Hominy Feed and Wheat Middlings

Hominy feed and wheat middlings are two cereal grain byproducts with steady to slightly declining tonnage. Hominy feed is a byproduct of the production of pearl hominy grits. Hominy feed is 12% CP with an energy value similar to shelled corn. Many nutritionists replace shelled corn with equivalent amounts of hominy feed; however, the starch content can vary among processors and should be measured when making significant substitution of corn with hominy feed. Wheat middlings are a byproduct of wheat flour production. This byproduct contains the screenings from cleaning, particles of bran, germ, and flour remnants. Wheat midds typically contain about 18% CP; however, more than 75% of this protein is rapidly degraded in the rumen. The starch content is only about half that of shelled corn, and once again, considerable variations exist among processors. Proper analytical characterization is important. Inclusion rates of wheat midds in dairy diets tend to be low because of the rates of fermentation of protein and starch fractions.

Summary

Cereal grain byproducts are important contributors of protein, fat, and fiber to dairy rations. In general, supplies of corn byproducts, such as corn distillers grain and CGF are increasing. The fermentation of corn to produce ethanol leaves behind about one-third of every bushel of corn as a byproduct of the distillation process. A gradual shift toward more domestic use of the byproduct of the corn syrup industry has increased the availability of CGF. Other cereal grain by-products, such as brewers grain, hominy feed, and wheat middlings, have similar to slightly lesser roles in dairy diets as US eating and drinking habits change. The proper nutritional characterization of these byproducts is important if we are to determine all of their feeding and economic benefits. Today's sophisticated dairy ration balancing programs require proper identification of protein and carbohydrate fractions. Variation among and within processors pose challenges as we try to improve the quality control in our ration formulation system.

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Table 1. Yearly change in U.S. cereal byproducts (tons/year) from 1990 to 1999 (all numbers X

Byproduct	Change
Brewers grain	-2
Barley residue	-71
Corn residue	901
Rice residue	109
Wheat residue	-27

[1]Adapted from Fadel and Asmus (2003).

Table 2. Ranking of the top 10 states from highest to lowest for milking cow numbers and byproduct tonnage produced.[1]

Milking cows	Byproduct tonnage
CA	IL
WI	IA
NY	MN
PA	IN
MN	OH
TX	MO
ID	NE
MI	SD
OH	ND
WA	AR

[1]Adapted from Fadel and Asmus (2003).

Table 3. Comparison of 1989 NRC nutrient values to the 2001 NRC nutrient values for select cereal byproducts (2001 values are **bold;** all values are on a 100% DM basis).[1,2]

Byproduct	CP (%)	Fat (%)	NDF (%)	ADF (%)	NEL (Mcal/lb)
Corn gluten feed	25.6/**23.8**	0.87/**0.79**	2.4/**3.5**	45.0/**35.5**	12.0/**12.1**
Distillers grain w/solubles		25.0/**29.7** 0.93/**0.90**	10.3/**10.0**	44.0/**38.8**	18.0/**19.7**

[1]Adapted from NRC 1989 and 2001.
[2]CP = crude protein, NDF = neutral detergent fiber, ADF = acid detergent fiber, and NE_L = net energy for lactation.

How Do I Know if a Change in the Ration was Beneficial?

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Abstract

Dairy producers want to continually improve, and the dairy support and feed industries want to be responsible for that change. How do you know that a change you made was beneficial? Obtaining the correct answer turns out to be a very complicated question. Controlled experiments are needed to be able to assign cause and effect to changes. On the farm, this is difficult to accomplish. There are too many variables that are changing. To compare experiments across farms is even more difficult. It is important to identify the problem that we are trying to change or correct. It is important to identify what the change is to accomplish and how this will occur. It is critical to recognize this so hopefully a correct evaluation can be made. Part of the decision making process to solve a problem should be to identify these areas. Another way to evaluate a change is to reverse the question, "How do I tell if a change is beneficial?" Instead focus on the question "What do I have to do to evaluate a change?" To evaluate change, one wants to minimize all of the other variables that could influence the results or to hold these variables constant so the change can cause an effect if possible.

Introduction

A tremendous amount of information on dairy production is available today. Producers want to continually improve, and the feed and dairy support industries want to be responsible. How do you know that a change you made was beneficial? To obtain the correct answer turns out to be a very complicated question. St-Pierre (1999) outlined the need to have a controlled experiment to be able to assign cause and effect to changes. On the farm, this is difficult to accomplish. There are too many variables that are changing. To compare experiments across farms is even more difficult.

It is important to identify the problem that we are trying to change or correct. The most common producer request is to improve low milk production. Typically, a ration change is the first solution considered. An attempt to discover the cause of the low milk production should be made before a change is made. Is it due to disease, improper ration balance, poor feeding management, or a high percentage of late lactation cows? It is important to try to identify potential problems before they become major problems. It is much easier to apply preventive maintenance than to correct a serious problem.

It is important to identify what the change is to accomplish and how this will occur. It is critical to recognize this so hopefully a critical evaluation can be made. Part of the decision making process to solve a problem should be to identify these areas.

Recently, I was offered a product to eliminate odor from our lagoon at the University

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of Georgia's dairy farm and to increase the nutritive value of our waste for fertilizer. Initially, two gallons were to be added to the lagoon. Then, we were to feed 2 oz/cow/day or 4 oz. per cow every other day. This would pass through the cow and continue the lagoon treatment. While the product was treating the lagoon, we would also see an increase in milk production from increased rumen efficiency, less manure because intake would not increase, somatic cell count would drop, herd health would improve, and our pregnancy rate would increase. How do you evaluate all of these areas? Can you decide if any change was due to the product?

There are two quotes that I feel serve as the guiding principles. The first is "If you can't measure it, you can't manage it." One has to be able to quantify change if one is to affect the process.

The second quote is by Bliss Crandall (DHI Computing Service, Inc., Provo, UT) "Dairy cows must be managed as individuals on a daily basis." As herds have gotten larger, this becomes more difficult but still should be a guiding principle.

Data

There are two types of data which have been used to guide us in our evaluation. The first type of data is "rules of thumb" or guidelines. These usually have been established over time and have been proven true by experience. Many of these have been developed from the underlying biology of the dairy cow. Some examples are: minimum forage content of the ration should be 40%, half of the cows should be chewing their cud, and maximum intake occurs at 100 to 120 days in milk. It is important to remember that these are guidelines and not absolutes. If these guidelines are not met, they should be viewed as indicators of potential problems and changes need to be made.

The second type of data used is benchmarks. Benchmarks are usually established by analyzing a data set and creating standards of performance. At the University of Georgia, we have evaluated several large data sets to establish benchmarks for production parameters (Smith et al. references, 2002). Significant differences have been found in the parameters for herd size, production levels, and region of the country. We have established benchmarks so that herds can be compared to their contemporaries. Benchmarks are useful to see where your herd lies in the population. For example, is it at the 50% level or 90% level? Also, benchmarks provide goals if you want to improve or advance to the next level or monitor your position over time. This evaluation program, DairyMAP (2000), is available on the web.

Economics

The simplest evaluation of a change is to calculate how much milk is needed to recover the cost of the product. The milk production has to increase at least that much to break even. In reality there may be other costs (e.g. feed and labor) that need to be included. Also, other factors (e.g. fresh cows, days in milk, and environment) may have caused the change and need to be accounted for in the evaluation. Accurate financial information is needed to made good decisions on the farm (deVries et al., 2003). Farms that have several years of accurate financial data are able to economically evaluate changes.

Cows talk

As one tries to evaluate the performance of the dairy farm, it is important to let the cows talk to you. Observe your cows and how they act. They can tell us a lot about how the dairy

farm is performing. The other thing is that cows don't lie. As far as I know, there is no reward to the cow that tells you what you want to hear.

When I look at a group of cows, I like to see cows that are interested in what is going on. They are not frightened and trying to escape through the back fence. Observe the group dynamics and flow of animals.

Cows should be eating, drinking, chewing their cud, milking, and moving freely between these activities. As we examine the herd, we need to note if these activities are not easily performed. Spend some time on "animal husbandry" versus "just the numbers".

Exceptions and distributions

The exceptions in the herd and the distribution of the individuals within the herd need to be examined as the data are evaluated. The cows that are exceptions may need special treatment or may have problems that are affecting them. An example is body condition score **(BCS)**. For the herd, the desired BSC is 2.5 at peak lactation. If one has 100 cows in this group and the average BCS is 2.5, things seem fine. A little closer examination shows that 97 of the 100 cows fall between 2.0 and 3.0 BCS. Again the herd seems fine, but the other three cows are at 1.5 BCS. They are the exceptions or outliers of the group. A closer look needs to be taken at those three individuals. Why are they low? Do they have Johnes', hardware disease, or lameness? A decision must be made about those individuals but not the group as a whole.

The distribution of the group can also be important. If the bulk tank fat test is 3.62%, it would seem that things are fine. When the individual cow's fat tests are examined for herd A, they range from 3.45 to 3.75%. This herd has no outliers and most cows are within a very small range. When herd B is examined, the fat test ranges from 2.0 to 3.9% and the cows are fairly evenly distributed across the range. Something is not working in Herd B as a significant portion of the cows are in the low 2% fat test. Further examination is required to determine the cause.

Areas of Concern

Another way to evaluate a change is to reverse the question, "How do I tell if a change is beneficial?" Instead, focus on the question "What do I have to do to evaluate a change?" To evaluate change, one wants to minimize all of the other variables that could influence the results and to have the situation so the change can cause an effect if possible. The following are several areas that need to be examined.

Ration

An old saying on the dairy farm is that there are three rations: 1) the ration calculated on paper, 2) the ration that is mixed, and 3) the ration the cow eats. Ideally, these would all be the same but one needs to check. Samples should be taken of the feed ingredients to determine their nutrient composition so rations can be accurately calculated. Nutrient composition of feed ingredients can vary by 15% or more from book values. Secondly, a sample should be taken of the mixed ration that is offered to the cows to insure that proper weighing and mixing are happening. Thirdly, a sample of the weigh back should be analyzed to see what the cows are actually consuming. These samples should be taken on a regular basis, especially when ingredient changes are made. The ration should be balanced for the cow's requirements. As we move into the area of nutrient management plans for the total farm, this will be critical as excess nutrients in the ration will have to be accounted for in the total plan.

Dry matter intake

Cows eat pounds not percentages. Balanced rations usually are quoted as having 16 or 18% crude protein **(CP)**. It is then assumed that cows will consume so many pounds of dry matter **(DM)**. For example, if cow A eats 50 lb of a 16% CP ration, she is consuming 8 lb of protein, but if she eats only 44 lb, then she is consuming 7.04 lb of protein. How much difference in milk production occurs?

Determining the DM intake is critical in evaluating the nutrition program. First, determine how much is offered and then determine the weigh back on feed left after 24 hours. Combine this information with the nutrient composition analysis of the ration and the weigh back to calculate the nutrient intake of the cows. This can also be used to determine if the cows are eating the feed. Try to calculate the amount of feed wasted by the cow as she eats. How much feed is dragged onto the ground?

Dry matter percentage

One of the easiest tests to run is the ration DM content. If the DM intake is important, then the DM percentage must be calculated. It should remain fairly constant. If several wet feeds (silages or by-products) are being fed, the individual feeds as well as total ration should be checked. For example, if the ration calls for 1000 lb of 33% DM silage, then 330 lb of silage DM is in the ration. If the DM drops to 28%, the ration would contain 50 lb less of silage DM. This will reduce the nutrient content of the ration and make it unbalanced. If the DM percentage increases, extra nutrients will be fed, and the ration will be unbalanced. Either of these situations could have negative effects on milk production and the pocketbook. The DM percentage can be calculated using commercial units or a microwave oven. It is time well spent.

Delivery system

How the feed is delivered to the cow will influence what she eats. Probably, the ideal system would be to hand feed every part of the ration. This would insure that the proper amounts are given to the cow and any sorting could be accurately monitored.

In theory, the total mixed ration **(TMR)** system closely follows this philosophy. All ingredients are mixed together in the proper amounts and given to the cow, "A balanced ration in every bite." If the cow eats more than the calculated amount, the ration is still balanced. Problems occur when the ration is not mixed well or over mixed. Also, cows may be able to sort the different ingredients and consume an unbalanced ration.

I have come to the conclusion that the partial TMR is the worst possible system. In this system, long stem hay (usually round bales) is offered free-choice and all the rest of the ingredients are mixed together and fed. The cow is supposed to choose 3 lb of hay throughout the day to balance her diet. For over 100 years, experiments have shown that cows do not choose their diet to balance their requirements in a cafeteria style feeding system. Why would we expect her to eat only 3 lb of hay every day from the round bale?

Bunk management

The first step in bunk management is to insure that adequate space is available. A minimum of two feet per cow is desired. Besides minimum space, good cow flow is required. Do the first five cows block the alley way so the other cows have to wait for them to move? Does the water trough in the middle of the feed bunk cause a blockage when several cows want to drink? Is the last 15 feet of the feed bunk in

the sun for part of the day? Is the feed bunk covered for shade? Are there fans and water for cooling? Both of these will entice cows to eat during our hot summers.

How much feed is in the feed bunk? For high producing cows and cows in the first half of lactation, feed should always be available. It is recommended that 5% weigh back be allowed everyday. This old feed should not be allowed to build up and become moldy. It can rapidly infect the fresh feed.

The other situation that causes problems is feeding the high herd ration to the late lactation group by limiting the amount of feed offered. In theory, the requirements of the individual cows will be met if they consume the proper amount of feed. The problem is that the more aggressive cows over-eat the ration and the less aggressive cows are short of nutrients. If the cows are fed at 8:00 AM and the bunk is clean at 10:00 AM, either not enough feed is being fed or individual cows are not getting their proper share of the ration.

Pattern of eating

In general, dairy cows are meal eaters. They will consume a large amount of feed, drink water, and ruminate. All cows typically want to eat a big meal after milking. Ideally, fresh feed should be available to the cow when she finishes milking. Cows will eat a large meal for 30 minutes, go to get a drink (fairly large), return to eat, drink again, return to eat, drink, and then go to chew their cud for 2 to 4 hours. She will return to eat and drink again and resume rumination. Can your cows accomplish this easily? If there are blocked feed alleys, too few waterers, or a long distance to water, she may decide not to eat again. The system should encourage the cow to return to the feed bunk.

Water

Water is the most essential nutrient, especially for milk production. A cow will consume 4 to 5 lb of water for every pound of milk produced. A cow producing 100 lb of milk will drink 60 gallons of water a day. Will your system fill the tank fast enough? Clean fresh water should be readily available at all times. Oftentimes, there are adequate water tanks available for the herd, but one cow standing at the water tank can block a dozen cows who want a drink. Research has shown that cooler water is more appealing than hotter water. Are waterers in the shade? Cows that have access to water 24 hours a day will drink more than cows that can only drink two or three times a day.

Balance ration

Many problems occur when the system gets out of balance. Everyone wants to push their cows. The easiest way to get a few more pounds of milk is by adding a few pounds of grain. Get a good response from two pounds of additional grain and producers will keep pushing the grain and problems occur.

One of the main lessons from the diversion program in the mid-1980's was that there were several herds that tried to reduce milk production by reducing the amount of grain fed. Instead, milk production increased because the ration was now balanced. Other herds tried to reduce milk production by selling cows. Instead, they had increased milk production because the cows left had more bunk access and got more feed. The entire system must be in balance.

It is critical to remember that a dairy cow is a ruminant that is designed to digest forage. Much effort in ration balancing is designed to maintain minimum forage content in the ration. The dairy cow needs not only forage, but the forage needs to be of adequate physical size.

Dave Mertens (USDA Forage Center, Madison, WI) has termed this effective fiber. This effective fiber causes: (1) rumen mat formation to trap small particles for rumen digestion, (2) a physical stimulus to the rumen wall to cause contractions (the scratch factor), and (3) a large amount of time spent by a cow chewing her cud which produces salvia to balance rumen pH. Requirements have been set over the years to accomplish this. A minimum of 17% crude fiber, minimum 22% acid detergent fiber, minimum 33% neutral detergent fiber **(NDF)**, minimum 40% of ration DM from forage, and 75% of ration NDF from forage are all attempts to provide minimum roughage to the dairy cow. The Penn State particle size box with two sizes of screens provides the distribution of particles and indicates the level of effective fiber in the ration. The TMR should have 5 to 15% on the top screen, and corn silage should have 10 to 20% on the top screen. Testing the ration and weigh back will indicate how much sorting the cows are doing. If the ration is at the minimum fiber level, then sorting could put the cow in a critical situation.

Manure

The consistency of the manure is an indicator of the balance of the ration. Firmer manure piles indicate adequate fiber in the ration. Excessive grain and acidosis can result in diarrhea. Low manure pH indicates excessive acid from hindgut fermentation, resulting from inadequate rumen fermentation. This may be a result of low effective fiber, fineness of grind, or excessive starch. The manure can also be screened to determine the fiber size.

Risk management

As one evaluates a farm, more than likely several areas for improvement will be highlighted. Priorities need to be set for each of these areas. What is the risk for potential losses? What is the cost of correcting the problem? What is the return for the change? Cost-benefit ratios can be calculated and a plan can be developed to address the different areas.

Summary

As you have reached this point, I hope you say "I know all of that." There is plenty of knowledge available to us. The problem is the proper and timely application of that information. Not only do we need to accurately evaluate changes that are mad,e but we also need to make the conditions so that we minimize other variables and can measure a response to our change.

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Fine-Tuning Energy Calculations

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Abstract

The concentrations of net energy for lactation **(NEL)** of feeds is currently used by most ration formulation programs to balance diets for dairy cows. This practice is inherently incorrect because feeds do not have NEL values; only diets have NEL values. However, because commonly used programs require NEL values for feeds, this paper provides adjustment factors that can be applied to feed NEL values to increase the accuracy of the NEL value of the diet. The NRC (2001) approach should be used to generate initial NEL concentrations with the exception that a standard discount of 0.92 (i.e., 8%) is used. This NEL-3X value can be calculated by feed analysis labs and be printed on feed analysis reports. On average, the NRC model calculates NEL balance correctly, but the NRC model appears to over or underestimate NEL values of diets with certain common feeds. These errors are likely caused by errors in estimating the digestibility of the starch and/or neutral detergent fiber. The NRC model does not appear to adequately adjust NEL values for different types of corn grain (e.g., high moisture, steam-flaked, or finely ground) and the values may need to be adjusted by up to 10%. The NRC model appears to adequately estimate NEL values of diets with different types of corn silage but adjustments are needed when the corn silage is processed ($\pm$ 7.5%). Based on limited data, in vitro NDF digestibility does not appear to increase the accuracy of NEL estimates of corn silage compared with the standard NRC model. Other factors will affect the NEL values of feeds, but at the current time, we cannot quantify these effects. Nutritionists should be aware that these factors exist and additional adjustments may be needed for certain feeds.

Introduction

Accurate estimates of dietary concentrations and intake of NEL are needed for ration formulation, and probably more importantly, for ration evaluation. Daily net energy balance (intake of NEL minus NEL used for maintenance, milk production, and fetal growth) determines changes in body condition and body weight. Accurate estimates of NEL balance will allow for the proper management of changes in body condition.

Fine-tuning is defined as making small adjustments to improve the performance or accuracy of something. Implicit in that definition is that you have a reasonably accurate starting point. For NEL concentrations, the starting point is usually either a value from a table (e.g., NRC, 2001) or a value from a feed analysis report. Those values are then entered into a computer program and a diet is formulated. A nutritionist then may modify or fine-tune the diet based on their expertise and experience. This approach assumes nutrients from different feedstuffs are additive (i.e., the ingredient and nutrient

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composition of the final diet has no effect on the nutrient value of the individual ingredients). The metabolizable protein **(MP)** concept is the best example of non-additivity For example, urea is an excellent source of MP when added to a diet deficient in rumen degradable protein, but if urea was added to a diet with excess rumen degradable protein, it would contribute no MP. With the MP system, feeds are not given MP values, only the diet has an MP concentration. Similar to MP, NEL should be considered non-additive and only diets, not ingredients, should have an NEL value. Although difficult and expensive, we can measure NEL concentrations in diets, we cannot measure the NEL of individual feedstuffs within a diet. Because we cannot measure the NEL of a feedstuff, we should not 'fine-tune' NEL values for feeds; however, we can and often should fine-tune NEL values for diets. This causes a conundrum because with most ration balancing software, the only way a nutritionist can fine-tune the energy value of the diet is to adjust the NEL values of individual feeds.

This paper will present approaches to fine-tune NEL values of selected feeds because most of the formulation programs currently used require that information. However, the reader must remember that individual feed ingredients do not have NEL values.

The Starting Point

The NEL concentration of a diet is a function of the gross energy **(GE)** of the diet, the digestibility of specific nutrients, the efficiency of converting the digestible energy **(DE)** provided by those nutrients to metabolizable energy **(ME)**, and then the efficiency of converting the ME provided by the different nutrients into NEL. Although genetics of the cow will undoubtably influence the efficiency of digestion and the efficiency of converting DE to NEL, inadequate data are available to make any adjustments for this variability. However, equations are available to account for much of the variability in NEL concentrations caused by variation in feed composition.

To fine-tune the NEL concentration of a diet, you must have an initial NEL value, and the amount of fine-tuning required depends on the accuracy of the initial value. Numerous equations are used by commercial laboratories to estimate NEL values of feeds. For this paper, the initial NEL values will be those calculated using the NRC (2001) model and standard feed composition inputs [crude protein **(CP)**, neutral detergent fiber **(NDF)**, ash, lignin, and neutral detergent insoluble and acid detergent insoluble CP]. In addition to feed composition, the NRC model also adjusts NEL values for dry matter **(DM)** intake and for the interaction between diet composition and intake, but feed laboratories will not know DM intake or diet composition. A standard discount of 8% was used to calculate NEL-3X concentrations. Net energy values calculated using NRC equations appear accurate on average (NRC, 2001).

Variation in Gross Energy

The nutrient fractions that have the greatest impact on GE concentrations are ash,CP, carbohydrate, and fat (Table 1). In the NRC system, carbohydrate is defined as NDF plus nonfiber carbohydrate **(NFC)** which is defined as 100 - NDF - CP - fatty acids - ash. The use of these crude fractions introduces some error into the GE calculation. The 'carbohydrate' fraction contains NDF, starch, simple sugars, organic acids (if the feed is fermented), and several minor compounds. The GE concentration of starch and NDF are probably similar but simple sugars such as glucose and sucrose have about 10% less GE per pound than does starch. This means that the NRC system will slightly overestimate GE of feeds that contain substantial amounts of

simple sugars (e.g., molasses). The predominant organic acids found in well-fermented silage (acetic and lactic) have about 15% less GE than does starch, which means that silage will have slightly less GE than the value estimated by NRC. The GE contributed by CP is a function of the amino acid composition of the protein and the proportion of true protein and nonprotein N. The NRC value (1.14 Mcal/lb) for CP is a reasonable estimate for plant-based feeds that contain predominantly true protein (most non-fermented feeds). A large proportion of the CP in silage can be nonprotein N which generally has a lower GE concentration than protein, therefore GE of silage CP is overestimated by the NRC system. The GE value for long chain fatty acids (4.3 Mcal/lb) is a reasonable average for fatty acids contained in common feeds, but different long chain fatty acids have different GE values. As fatty acid chain length increases, the GE per pound increases and saturated fatty acids have slightly less GE per pound than unsaturated fatty acids. Although there are several factors affecting GE that are not accounted for by the NRC system, in practice, most of these factors will not greatly affect the end results. The GE concentrations of silage is probably overestimated by 1 or 2%. For feeds that contain a large proportion of simple sugars (e.g., molasses and table sugar or sucrose), GE is overestimated by about 6%, but because those feeds generally make up a small proportion of the diet, the overall effect on diet NEL would be small. These over estimations of GE would carry through to NEL.

Variation in Digestibility

Schneider (1947) provided digestibility data measured using sheep that were fed diets comprised of a single feedstuff (about 900 observations). The concentration of total digestible nutrients **(TDN)** in those feeds (i.e., diets) ranged from less than 25% to more than 125%. If feeds that will probably never be fed to dairy cows in the U.S. (e.g., tree leaves) are removed, the range in TDN was 35% to 125%. Assuming that TDN is a reasonable proxy for DE, the variation in energy digestibility among potential feedstuffs is extremely large. These data, however, may not be appropriate for dairy cattle and dairy cattle diets. Lactating dairy cows are usually not fed diets with only one ingredient and the variability in energy digestibility is much less among mixed diets than among feedstuffs. Energy digestibility (86 treatment means) of mixed diets fed to lactating cows varied from 60 to 78% (mean = 68%) and DE concentrations varied from 1.28 to 1.54 Mcal/lb (mean = 1.38 Mcal/lb) (Wilkerson et al., 1997b). Although the variation in energy digestibility and DE concentrations are much less among diets than among feedstuffs, the variation is still substantial.

For the purpose of estimating energy values, feeds can be broken down into five major nutrient fractions (CP, fatty acids, NDF, starch, and the non-starch portion of NFC). Of the common nutrient fractions, digestibility of NDF is probably the most variable, but digestibility of starch can also vary substantially. For a wide range of diets, total tract NDF digestibility measured in lactating dairy cows ranged from 29 to 64% with an average of 46% (Wilkerson et al., 1997b). Firkins et al. (2001) reported a range in total tract starch digestibility in lactating dairy cows of 70 to 99% (average = 91%). Because starch and NDF comprise 50 to 60% of dietary DM for typical diets, variation in digestibility of those fractions can have a large impact on the DE concentration in the diet and energy values of feeds that provide large quantities of these nutrients may need fine-tuning.

The other fractions either make up a relatively small portion of the diet or digestibility is less variable. The non-starch portion of

NFC is a heterogenous mixture of simple sugars, organic acids, neutral detergent soluble fiber, and a host of minor compounds. Most of these constituents would be expected to be highly digestible (approximately 100%). The digestibility of CP is variable, but the equations used by NRC (based on acid detergent insoluble CP) appear to account for most of the variation and little additional fine-tuning appears to be required. The NRC assumes that fatty acids from all feeds except fat supplements is constant. This probably is not true, but we have not been able to quantify factors that significantly affect the digestibility of fatty acids. For linted cottonseed, particle size (ground vs. whole seeds) did not affect fatty acid digestibility (Pires et al., 1997). Similarly, digestibility of fatty acids from roasted soybeans was not consistently affected by particle size (Tice et al., 1993). Roasting soybeans also has not had a consistent effect on fatty acid digestibility (Aldrich et al., 1995; Tice et al., 1994). Probably the most important fine-tuning that should be done regarding the energy contribution of fat from plant-based feeds is to base the values on accurate fatty acid concentration data. Feeds that contain appreciable concentrations of fatty acids should be assayed for fatty acids and actual analytical data, rather than table values, used to estimate NEL. Accurate estimates of fatty acid digestibility are essential for fat supplements. The NRC has averages of measured digestibilities for fatty acids from several common fat supplements. Although variation exists in digestibility of fatty acids within a fat supplement, the use of the NRC average values gave good estimates of dietary DE when evaluated using independent data (Weiss and Wyatt, 2004). If the NRC does not contain a digestibility value for a specific fat supplement, users should request the information from the manufacturer or supplier of the supplement. Because fat supplements are only fed to provide NEL, I would not use a product if fatty acid digestibility (measured in lactating dairy cows) data were not available.

General Approach

For the feeds listed below, the general approaches for fine-tuning NEL concentrations are outlined in Tables 2 and 3. The first step is to calculate NEL-3X concentrations using NRC (2001) equations. These values are then either increased or decreased by a certain percentage. The proposed adjustments are empirical and are based on changes in digestibility, milk yield, yield of components, and (or) changes in gross efficiency (yield of fat-corrected milk divided by DM intake).

Corn Grain

The only method to adjust starch (actually NFC) digestibility incorporated into the NRC model is the processing adjustment factor **(PAF)**. Diets for lactating cows typically contain between about 20 and 35% starch (dry basis), and total tract starch digestibility measured using lactating dairy cows ranged from about 70% to 100%, with a mean of 91% (Firkins et al., 2001) Assuming an average dietary starch concentration of 28% and no interactions between starch digestibility and digestibility of other nutrients, a range in starch digestibility equal to the mean (91%) plus or minus two standard deviations (7%) would cause DE concentrations of diets to vary by $\pm$ 0.07 Mcal/lb from the DE value calculated using average starch digestibility (approximately $\pm$ 5% of a reasonable average for DE concentrations of dairy diets). Varying NFC digestibility using the PAF in the NRC model will only vary discounted DE concentrations by about $\pm$ 2%, suggesting that additional fine-tuning may be required for corn grain. Factors known to influence digestibility of corn grain include:

- Particle size
- Chemical form of starch (amylopectin vs. amylose)
- Maturity at harvest (i.e., high moisture vs. dry corn)
- Heat and steam treatment
- Interactions of the above factors

Dry grinding

Most studies report increased total tract digestibility of starch when cows are fed 'ground' corn compared with 'cracked' corn (reviewed by Firkins et al., 2001). Because particle size of the corn was not reported in most studies, a quantitative relationship between particle size of corn and digestibility cannot be derived. Assuming differences in total diet digestibility are completely caused by changes in digestibility of the corn, ground corn has 4 to 6% more DE per pound than does cracked corn when fed to lactating dairy cows (NRC, 2001). Based on studies that actually measured NEL (Wilkerson et al., 1997a) and in overall differences in milk production (Firkins et al., 2001), diets with ground dry corn have 1 to 3% more NEL than do diets with cracked corn. This difference is greater than the difference estimated by the NRC model (< 1%) for most diets, suggesting that the NRC model under estimates the NEL of ground corn, overestimates the NEL of cracked or, or both. *Proposed adjustment*: Reduce NEL-3X value for cracked corn by 2.5% and increase NEL-3X value for ground corn by 2.5%. These values were derived by assuming diets with cracked corn have on average 1.5% less NEL than diets with ground corn and by assuming corn comprised 30% of the diet.

High moisture corn

By all measures, diets with high moisture corn, on average, have more energy than dry corn. The average difference in organic matter digestibility is about 4% (Firkins et al., 2001), differences in DE and NEL ranged from 5 to 8% (two studies: Tyrrell and Varga, 1987; Wilkerson et al., 1997a), and differences in milk energy output relative to intake averages about 4% (Firkins et al., 2001). The NRC model would estimate about a 1% difference between diets with high moisture corn and diets with dry corn. Based on limited data, diets with ground (particle size not measured) high moisture corn had statistically equal NEL values compared to diets with rolled high moisture corn (Wilkerson et al., 1997a). The effect of moisture concentration of high moisture corn on digestibility and milk production in lactating cows is lacking. In vitro digestibility of starch from corn grain was increased as moisture concentration increased, but this appeared to be mostly a function of kernel fragility (i.e., as moisture concentration increased, particle size decreased) (Allen et al., 2003). Presumably, as moisture concentration of high moisture corn becomes more similar to dry corn, differences between the two would diminish; however, this does not mean that extremely wet high moisture corn has more energy than average high moisture corn. *Proposed adjustment*: Increase NEL-3X value of high moisture (rolled or ground) by 10%. This value was derived by assuming that diets with high moisture corn have 4% more NEL than diets with dry ground corn, that the NRC model underestimates differences between ground dry corn and high moisture corn by 3%, and by assuming corn comprised 30% of the diet. As the DM concentration of high moisture corn increases above 75%, a smaller adjustment would presumably be appropriate.

Steam-flaked corn

Digestibility of organic matter for diets with steam-flaked corn is 1 to 2% higher than diets with ground or cracked dry corn, which is similar to the change in energy-corrected milk yield (Firkins et al., 2001). On average, the NRC

estimates that diets with steam-flaked corn has about 0.5% more NEL than diets with ground corn. To fine-tune the energy value of steam-flaked corn, flake density must be known. As flake density increases above about 28 to 30 lb/bushel, steam-flaked corn becomes more similar to ground corn. In the review by Firkins et al. (2001), steam-rolled corn (approximate density of 38 lb/bu) was essentially equal to dry ground corn with respect to organic matter digestibility and milk production. The relationship between flake density and energy value is likely not linear. Extremely low density flakes may have detrimental effects on ruminal digestion and may result in lower, not higher, dietary NEL values. *Proposed adjustment*: For steam-flaked corn with a density of approximately 29 lb/bu, NEL-3X values should be increased by 3 or 4%. This value was derived by assuming that diets with steam-flaked corn have 1.5% more NEL than diets with dry ground corn, that the NRC model underestimates that difference by 1 percentage unit, and that corn comprised 30% of the diet. As density increases, the adjustment would be less.

Chemical structure of starch

Corn starch can be branched (amylopectin) or linear chains (amylose) of glucose. Corn grain with mostly amylopectin is less dense and more floury when ground than corn with a high proportion of amylose (more flinty). Across corn hybrids, the structure of starch is a continuum, ranging from very floury to very flinty. Average dent corn is intermediate. Vitreousness is a measure of flintiness (flinty corn has high vitreousness). In situ and in vitro studies have shown that vitreousness has a strong inverse relationship with ruminal starch digestibility (Allen et al., 2003; Correa et al., 2002), suggesting that ruminal starch digestibility in vivo will be higher for floury corn than for flinty corn, with dent corn being intermediate. Very little data are available comparing different types of corn grain on total tract digestibility or milk yield with lactating dairy cows. Based on two studies (Akay and Jackson, 2001; Schroeder et al., 1996), diets with waxy corn (very low vitreousness) had about 4% more energy than diets based on dent corn. Density of whole kernels is positively correlated with vitreousness (Correa et al., 2002), suggesting that density might have value in fine-tuning NEL values of different types of corn hybrids. *Proposed adjustment*: None at this time, but the NEL of very dense, highly vitreous corn is probably overestimated and floury corn may be underestimated. More data with lactating cows are necessary before this relationship can be quantified.

Corn Silage

Corn silage contains appreciable concentrations of both starch and NDF, and variation in digestibility of either fraction can have a substantial affect on its energy value. Although highly variable, the average starch concentration for corn silage is about 30% and NDF concentration averages about 45%. The digestibilities of starch and NDF provided by corn silage cannot be directly measured in lactating dairy cows fed typical mixed diets because diets contain other sources of starch and NDF. However, digestibility of total dietary starch by lactating dairy cows ranged from about 88 to 98% when corn silage provided 20 to 65% of the dietary starch (Bal et al., 1997; Johnson et al., 2003; Weiss and Wyatt, 2000), which is within the range of starch digestibilities when most of the starch comes from corn grain. Digestibility of dietary NDF by lactating dairy cows fed mixed diets when corn silage was the sole forage fed and provided most of the dietary NDF ranged from 46 to 55% (Beckman, 2003; Tine et al., 2001; Weiss and Wyatt, 2000). Factors that can affect digestibility of starch and/or NDF from corn silage include:

- Corn plant maturity at harvest
- Hybrid
- Kernel processing
- Interactions among those factors

Maturity effects

The DM concentration of corn silage is positively correlated with maturity (drier plants tend to be more mature). Data from three different experiments (Bal et al., 1997; Johnson et al., 2003) in which corn silages with different DM concentrations were fed and digestibility measured were compiled to derive equations to adjust energy values of corn silage based on DM (i.e., maturity). Digestible energy values of the total diet were taken from the paper or calculated from organic matter digestibility and regressed on DM concentration of the corn silage with trial effects included in the model. If the change in DE concentration is assumed to be caused entirely by the corn silage, DE concentration of the corn silage decreases 0.01 Mcal/lb of DM per every 1 percentage unit increase in DM concentration. Assuming an average efficiency of converting DE to NEL of 0.54, the NEL of corn silage would change 0.005 Mcal/lb for every 1 percentage unit increase in DM concentration above 28%. Although the only variable included in the regression was DM concentration, the nutrient composition of the silage changes as plants mature (e.g., lignin as a percentage of NDF tends to increase and NDF tends to decrease). The difference in NEL between a corn silage with 35% DM and 45% DM (i.e., 10 x 0.005 = 0.05 Mcal NEL/lb) was the same as that estimated by NRC between average normal (35% DM) and average mature (44% DM) corn silage, suggesting that on average, the NRC model accounts for the affect of corn silage maturity. Undoubtably, the affect of plant maturity on NEL of corn silage is dependent on hybrid. For a hybrid in which the vitreousness of the grain did not change appreciably with maturity, DE concentrations did not change appreciably, but a hybrid in which vitreousness increased with maturity, DE concentrations decreased with maturity (Johnson et al., 2003). This suggests that more accurate estimates of energy from corn silage will require information regarding vitreousness. *Proposed adjustment:* Analyze the silage for standard nutrients and calculate NEL-3X. For silages with DM concentrations equal to or less than 28%, set PAF at 1.00 and for every 2 unit increase in DM concentration, decrease PAF by 0.015 units.

Hybrid effects

Corn silage hybrids have been developed to have increased NDF digestibility, different concentrations of nutrients (e.g., starch, NDF, and fatty acids), and different physical characteristics of starch. These differences should lead to differences in available energy concentrations of diets that include silage from different hybrids. However, reported differences (within experiments) in DE, digestible organic matter, TDN, or NEL concentrations between diets with different corn silage hybrids have been remarkably small (Akay and Jackson, 2001; Johnson et al., 2002; Kuehn et al., 1999; Nennich et al., 2003; Tine et al., 2001; Weiss and Wyatt, 2000; 2002). The measured NEL concentration of a diet based on brown midrib **(bmr)** corn silage was the same as that for a diet based on its isogenic control when fed at ad libitum intake (Tine et al., 2001). A diet with corn silage from a flinty hybrid had the same DE concentration as a diet with corn silage from a dent hybrid (Johnson et al., 2002), and diets with corn silage from a dent or a waxy hybrid had similar DE concentrations (Akay and Jackson, 2001). A diet with high oil corn silage had a higher TDN concentration than conventional corn silage but only when silages did not undergo

kernel processing. Interactions have been found between hybrid and kernel processing, hybrid and maturity, and hybrid and diet formulation for dietary energy values. At the current time, we do not have adequate data to quantify the effects of these interactions based on measurable inputs. *Proposed adjustment*: Current data do not support adjusting NEL-3X values from those calculated from measured nutrient composition specific to each hybrid.

Kernel processing

On average, kernel processing of corn silage has little effect on energy values (e.g., DE, TDN, or DM digestibility) of diets when fed to lactating cows (Bal et al., 2000; Johnson et al., 2003; Johnson et al., 2002; Schwab et al., 2002; Weiss and Wyatt, 2000). An interaction between processing and corn silage maturity has been reported (Johnson et al., 2002). In that study, diets with processed immature corn silage tended to have less DE than diets with unprocessed corn silage, but processing tended to increase dietary DE with mature corn silage. One study reported that TDN increased when a conventional corn silage was processed, but processing did not affect TDN of a high oil hybrid (Weiss and Wyatt, 2000). *Proposed adjustment*: The NEL-3X value of immature corn silage (< one-third milk line) that has been processed should be reduced 7.5% and the NEL-3X of mature corn silage (> two-thirds milk line) should be increased by 7.5%. These values were derived by assuming processing reduced DE concentrations by 3% when immature corn silage was processed and increased DE concentrations 3% when mature corn silage was processed and by assuming corn silage comprises 40% of the diet. Corn silage from different hybrids probably respond differently to processing, but those changes cannot be quantified at this time.

Use of in vitro NDF digestibility

The NRC system estimates NDF digestibility using lignin. In vitro and in situ disappearance are two other options that can be used to estimate NDF digestibility. Brown midrib corn silage generally has higher in vitro NDF digestibility **(IVNDFD)** than its isogenic control (Eastridge, 1999); however, when fed to lactating dairy cows as a component of a mixed diet, in vivo NDF digestibility has not been consistently higher when bmr silage was fed (Oba and Allen, 2000; Tine et al., 2001). Furthermore, a diet with bmr corn silage had the same measured NEL concentration as a diet with the isogenic hybrid when fed to lactating cows at ad libitum intakes (Tine et al., 2001). Intake of NEL was significantly increased when bmr was fed, but energy concentration was not affected by hybrid. In another study, cows fed corn silage from a hybrid selected to have high IVNDFD (not a bmr) had equal in vivo NDF digestibility as did cows fed a typical corn silage even though IVNDFD differed between the hybrids (Weiss and Wyatt, 2002). Beckman (2003) found that using in situ or in vitro NDF digestibility (both at 30 hours) to estimate dietary DE was less accurate than using the lignin-based NRC equation with corn silage based diets that included different concentrations of soyhulls and cottonseed hulls. Although the data are extremely limited, available in vivo data with lactating cows fed mixed diets do not support the use of IVNDFD to estimate in vivo NDF digestibility or available energy concentrations of corn silage. The accuracy of using IVNDFD to calculate energy values of other feeds when fed in mixed diets to lactating dairy cows has not been evaluated.

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Table 1. Approximate gross energy values for different nutrient fractions (data derived from (Maynard et al., 1979).

Nutrient fraction	Gross energy, Mcal/lb
Ash	0
Carbohydrate	1.9
Crude protein[1]	2.5
Long chain fatty acids	4.3
Triglyceride (from a fat supplement)	4.0
'Normal' silage organic acids[2]	1.6
Typical dairy diet[3]	1.94

[1] Value based on plant proteins in which essentially all the CP fraction is true protein or free amino acids. The CP fraction of silages with substantial amounts of non-protein, non-amino acid nitrogen will have a lower gross energy value.
[2] Value assumes that silages contain only trace amounts of butyric and propionic acids. The organic acid fraction from poorly fermented silages that have high concentrations of butyric acid will have a higher gross energy.
[3] The typical dairy diet contained 17% CP, 5% ash, 2% long chain fatty acids, 3% organic acids, and 73% carbohydrate.

Table 2. Suggested method to estimate NEL values of feeds[1].

Step	Procedure
1	Calculate DE of feeds using Equation 2-8 (NRC, 2001)
2	Assume an 8% discount factor (i.e., multiply value from step 1 by 0.92)
3	Calculate ME of feeds using Equation 2-10 (NRC, 2001)
4	Calculate NEL of feeds using Equation 2-12 (NRC, 2001)
5	Divide NEL (Mcal/kg) by 2.2 to obtain NEL (Mcal/lb) if desired
6	Apply necessary adjustments to NEL value for certain feeds[2]

[1]NEL = net energy for lactation, DE = d igestible energy, and ME = metabolizable energy.
[2]See Table 3.

Table 3. Proposed adjustments of NEL values for selected feeds[1, 2].

Feed	Adjustment
Cracked dry corn (mean particle size > 1 mm)	NEL-3X times 0.975
Ground dry corn (mean particle size < 1 mm)	NEL-3X times 1.025
High moisture ground corn (DM = 75%)	NEL-3X times 1.10
Steam-flaked corn (density = 28 lb/bu)	NEL-3X times 1.035
Mature corn silage	For every 1 percentage increase in DM above 28%, reduce PAF by 0.008 units
Processed immature corn silage	NEL-3X times 0.925
Processed mature corn silage	NEL-3X times 1.075
Corn silage with high NDF digestibility	Calculate NEL-3X using measured NDF and lignin

[1]NEL = net energy for lactation, DM = dry matter, and NDF = neutral detergent fiber.
[2]The NEL-3X value is initially calculated as described in Table 2.

Feeding Programs in High Producing Dairy Herds

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Abstract

The feeding and management practices of six Wisconsin high-producing, freestall-parlor dairy herds were surveyed during the winter of 2004. The number of milking cows ranged from 276 to 566 and the rolling herd average **(RHA)** for milk ranged from 29,055 to 31,195 lb across the herds. Milking frequency was 4x for one herd, 4x and 3x for one herd, and 3x for four herds. Four of the six herds used sand bedding. Bunk space and stall stocking density for high-production groups ranged from 1.2 to 2.1 ft per cow and 100 to 122% across the herds. All herds maintained two dry cow groups, but half of the herds fed only one dry cow diet. All herds fed total mixed rations **(TMR)**. Across herds, forage in diets for high-production groups ranged from 45 to 53% (DM basis) and was comprised of 41 to 68% corn silage (DM basis). Whole cottonseed was fed in all herds, while high-moisture shelled corn was fed solely in three herds, dry shelled corn solely in two herds, and a mixture in one herd. Dietary CP and P formulations for high-production groups ranged from 17.0 to 18.5% and 0.37 to 0.41% (DM basis), respectively, across the herds. Analysis of high group TMR samples for CP and P ranged from 16.7 to 18.4% and 0.35 to 0.44% (DM basis), respectively, across the herds. Estimated average feed efficiency (bulk-tank milk/feed, lb/lb) and feed cost per hundredweight of bulk-tank milk ranged from 1.57 to 1.70 and $4.01 to 4.50, respectively, across the herds.

Introduction

AgSource DHI (AgSource Cooperative Service, Verona, WI) reported 37 Wisconsin dairy herds with RHA milk ranging from 30,000 lb to about 34,000 lb per cow at year-end 2003. The purpose of this paper is to report on a survey of feeding and management practices that was conducted in a subset of these high-producing dairy herds.

Survey Methods

Six Wisconsin freestall-parlor dairy herds with RHA milk of about 30,000 lb per cow were surveyed for their feeding and management practices. This survey represents a snapshot in time, and herd visits and data collection were for the January-February, 2004 time period.

Herd managers, and their respective nutritionists, were interviewed during our herd visit utilizing a common survey form designed to collect information on feeding and management practices. Herd nutritionists provided diet ingredient and nutrient specifications, along with corresponding forage test results. Pen intakes were estimated from discussions with nutritionists and managers, and feed efficiencies (milk/feed) were calculated. Feed costs were calculated using common corn silage, alfalfa silage, alfalfa hay, and corn grain prices ($70/ton

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DM, $70/ton DM, $120/ton as fed, and $2.50/bu) across herds, and prices for all other dietary ingredients were as provided by nutritionists and(or) managers. The high group TMR were evaluated using the NRC (2001) Model. All survey herds were enrolled in DHI milk testing programs, and herd summary sheets were a major data source. Bunk space and water space were determined by making physical measurements and counting cows within pens.

Samples of corn silage, alfalfa silage, corn, and high group TMR were obtained during our visits. Fermentation profile analyses of corn silage, alfalfa silage, and high-moisture corn samples (shipped on ice) were performed using high pressure liquid chromatography **(HPLC)** by Dairyland Laboratories (**DLL**; Arcadia, WI). Particle sizes of dry and high-moisture corn samples were determined at DLL. Kernel processing score (% of starch passing thru 4.75 mm sieve) was determined on corn silage samples by DLL. At the University of Wisconsin Soil & Forage Analysis Laboratory (**UWFTL**; Marshfield, WI), particle size using the Penn State Separator Box and UW Recommended [near infrared reflectance **(NIR)** with wet chemistry NDF, NDF digestibility **(NDFD)**, and ash for summative energy calculations] analyses were performed on corn silage and alfalfa silage samples. The rumen undegraded protein **(RUP)** of alfalfa silage samples was determined at UWFTL using NIR calibration from ruminal in situ dacron bag data. Also at UWFTL, wet chemistry "TMR Quality Control" analyses (includes NDFD) and particle size analyses using the Penn State Separator Box were performed on high group TMR. The procedure used to sample TMR on the farms was as follows (Pat Hoffman, University of Wisconsin-Madison, Marshfield; personal communication): 1) mix TMR as per normal procedures, 2) distribute high group TMR in bunk, 3) immediately fill a 5-gallon bucket with handfuls of TMR from the top, middle, and bottom of the TMR windrow across the entire length of the TMR windrow, 4) tip the 5-gallon bucket upside down on a large clean surface and lift the bucket up, 5) with a thin piece of wood or sheet metal, cut the coned TMR sample in half, and 6) discard one half of the sample and submit the other half for analysis.

Results

General herd information is presented in Table 1. General feeding and management information by groups within herds is presented in Tables 2 through 7b. Refer to Tables 8, 9, 10, and 11 for analytical data for alfalfa silage, corn silage, corn grain, and high group TMR, respectively. Ingredient and nutrient composition of formulations are presented in Tables 12a through 18b. These tables also provide DM intake, feed efficiency, and feed cost estimates. Results of NRC (2001) Model evaluation of high group TMR appear in Table 19.

References

National Research Council. 2001. Nutrient requirements of dairy cattle. 7th rev. ed., Natl. Acad. Sci., Washington, DC.

Table 1. General information for six selected high-producing WI dairy herds surveyed during January - February, 2004.[1]

Item	HensenBros Dairy Inc.	Koepke Farms Inc.	Rosy Lane LLC	Holstein Bros. Farm	So-Fine Crave LLC	Bovine Farms	Oechsner
Location	Waunakee	Oconomowoc	Watertown	Waterloo	Westfield	Brownsville	
DHI No. of Cows Milking	291	276	482	566	398	364	
DHI RHA Milk, lb	30,780	31,195	31,192	29,055	30,405	30,284	
DHI MLM, lb/cow	101	100	100	90	103	94	
DHI Cow Peak, lb/cow	130	134	142	123	134	119	
DHI Heifer Peak, lb/cow	95	96	106	94	96	88	
Times Milked	3x	4x, 3x	3x	4x	3x	3x	
Bulk Tank: Milk, lb/cow	90	92	90	90	92	94	
Milk Fat, %	3.8	3.7	3.8	3.7	3.8	3.7	
Milk True Protein, %	3.0	3.0	3.0	3.0	3.0	3.0	
Milk SCC, cells/ml	140,000	119,000	160,000	225,000	181,000	218,000	
DIM	179	174	184	195	198	173	
BST, % of Herd	75	70	83	68	63	75	
% DHI Annual Turnover	18	44	34	38	34	30	
DHI Average Age, mo	41	41	40	41	41	48	
% Milking Heifers	34	38	38	48	34	28	
Heifer Calving Age, mo	23	23	22	23	25	22	
Target Days Dry	50 - 60	50 - 60	50	60	45	55	
DHI Days Dry (% > 70 days)	64(19%)	66(20%)	69(21%)	75(26%)	61(---)	53(9%)	
Number of Dry Cow Groups	2	2	2	2	2	2	
Number of Dry Cow Diets	2	1	1	1	2	2	
Days in Pre-Fresh Target	21	21	14	21	21	14 21	
Post-Fresh Group	Yes	Yes	Yes	Yes	Yes	Yes	
Days in Post-Fresh Target	14	5 15	25 30	3 6	0 60	14 21	
Times Post-Fresh Milked	3x	3x	3x	4x	3x	3x	
Total Mixed Ration	Yes	Yes	Yes	Yes	Yes	Yes	
TMR Inventory Program	No	Yes	Yes	No	No	No	
Diet Formulation	James Bailey, ANC	John Koepke	Paul Roden, Homestead Ag Products	Garrit DeBruin, Prescription	Mark Natzke, Ag. Consultant Team	Steve Hellenbrand, Purina	

[1]DHI = Dairy Herd Improvement, RHA = rolling herd average, DIM = days in milk, MLM = management level milk (adjusted for DIM and parity), SCC = somatic cell count, BST = bovine somatotropin, and TMR = total mixed ration.

Table 2. General feeding and management information from Hensen Brothers Dairy, Inc. when surveyed January 29, 2004.[1]

Item	Mature Cow Group	Heifer & Fresh Cow Group	Pre-Fresh Group	Far-Off Dry Middle & Springer Group	Close-Up Group
Number of Cows	84	91	108	40	14
DHI Milk, lb/cow	107	85	99	—	—
Stall Stocking Density, %	106	115	106	70	41
Stall Base	Mattress	Mattress	Mattress	Sand, Tires	Mattress
Stall Bedding	Sawdust	Sawdust	Sawdust	Sand	Sawdust
Stall Width, inches	48	48	48	48	48
Bunk Type	Enclosed Drive-By	Enclosed Drive-By	Enclosed Drive-By	Enclosed Drive-By	Enclosed Drive-By
Bunk Space, ft/cow	2.1	1.8	1.4	2.3	6.4
Times Fed	1X	1X	1X	1X	1X
Times Pushed-Up	0	0	0	0	0
Feed Refusal Target, %	0	0	0	0	0
Group Free-Stall Configuration	2-row	2-row	3-row	3-row	2-row
Self-Locks	No	No	Yes	Yes	No
Type of Waterers	Trough	Trough	Trough	Trough	Hole
Number of Waterers in Pen	2	2	2	2	4 Holes
Farthest In-Pen to Water, ft	88	83	45	45	45
In-Pen Cubic-ft Water Per Cow	0.14	0.12	0.08	0.16	0.07-0.14
Summer Ventilation	Tunnel	Tunnel	Tunnel	Tunnel	Tunnel
Use of TMR Preservative	Summer	Summer	Summer	Summer	Summer
Hay	Yes	Yes	Yes	Yes	Yes
Wheat Straw	Yes	Yes	Yes	Yes	Yes
Hay or Straw Processing	Screw	Screw	Screw	Screw	Screw

[1]DHI = Dairy Herd Improvement and TMR = total mixed ration.

Table 3a. General feeding and management information from Koepke Farms, Inc. when surveyed February 2, 2004.[1]

Item	Fresh Group	High West Group	High Group	Medium Group	Low Group
Number of Cows	13	60	74	67	65
DHI Milk, lb/cow	62	112	103	90	66
DIM	10	54	157	212	315
Stall Stocking Density, %	92	100	97	120	112
Stall Base	Sand	Sand	Sand	Sand	Sand
Stall Bedding	Sand	Sand	Sand	Sand	Sand
Stall Width, inches	54	48	48	48	48
Bunk Type	Enclosed Drive-By	Enclosed Drive-By	Enclosed Drive-By	Backed, Uncovered, Outside, Drive-By	Backed, Uncovered, Outside, Drive-By
Bunk Space, ft/cow	3.0	1.7	1.4	1.8	1.2
Times Fed	1X	1X	1X	1X	1X
Times Pushed-Up	0	0	0	0	0
Feed Refusal Target, %	0	0	0	0	0
Group Free-Stall Configuration	3-row	3-row	3-row	2-row	2-row
Self-Locks	No	No	No	No	No
Type of Waterers	Trough-Holes +Summer Tank	Trough-Holes	Trough-Holes	Trough-Holes +Summer Tank	Trough-Holes +Summer Tank
Number of Waterers in Pen	1 - 2	2	2	1 - 2	1 - 2
Farthest In-Pen To Water, ft	60	50	50	50 - 100	50 - 100
In-Pen Cubic-ft Water Per Cow	0.03 1.5	0.16	0.13	0.10 0.23	0.10 - 0.24
Summer Ventilation	Oscillating	Oscillating	Oscillating	Tunnel 3 ft Fan/Mister	Tunnel 3 ft Fan/Mister + Mister
Use of TMR Preservative	Summer	Summer	Summer	Summer	Summer
Hay	No	No	No	No	No
Haylage	Yes	Yes	Yes	Yes	Yes
Corn Silage	Yes	Yes	Yes	Yes	Yes
Whole Cottonseed	Yes	Yes	Yes	Yes	No
Hi-Moisture Shelled Corn	No	No	No	No	No

[1]DHI = Dairy Herd Improvement, DIM = days in milk, and TMR = total mixed ration.

Table 3b. General feeding and management information from Koepke Farms, Inc. when surveyed February 2, 2004.[1]

Item	Far-Off Dry Group	Pre-Fresh Group
Number of Cows	30	20
Stall Stocking Density	100%	113 sq ft per cow
Stall Base	Sand	Dirt
Stall Bedding	Sand	Straw or Sand Pack
Stall Width, inches	48	45 x 50 ft
Bunk Type	EnclosedDrive-By	Enclosed Drive-By
Bunk Space, ft/cow	1.4	2.5
Times Fed	1X	1X
Times Pushed-Up	0	0
Feed Refusal Target, %	0	0
Group Free-Stall Configuration	3-row	—
Self-Locks	No	No
Type of Waterers	Trough-Holes	Trough-Holes
Number of Waterers in Pen	1	1
Farthest In-Pen to Water, ft	50	25
In-Pen Cubic-ft Water per Cow	0.12	0.16
Summer Ventilation	Fans	Fans
Use of TMR Preservative	Summer	Summer
Hay	No	No
Corn Stalklage	Yes	Yes
Haylage	Yes	Yes
Corn Silage	Yes	Yes
Whole Cottonseed	No	No
Soy Hulls	Yes	Yes
Hi-Moisture Shelled Corn	No	No
Dry Corn	No	No

[1]TMR = total mixed ration.

Table 4a. General feeding and management information from Rosy-Lane Holstein , LLC when surveyed February 2, 2004.[1]

Item	High 2-yr Olds	Low 2-yr Olds	High Large Cows	High Small Cows	Low Cows
Number of Cows	95	87	80	87	95
DHI Milk, lb/cow	84	79	105	106	94
Stall Stocking Density, %	122	112	119	112	123
Stall Base	Sand	Sand	Sand	Sand	Sand
Stall Bedding	Sand	Sand	Sand	Sand	Sand
Stall Width, inches	45	45	45	45	45
Bunk Type	Drive-Thru	Drive-Thru	Drive-By	Drive-Thru	Drive-By
Bunk Space, ft/cow	1.1	1.2	1.2	1.2	1.3
Times Fed	1X	1X	1X	1X	1X
Times Pushed-Up	2X	2X	2X	2X	2X
Feed Refusal Target, %	0	0	0	0	0
Group Free-Stall Configuration	3-row	3-row	3-row	3-row	3-row
Self-Locks	Yes	Yes	Yes	Yes	Yes
Type of Waterers	Trough	Trough	Trough	Trough	Trough
Number of Waterers in Pen	2	2	2	2	4
Farthest In-Pen to Water, ft	53	53	53	53	60
In-Pen Cubic-ft Water Per Cow	0.17	0.18	0.15	0.18	0.25
Summer Ventilation	Fans	Fans	Fans	Fans	Fans
Use of TMR Preservative	Summer	Summer	Summer	Summer	Summer
Hay	No	No	No	No	No
Haylage	Yes	Yes	Yes	Yes	Yes
Corn Silage	Yes	Yes	Yes	Yes	Yes
Whole Cottonseed	Yes	Yes	Yes	Yes	Yes
High Moisture Shelled Corn	No	No	No	No	No
Dry Corn	Yes	Yes	Yes	Yes	Yes

[1]DHI = Dairy Herd Improvement and TMR = total mixed ration.

Table 4b. General feeding and management information from Rosy-Lane Holstein, LLC when surveyed February 2, 2004.[1]

Item	Fresh Group	Far-Off Dry Group	Pre-Fresh Group
Number of Cows	38	70	15
Stall Stocking Density, %	86	78	100
Stall Base	Sand	Sand	Sand
Stall Bedding	Sand	Sand	Sand
Stall Width, inches	45	48	45
Bunk Type	Drive-Thru	Drive-By	Drive-Thru
Bunk Space, ft/cow	2.0	2.0	1.5
Times Fed	1X	1X	1X
Times Pushed-Up	2X	2X	2X
Feed Refusal Target, %	0	0	0
Group Free-Stall Configuration	3-row	3-row	3-row
Self-Locks	No	Yes	No
Type of Waterers	Trough	Trough	Trough
Number of Waterers in Pen	1	2	1
Farthest In-Pen to Water, ft	35	72	15
In-Pen Cubic-ft Water per Cow	0.21	0.23	0.40
Summer Ventilation	Fans	Fans	Fans
Use of TMR Preservative	Summer	Summer	Summer
Hay	Yes	No	No
Oatlage	No	Yes	Yes
Haylage	Yes	Yes	Yes
Corn Silage	Yes	Yes	Yes
Whole Cottonseed	Yes	No	No
High Moisture Shelled Corn	No	No	No
Dry Corn	Yes	No	No

[1]TMR = total mixed ration.

Table 5a. General feeding and management information from Crave Brothers Farm when surveyed February 3, 2004.[1]

	>150 DIM Group	<150 DIM 2-yr Olds	Fresh Mature Cows	Pregnant, DNB Cows	Low Cows
Number of Cows	112	96	96	112	145
DHI Milk, lb/cow	98	84	113	90	67
DIM	191	91	64	233	341
Stall Stocking Density, %	129	110	100	117	106
Stall Base	Dirt, Tires	Dirt, Tires	Dirt, Tires	Dirt, Tires	Dirt, Tires
Stall Bedding	Oat Hulls	Oat Hulls	Oat Hulls	Oat Hulls	Oat Hulls
Stall Width, inches	46	46	48	46	47
Bunk Type	Drive-Thru	Drive-Thru	Drive-Thru	Drive-Thru	Uncovered, Outside Drive-
By					
Bunk Space, ft/cow	1.7	2.0	2.0	1.7	2.0
Times Fed	1X	1X	1X	1X	1X
Times Pushed-Up	4X	4X	4X	4X	4X
Feed Refusal Target, %	3 - 5	3 - 5	3 - 5	3 - 5	Receive
Refusals					
Group Free-Stall Configuration	2-row	2-row	2-row	2-row	2-row
Self-Locks	Yes	Yes	Yes	Yes	No
Type of Waterers	Trough	Trough	Trough	Trough	Trough
Number of Waterers in Pen	3	3	3	3	3 - 4
Farthest In-Pen to Water, ft	60	60	60	60	100
In-Pen Cubic-ft Water per Cow	0.30	0.35	0.35	0.30	0.05 0.20
Summer Ventilation	Fans	Fans	Fans	Fans	Outside, Free-Stall Shades
Use of TMR Preservative	Summer	Summer	Summer	Summer	Summer
Hay	No	No	No	No	No
Haylage	Yes	Yes	Yes	Yes	Yes
Corn Silage	Yes	Yes	Yes	Yes	Yes
Whole Cottonseed	Yes	Yes	Yes	Yes	Yes
High Moisture Shelled Corn	Yes	Yes	Yes	Yes	Yes

[1]DIM = Days in milk, DNB = do not breed, DHI = Dairy Herd Improvement, and TMR = total mixed ra-

Table 5b. General feeding and management information from Crave Brothers Farm when surveyed February 3, 2004.[1]

Item	Pre-Fresh Group	Fresh & Hospital Group	Maternity	Far-Off Dry
Number of Cows	26	12	12	55
Stall Stocking Density	72%	100%	250 sq ft per cow	90 sq ft per cow
Stall Base	Dirt, Tires	Dirt, Tires	Dirt	Dirt
Stall Bedding	Oat Hulls	Oat Hulls	Straw	Straw
Stall Width, inches	50	47	—	—
Bunk Type	Uncovered, Outside Drive-By	Enclosed Drive-By	H-Bunk Drive-By	Uncovered, Outside Drive-By
Bunk Space, ft/cow	2.0	2.0	5.0	1.5
Times Fed	1X	1X	1X	1X
Times Pushed-Up	4X	0	0	4X
Feed Refusal Target, %	3 - 5	0	0	0
Group Free-Stall Configuration	2-row	2-row	Straw Pack	Straw Pack
Self-Locks	Yes	Yes	No	No
Type of Waterers	Trough-Holes	Trough	Trough	Trough-Holes
Number of Waterers in Pen	2 Holes	1	1	4 Holes
Farthest In-Pen to Water, ft	50	40	40	50
In-Pen Cubic-ft Water per Cow	0.53	1.3	1.3	0.05
Summer Ventilation	—	Fans	Fans	—
Use of TMR Preservative	Summer	Summer	Summer	Summer
Hay	No	Yes	No	No
Haylage	Yes	Yes	Yes	Yes
Corn Silage	Yes	Yes	Yes	Yes
Whole Cottonseed	No	Yes	No	No
High Moisture Shelled Corn	No	Yes	No	No
Dry Corn	No	Yes	No	No

[1]TMR = total mixed ration.

Table 6. General feeding and management information from So-Fine Bovines, LLC when surveyed February 5, 2004.[1]

Item	High Group	Low Group	Post-Fresh Group	Pre-Fresh Group	Far-Off Dry
Number of Cows	140	163	81	27	38
DHI Milk, lb/cow	118	76	100	—	—
DIM	146	313	55	—	—
Stall Stocking Density, %	104	109	109	113	100
Stall Base	Sand	Sand	Sand	Sand	Sand
Stall Bedding	Sand	Sand	Sand	Sand	Sand
Stall Width, inches	48	48	48	48	48
Bunk Type	Drive-Thru	Drive-By	Drive-Thru	Drive-Thru	Outside, Feed Wagon
Bunk Space, ft/cow	1.4	1.5	1.6	1.9	—
Times Fed	1X	1X	1X	1X	1X
Times Pushed-Up	7X	7X	7X	7X	0
Feed Refusal Target, %	3	3	3	3	0
Group Free-Stall Configuration	3-row	3-row	3-row	3-row	3-row
Self-Locks	Yes	No	Yes	Yes	No
Type of Waterers	Trough	Trough	Trough	Trough	—
Number of Waterers in Pen	3	3	2	1	—
Farthest In-Pen to Water, ft	48	30	63	48	—
In-Pen Cubic-ft Water per Cow	0.13	0.13	0.06 - 0.13	0.19	—
Summer Ventilation	Fans	Fans	Fans	Fans	—
Use of TMR Preservative	No	No	No	No	No
Hay	Yes	No	Yes	Yes	Yes
Haylage	Yes	Yes	Yes	Yes	Yes
Corn Silage	Yes	Yes	Yes	Yes	Yes
Wheat Straw	Yes	Yes	Yes	Yes	No
Whole Cottonseed	Yes	Yes	Yes	No	No
High Moisture Shelled Corn	Yes	Yes	Yes	Yes	Yes
Corn Gluten Feed	Yes	Yes	Yes	No	No
Beet Pulp	Yes	No	Yes	Yes	No

[1]DHI = Dairy Herd Improvement, DIM = days in milk, and TMR = total mixed ration.

Table 7a. General feeding and management information from Oechsner Farms when surveyed February 10, 2004.[1]

Item	High Cows	High 2-yr Olds	Post-Fresh Group	Low Cows	Low 2-yr Olds
Number of Cows	96	92	28	93	57
Stall Stocking Density, %	117	112	108	113	101
Stall Base	Clay	Clay	Clay	Clay	Clay
Stall Bedding	Sand	Sand	Sand	Sand	Sand
Stall Width, inches	46	46	46	46	46
Bunk Type	Drive-Thru	Drive-Thru	Drive-Thru	Drive-Thru	Drive-Thru
Bunk Space, ft/cow	1.9	2.2	2.1	1.9	2.1
Times Fed	1X	1X	1X	1X	1X
Times Pushed-Up	12X	12X	12X	12X	12X
Feed Refusal Target, %	3	3	3	3	3
Group Free-Stall Configuration	2-row	2-row	2-row	2-row	2-row
Self-Locks	Yes	Yes	Yes (partial)	No	No
Type of Waterers	Trough	Trough	Trough	Trough	Trough
Number of Waterers in Pen	2	2	1	2	1
Farthest In-Pen to Water, ft	90	100	50	90	120
In-Pen Cubic-ft Water per Cow	0.06	0.06	0.13	0.06	0.05
Summer Ventilation	Fans	Fans	Fans	Fans	Fans
Use of TMR Preservative	No	No	No	No	No
Hay	Yes	Yes	Yes	Yes	Yes
Haylage	Yes	Yes	Yes	Yes	Yes
Corn Silage	Yes	Yes	Yes	Yes	Yes
Whole Cottonseed	Yes	Yes	Yes	Yes	Yes
High Moisture Shelled Corn	Yes	Yes	Yes	Yes	Yes
Dry Corn	No	No	No	No	No

[1]TMR = total mixed ration.

Table 7b. General feeding and management information from Oechsner Farms when surveyed February 10, 2004.[1]

Item	Far-Off Dry Group	Pre-Fresh Group	Maternity
Number of Cows	40	20	8
Stall Stocking Density	89%	69 sq ft per cow	110 sq ft per cow
Stall Base	Concrete	Dirt	Concrete
Stall Bedding	Sand	Straw Pack	Straw Pack
Stall Width, inches	45	49 x 28 ft	12 x 14 ft or 11 x 30 ft
Bunk Type	Uncovered, Outside H-Bunk	Uncovered, Outside H-Bunk	Floor Manger
Bunk Space, ft/cow	2.3	2.4	5.0
Times Fed	1X	1X	1X
Times Pushed-Up	0	0	2X
Feed Refusal Target, %	0	0	0
Group Free-Stall Configuration	2-row	Straw Pack	Straw Pack
Self-Locks	No	No	No
Type of Waterers	Trough-Holes	Trough-Holes	Trough-Holes
Number of Waterers in Pen	4 Holes	2 Holes	2 Holes
Farthest In-Pen to Water, ft	75	45	15
In-Pen Cubic-ft Water per Cow	0.03	0.01	0.12
Summer Ventilation	Tunnel	—	Tunnel
Use of TMR Preservative	No	No	No
Hay	No	Yes	Yes
Straw	Yes	Yes	Yes
Haylage	No	Yes	Yes
Corn Silage	Yes	Yes	Yes
Oatlage	Yes	Yes	Yes
Beet Pulp	No	Yes	Yes
High Moisture Shelled Corn	No	Yes	Yes
Dry Corn	No	No	No

[1]TMR = total mixed ration.

Table 8. Alfalfa silage data for six selected high-producing WI dairy herds surveyed during January - February, 2004.[1]

Item	Hensen	Koepke	Koepke	Rosy Lane	Crave	So-Fine	So-Fine	Oechsner	Oechsner
		Silo 1	Silo 2			Bunk 1	Bunk 2	1st cut	2nd cut
Cutting schedule	4x	4x	4x	3x,4x	4x	4x	4x	4x	4x
Storage	Bunkers	Uprights Bags	Uprights Bags	Bags	Bags	Bunkers	Bunkers	Bags	Bags
Additive	LAB	LAB	LAB	LAB	LAB	LAB	LAB	LAB	LAB
DM, %	49	52	31	32	40	28	44	39	39
% Coarse Screens	14	5	5	25	14	34	14	32	32
% Medium Screens	65	60	70	55	66	56	71	55	53
% Fine Screen & Pan	21	35	25	20	20	10	15	13	15
MPL, inches	0.32	0.22	0.29	0.39	0.33	0.53	0.38	0.47	0.46
pH	4.4	4.4	4.9	4.5	4.5	5.3	4.3	4.3	4.2
% Lactate (DMB)	2.9	2.7	3.1	5.2	5.0	0.6	4.2	4.3	5.2
% Acetate (DMB)	2.6	2.6	4.4	2.7	1.3	5.5	0.4	1.5	0.8
% Butyrate (DMB)	—	—	—	—	—	1.0	—	—	—
Lactate (% of total)	52	51	39	66	79	8	91	74	87
% Ethanol (DMB)	1.2	—	2.0	—	—	—	—	—	—
Ammonia (% of CP)	1.8	12.6	21.6	19.3	12.3	44.0	14.5	17.0	13.6
% CP (DMB)	23.2	18.6	21.9	20.1	23.8	25.5	20.7	18.6	20.2
RUP (% of CP)	20	20	20	20	16	18	17	21	20
% NDF (DMB)	36.1	35.3	39.2	41.7	36.4	36.9	35.4	40.8	40.8
NDFD (% of NDF)	45	40	50	46	58	39	42	42	43
% NFC (DMB)	26.7	35.3	26.3	24.8	25.7	23.8	31.0	28.4	27.6
% Ash (DMB)	14.3	10.3	11.1	12.1	13.4	13.3	11.0	11.2	10.7
% TDN_{1x} (DMB)	60.3	62.9	62.8	59.1	64.7	58.2	61.8	59.3	60.2

[1]LAB = Lactic acid bacteria, DM = dry matter, MPL = mean particle length, DMB = DM basis, CP = crude protein, RUP = rumen undegraded protein, NDF = neutral detergent fiber, NDFD = NDF digestibility, NFC = nonfiber carbohydrates, and TDN_{1X} = total digestible nutrients at one times maintenance.

Table 9. Corn silage data for six selected high-producing WI dairy herds surveyed during January - February, 2004.[1]

Item	Hensen	Koepke	Rosy Lane	Crave	So-Fine	Oechsner
Hybrid	Dual Purpose & Leafy	Dual Purpose	Dual Purpose	Bm_3	Dual Purpose	Dual Purpose
Storage	Bunkers	Bags & Upright	Piles	Bunkers	Bunkers	Bunkers Bags
Kernel Processed	Yes	Yes	Yes	Yes	Yes	Yes
Additive	LAB	LAB	LAB	LAB	No	Urea-Molasses
DM, %	29	36	30	36	36	31
% Coarse Screens	16	19	15	21	8	32
% Medium Screens	70	63	72	68	74	59
% Fine Screen & Pan	14	18	13	11	18	9
MPL, inches	0.42	0.38	0.41	0.45	0.34	0.51
pH	3.7	3.8	3.8	3.7	3.7	3.9
% Lactate (DMB)	3.6	6.8	6.2	4.5	4.1	3.3
% Acetate (DMB)	0.38	1.0	3.3	2.6	2.4	3.1
Lactate (% of total acids)	91	88	65	64	57	52
% Ethanol (DMB)	1.1	—	—	0.6	0.8	1.3
Ammonia (% of CP)	3.3	12.0	13.0	14.0	18.7	36.1
% Starch (DMB)	22.6, 27.3	31.1, 31.4	23.9, 26.5	25.6, 29.4	31.4, 32.8	30.1, 24.0
Kernel Processing Score, % starch thru 4.75 mm sieve	68	77	63	47	56	41
% CP (DMB)	8.7	8.0	7.9	8.1	8.4	10.8
% NDF (DMB)	49.0	42.8	45.5	45.6	39.3	40.8
NDFD (% of NDF)	61	62	62	67	63	61
% NFC (DMB)	30.9	42.8	37.8	37.7	43.9	41.4
% Ash (DMB)	9.5	4.8	7.0	6.7	6.5	5.2
% TDN_{1x} (DMB)	65.8	73.4	70.2	72.5	73.0	73.2

[1]BM_3 = brown midrib, LAB = lactic acid bacteria, DM = dry matter, MPL = mean particle length, DMB = DM basis, CP = crude protein, NDF = neutral detergent fiber, NDFD = NDF digestibility, NFC = nonfiber carbohydrate, and TDN_{1X} = total digestible nutrients at one times maintenance.

Table 10. Corn grain data for six selected high-producing WI dairy herds surveyed during January-February, 2004.[1]

Item	Hensen	Koepke	Rosy Lane	Crave	So-Fine	Oechsner
Corn Type	Hi gh Moisture	Dry	Dry	High Moisture	High Moisture	High Mois-ture
Storage	Shelled Upright Silos	Shelled Farm Bins	Shelled Mill Bought	Shelled Upright Silos	Shelled Bags	Shelled Bags
Processing	Roller Mill	Hammermill 3/16" screen	Hammermill	Roller In & Hammer Out	Hammermill	Roller Mill on Bagger
Additive	LAB	—	—	LAB	No	LAB
DM, %	74	84	85	74	76	74
MPS, microns	2071	794	573	929	1459	1897
% passing #16 or 1180 micron sieve	12	57	90	51	28	17
pH	4.0	—	—	—	4.1	3.9
% Lactate (DMB)	2.1	—	—	—	0.7	1.0
% Acetate (DMB)	0.6	—	—	—	—	0.1
Lactate (% of total acids)	77	—	—	—	100	90
% Ethanol (DMB)	—	—	—	—	—	0.4

[1]LAB = Lactic acid bacteria, DM = dry matter, MPS = mean particle size, DMB = DM basis, and CP = crude protein.

Table 11. High-group TMR sample analysis for six selected high-producing WI dairy herds surveyed January - February, 2004.[1]

Item	Hensen	Koepke	Rosy Lane	Crave	So-Fine	Oechsner
DM, %	53	57	46	40	49	48
% CP (DMB)	18.0	16.7	17.1	17.4	18.4	18.4
% NDF (DMB)	30.1	30.1	29.2	31.0	27.3	29.5
NDFD (% of NDF)	53	62	65	67	61	51
% NFC (DMB)	40.2	42.0	42.8	38.2	41.4	40.1
% Fat (DMB)	5.2	6.0	5.9	5.1	5.0	5.6
% TDN_{1x} (DMB)	71	74	75.8	71.3	72.6	71.5
% Ca (DMB)	1.07	0.93	0.93	1.07	0.71	0.96
% P (DMB)	0.43	0.38	0.37	0.38	0.35	0.44
% Mg (DMB)	0.29	0.34	0.38	0.37	0.33	0.38
% K (DMB)	1.49	1.63	1.44	1.61	1.35	1.52
% Coarse Screen	10	10	15	8	7	12
% Medium Screen	39	32	35	54	39	39
% Pan	51	58	50	38	54	49

[1]TMR = total mixed ration, DM = dry matter, CP = crude protein, DMB = DM basis, NDF = neutral detergent fiber, NDFD = NDF digestibility, NFC = nonfiber carbohydrates, and TDN_{1X} = total digestible nutrients at one times maintenance.

Table 12a. Ingredient composition of formulations for Hensen Brothers Dairy, Inc. when surveyed January 29, 2004.

Item	Mature Cow Group	Heifer & Fresh Cow Group	Middle Group	Far-Off Dry & Springer Group	Pre-Fresh Group
Ingredients, % of DM					
Wheat Straw	1.5	1.0	1.7	5.0	3.5
Baled Hay	7.2	5.8	7.8	9.3	3.3
Haylage	9.9	9.1	10.5	53.3	21.1
Corn Silage	23.4	25.9	22.2	31.1	35.8
High Moisture Shelled Corn	29.6	27.0	28.9	---	10.0
Corn Starch	0.8	0.9	0.8	---	---
Corn Gluten Feed	2.3	2.6	2.5	---	---
Whole Cottonseed	9.2	9.3	8.4	---	3.5
Soy Hulls	---	---	---	---	---
Liquid Feed Supplement	1.7	2.3	1.8	---	2.9
Soybean Meal, 48% CP	6.5	7.3	7.0	---	---
Distillers Dried Grains	3.1	3.5	3.3	---	---
Soy Plus®	---	---	---	---	4.1
Blood Meal	1.2	1.3	1.3	---	---
Urea	0.2	0.3	0.3	---	---
Tallow	0.2	0.3	0.3	---	---
Megalac-R®	0.4	0.4	0.4	---	0.9
Minerals/Vitamins/Additives	2.8	3.0	2.8	1.3	9.8
List of Feed Additives					
Sodium Bicarbonate	Y	Y	Y	---	---
Omnigen-AF®	Y	Y	Y	---	Y
Sel Plex®	Y	Y	Y	---	---
Soy Chlor®	---	---	---	---	Y
Bio-Chlor®	---	---	---	---	Y
Nutro-Cal®	---	---	---	---	Y
Biotin	Y	Y	Y	---	Y
Micro N-R-G®	Y	Y	Y	---	Y
Bacteria/Yeast/Enzymes					

Table 12b. Nutrient composition of formulations, intake, feed efficiency, and feed cost for Hensen Brothers Dairy, Inc. when surveyed January 29, 2004.[1]

Item	Mature Cow Group	Heifer & Fresh Cow Group	Middle Group	Far-Off Dry & Springer Group	Pre-Fresh Group
Nutrients					
% DM	52	51	53	43	43
% CP (DMB)	17.0	17.3	17.4	13.5	15.5
RUP (% of CP)	38	37	38	28	39
% NDF (DMB)	29.2	29.7	29.0	48.4	37.0
% NDF from forage (DMB)	19.1	19.1	19.1	43.2	30.4
% Forage (DMB)	45	45	45	96	66
% NFC (DMB)	38.1	37.4	37.8	25.3	32.0
% Fat (DMB)	5.7	5.6	5.8	2.8	3.5
% TDN_{1x} (DMB)	76.8	76.6	76.6	62.1	70.1
% Ca (DMB)	1.0	1.07	1.06	0.91	1.25
% P (DMB)	0.40	0.41	0.41	0.35	0.40
% Mg (DMB)	0.36	0.38	0.36	0.40	0.44
% K (DMB)	1.16	1.17	1.19	1.83	1.45
% Salt (DMB; added)	0.22	0.22	0.23	0.21	0.12
Supp. Vitamin A, IU/lb DM	3333	3745	3588	3572	4528
Supp. Vitamin D, IU/lb DM	833	936	897	1179	1509
Supp. Vitamin E, IU/lb DM	33	38	36	36	113
DM Intake, lb/cow/day	60	44.5	55	28	26.5
DHI Milk/DMI, lb/lb	1.78	1.91	1.80	---	---
Tank Milk/DMI, lb/lb (1.70)	---	---	---	---	---
Feed Cost, $/cow/day	4.49	3.46	4.21	1.13	2.91
Feed Cost, $/cwt DHI Milk	4.20	4.07	4.25	---	---
Feed Cost, $/cwt Tank Milk ($4.50)	---	---	---	---	---

[1]DM = dry matter, CP = crude protein, DMB = DM basis, RUP = rumen undegraded protein, NDF = neutral detergent fiber, NFC = nonfiber carbohydrates, TDN_{1X} = total digestible nutrients at one times maintenance, IU = international unit, DHI = Dairy Herd Improvement, and DMI = DM intake.

Table 13a. Ingredient composition of formulations for Koepke Farms, Inc. when surveyed February 2, 2004.

Item	High West & Fresh Groups	High Group	Medium Group	Low Group	Dry Groups
Ingredients, % of DM					
Corn Stalklage	---	---	---	---	32.4
Haylage	20.4	23.6	23.5	29.5	26.7
Corn Silage	24.5	24.3	24.1	26.1	5.6
Dry Shelled Corn	24.4	26.2	26.0	20.5	---
Corn Gluten Feed	3.4	1.2	3.6	12.9	---
Soy Hulls	---	---	---	---	30.2
Whole Cottonseed	7.3	7.8	7.8	---	---
Roasted Soybeans	11.4	9.3	7.7	2.9	---
Linseed Meal	2.9	3.5	2.8	5.4	---
Blood Meal	1.2	0.3	0.2	---	---
Feather Meal	0.4	0.3	0.8	0.6	---
Urea	---	0.1	0.1	0.1	0.2
Minerals/Vitamins/Additives	4.1	3.4	3.4	2.0	4.9
List of Feed Additives					
Sodium Bicarbonate	Y	Y	Y	Y	---
Potassium Carbonate	Y	Y	Y	Y	---
Omnigen-AF®	Y	Y	Y	Y	Y
Biotin	Y	Y	Y	Y	Y
4-Plex®	Y	Y	---	---	Y
Niacin	Y	---	---	---	Y
Priority One® (DFM)[1]	Y	Y	---	---	Y

[1]DFM = direct fed microbial.

Table 13b. Nutrient composition of formulations , intake, feed efficiency, and feed cost for Koepke Farms, Inc. when surveyed February 2, 2004.[1]

Item	High West & Fresh Groups	High Group	Medium Group	Low Group	Dry Groups
Nutrients					
% DM	56	57	56	52	65
% CP (DMB)	17.2	17.0	16.8	16.5	13.1
RUP (% of CP)	36	37	36	36	36
% NDF (DMB)	29.4	30.0	29.7	32.3	54.8
% NDF from forage (DMB)	19.1	20.3	19.9	23.4	36.4
% Forage (DMB)	45	48	48	56	65
% NFC (DMB)	41.0	42.3	41.7	41.7	23.9
% Starch (DMB)	29.1	29.3	30.1	29.5	13.5
% Fat (DMB)	6.1	5.8	5.5	3.4	2.7
% TDN_{1x} (DMB)	77	75	75	72	60
% Ca (DMB)	1.01	0.96	0.96	0.91	1.01
% P (DMB)	0.41	0.40	0.40	0.40	0.37
% Mg (DMB)	0.33	0.35	0.33	0.31	0.40
% K (DMB)	1.65	1.60	1.59	1.48	1.39
% Salt (DMB; added)	0.50	0.50	0.50	0.60	0.28
Supp. Vitamin A, IU/lb DM	2211	2484	2484	2852	6160
Supp. Vitamin D, IU/lb DM	556	625	625	718	1551
Supp. Vitamin E, IU/lb DM	9	10	10	12	60
DM Intake, lb/cow/day	52 - 57	62	62	54	25
DHI Milk/DMI, lb/lb	1.20 1.97	1.66	1.45	1.22	---
Tank Milk/DMI, lb/lb (1.57)	---	---	---	---	---
Feed Cost, $/cow/day	3.62 4.05	4.23	3.79	2.63	1.22
Feed Cost, $/cwt DHI Milk	3.62 5.83	4.11	4.21	3.99	---
Feed Cost, $/cwt Tank Milk ($4.01)	---	---	---	---	---

[1]DM = dry matter, CP = crude protein, DMB = DM basis, RUP = rumen undegraded protein, NDF = neutral detergent fiber, NFC = nonfiber carbohydrates, TDN_{1X} = total digestible nutrients at one times maintenance, IU = international unit, DHI = Dairy Herd Improvement, and DMI = DM intake.

Table 14. Ingredient composition of formulations for Rosy Lane Holsteins, LLC when surveyed February 2, 2004.

Item	Milk Groups	Dry Groups
Ingredients, % of DM		
Oatlage	---	38
Haylage	24	29
Corn Silage	22	31
Dry Shelled Corn	26.1	---
Whole Cottonseed	9.5	---
Roasted Soybeans	2.3	---
Liquid Feed Supplement	2.9	---
Soybean Meal, 48% CP	7.0	---
Distillers Dried Grains	0.70	---
Corn Gluten Meal , 60% CP	0.7	---
Blood Meal	1.1	---
Tallow	0.4	---
Energy Booster®	1.0	---
Minerals/Vitamins/Additives	2.3	2.0
List of Feed Additives		
Probios TC® (DFM)[1]	Y	Y
Magnesium Sulfate	---	Y
Yeast	Y	---
Omnigen-AF®	Y	Y
Biotin	Y	Y
4-Plex®	Y	Y

[1]DFM = Direct fed microbial.

Table 15. Ingredient composition of formulations for Crave Brothers Farm when surveyed February 3, 2004.

Item	Milk Groups	Dry Groups
Ingredients, % of DM		
Haylage	16	57
Corn Silage	34	36
Oat Hulls	---	6.1
Dry Shelled Corn	7.7	---
High Moisture Shelled Corn	9.8	---
Liquid Whey	4.9	---
Whole Cottonseed	2.6	---
Soy Hulls	7.2	---
Roasted Soybeans	5.2	---
Soybean Meal, 48% CP	7.2	---
Corn Gluten Meal, 60% CP	0.5	---
Blood Meal	0.7	---
Megalac®	0.5	---
Minerals/Vitamins/Additives	3.7	0.9
List of Feed Additives		
Probios TC® (DFM)[1]	Y	Y
Yeast	Y	N
Mepron®	Y (except Low Group)	N
Biotin	Y	N
4-Plex®	Y	N

[1]DFM = Direct fed microbial.

Table 16. Nutrient composition of formulations , intake, feed efficiency, and feed cost for Rosy Lane Holsteins, LLC and Crave Brothers Farm when surveyed February 2 and 3, 2004.[1]

Item	Rosy Lane Milk Groups	Rosy Lane Dry Groups	Crave Bros. Milk Groups	Crave Bros. Dry Groups
Nutrients				
% DM	51	41	43	49
% CP (DMB)	17.5	13.5	17.4	15.3
RUP (% of CP)	38	28	37	26
% NDF (DMB)	26.2	43.0	32.3	43.1
% NDF from forage (DMB)	20.4	43.0	22.5	39.2
% Forage (DMB)	46	98	50	93
% NFC (DMB)	43.5	32.4	40.1	32.6
% Fat (DMB)	5.9	2.1	4.6	3.3
% TDN_{1x} (DMB)	76.7	67.0	74.5	64.5
% Ca (DMB)	0.94	0.80	0.90	0.77
% P (DMB)	0.37	0.32	0.38	0.40
% Mg (DMB)	0.34	0.43	0.39	0.23
% K (DMB)	1.18	1.89	1.21	1.72
% Salt (DMB; added)	0.47	0.30	0.49	0.20
Supp. Vitamin A, IU/lb DM	3259	3517	2227	3333
Supp. Vitamin D, IU/lb DM	1086	1172	557	833
Supp. Vitamin E, IU/lb DM	10	69	14	33
DM Intake, lb/cow/day	55	30	56 (51 - 62)	30
DHI Milk/DMI, lb/lb	1.70	---	1.64 1.82	---
Tank Milk/DMI, lb/lb	1.64		1.61	
Feed Cost, $/cow/day	3.97	1.34	3.59 4.34	1.17
Feed Cost, $/cwt DHI Milk	4.27	---	3.85 4.28	---
Feed Cost, $/cwt Tank Milk	4.41	---	4.36	---

[1]DM = dry matter, CP = crude protein, DMB = DM basis, RUP = rumen undegraded protein, NDF = neutral detergent fiber, NFC = nonfiber carbohydrates, TDN_{1X} = total digestible nutrients at one times maintenance, IU = international unit, DHI = Dairy Herd Improvement, and DMI = DM intake.

Table 17a. Ingredient composition of formulations for So-Fine Bovines, LLC when surveyed February 5, 2004.

Item	High Group	Low Group	Post-Fresh Group	Pre-Fresh Group	Far-Off Dry
Ingredients, % of DM					
Wheat Straw	0.6	0.7	0.9	7	---
Hay	2.6	---	2.9	10	11
Haylage	19.5	23.1	10.1	20	28
Corn Silage	23.3	33.5	24.9	35	54
High Moisture Shelled Corn	21.6	18.6	20.3	10	2.4
Corn Gluten Feed	5.5	3.3	5.1	---	---
Beet Pulp	6.2	---	8.6	10	---
Whole Cottonseed	6.7	8.0	9.8	---	---
Soybean Meal, 48% CP	6.0	5.4	7.4	---	---
Soy Plus®	3.9	3.6	4.7	---	---
Fish Meal	0.7	0.6	0.8	---	---
Urea	0.1	0.09	0.1	---	---
Transition Custom	---	---	6.0	---	
Dry Cow Mix	---	---	---	---	4.6
Tallow	0.6	0.6	0.7	---	---
Minerals/Vitamins/Additives	2.7	2.5	3.7	2.0	---
List of Feed Additives					
Sodium Bicarbonate	Y	Y	Y	---	---
Zinpro-40®	Y	Y	Y	Y	---
Yeast	Y	Y	Y	Y	---
Probios TC® (DFM)[1]	Y	---	Y	Y	---
Biochlor	---	---	---	Y	---
Anionic Salts	---	---	---	Y	---

[1]DFM = Direct fed microbial.

Table 17b. Nutrient composition of formulations , intake, feed efficiency, and feed cost for So-Fine Bovines, LLC when surveyed February 5, 2004.[1]

Item	High Group	Low Group	Post-Fresh Group	Pre-Fresh Group	Far-Off Dry
Nutrients					
% DM	50	47	51	51	41
% CP (DMB)	17.9	17.9	17.9	13.8	14.8
RUP (% of CP)	36	35	37	27	29
% NDF (DMB)	30.9	31.3	31.1	39.3	42.9
% NDF from forage (DMB)	18.0	23.0	18.0	32.4	41.0
% Forage (DMB)	46	49	40	72	93
% NFC (DMB)	38.9	38.3	38.1	36.2	32.6
% Starch (DMB)	25.1	25.2	24.9	20.3	14.8
% Fat (DMB)	4.8	5.1	5.4	2.8	3.1
% TDN_{1x} (DMB)	75.6	75.0	76.2	66.8	67.0
% Ca (DMB)	0.84	0.81	0.95	1.30	0.81
% P (DMB)	0.40	0.41	0.44	0.40	0.33
% Mg (DMB)	0.36	0.36	0.39	0.39	0.36
% K (DMB)	1.28	1.32	1.13	1.25	1.62
% Salt (DMB; added)	0.27	0.26	0.47	0.24	0.12
Supp. Vitamin A, IU/lb DM	3102	2917	3752	7748	5623
Supp. Vitamin D, IU/lb DM	1034	972	1251	2137	1869
Supp. Vitamin E, IU/lb DM	13	12	20	41	35
DM Intake, lb/cow/day	68	57	44	26	30
DHI Milk/DMI, lb/lb	1.74	1.33	2.27	---	---
Tank Milk/DMI, lb/lb (1.58)	---	---	---	---	---
Feed Cost, $/cow/day	4.34	3.40	3.30	1.70	1.46
Feed Cost, $/cwt DHI Milk	3.70	4.48	3.30	---	---
Feed Cost, $/cwt Tank Milk ($4.05)	---	---	---	---	---

[1]DM = dry matter, CP = crude protein, DMB = DM basis, RUP = rumen undegraded protein, NDF = neutral detergent fiber, NFC = nonfiber carbohydrates, TDN_{1X} = total digestible nutrients at one times maintenance, IU = international unit, DHI = Dairy Herd Improvement, and DMI = DM intake.

Table 18a. Ingredient composition of formulations for Oechsner Farms when surveyed February 10, 2004.

Item	Milking Cows	High 2-yr Olds	Post-Fresh Group	Far-Off Dry Group	Pre-Fresh Group
Ingredients, % of DM					
Straw	---	---	---	9.7	2.6
Hay	4.4	4.9	17.7	---	15.5
Oatlage	---	---	---	36.9	13.8
Haylage	26.6	30.7	26.6	---	1.9
Corn Silage	21.9	16.9	14.5	36.2	34.6
High Moisture Shelled Corn	20.5	22.0	19.2	---	10.5
Dry Shelled Corn	---	---	---	8.7	---
Beet Pulp	---	---	---	---	8.3
Purina Milking Custom Ext, WCS[1]	20.6	19.6	17.0	---	---
Purina Prefresh Custom	---	---	---	---	8.9
Purina Dry Cow Custom	---	---	---	2.9	---
Roasted Soybeans	6.0	5.9	5.0	---	---
Soybean Meal, 48% CP	---	---	---	4.8	3.9
Minerals/Vitamins/Additives	---	---	---	0.8	---
List of Feed Additives					
Sodium Bicarbonate	Y	Y	Y	---	---
Zinpro-100®	Y	Y	Y	---	Y
Yeast	Y	Y	Y	---	Y
Anionic Salts	---	---	---	---	Y

[1]WCS = whole cottonseed.

Table 18b. Nutrient composition of formulations , intake, feed efficiency, and feed cost for Oechsner Farms when surveyed February 10, 2004.[1]

Item	Milking Cows	High 2-yr Olds	Post-Fresh Group	Far-Off Dry Group	Pre-Fresh Group
Nutrients					
% DM	54	54	58	49	55
% CP (DMB)	18.5	18.5	18.5	11.5	14.5
RUP (% of CP)	35	35	34	30	35
% NDF (DMB)	28.8	28.7	30.8	46.2	39.3
% NDF from forage (DMB)	21.2	21.2	24.0	43.8	31.9
% Forage (DMB)	53	53	58	83	69
% NFC (DMB)	40.7	40.9	38.7	33.4	36.1
% Starch (DMB)	27.3	27.9	26.0	19.2	20.2
% Fat (DMB)	6.4	6.3	5.8	2.9	2.7
% TDN_{1x} (DMB)	76.4	76.1	74.0	66.7	68.0
% Ca (DMB)	1.03	1.07	1.09	0.60	0.94
% P (DMB)	0.40	0.40	0.39	0.31	0.31
% Mg (DMB)	0.39	0.39	0.38	0.36	0.40
% K (DMB)	1.27	1.33	1.42	1.56	1.34
% Salt (DMB; added)	0.37	0.32	0.28	0.10	---
Supp. Vitamin A, IU/lb DM	4224	4016	3494	2640	3897
Supp. Vitamin D, IU/lb DM	721	686	597	767	1084
Supp. Vitamin E, IU/lb DM	14	13	11	71	79
DM Intake, lb/cow/day	58	52	45	27	30
Tank Milk/DMI, lb/lb (1.70)	---	---	---	---	---
Feed Cost, $/cow/day	4.10	3.63	2.95	1.39	1.76
Feed Cost, $/cwt Tank Milk ($4.15)	---	---	---	---	---

[1]DM = dry matter, CP = crude protein, DMB = DM basis, RUP = rumen undegraded protein, NDF = neutral detergent fiber, NFC = nonfiber carbohydrates, TDN_{1X} = total digestible nutrients at one times maintenance, IU = international unit, DHI = Dairy Herd Improvement, and DMI = DM intake.

Table 19. High-Group TMR evaluation using NRC (2001) Model for six selected high-producing WI dairy herds surveyed January - February, 2004.[1]

Item	Hensen	Koepke	Rosy Lane	Crave	So-Fine	Oechsner
NE_L Allowable Milk						
lb/day	104	110	99	105	114	102
% of observed	97%	107%	97%	93%	97%	104%
MP Allowable Milk						
lb/day	101	97	102	103	116	96
% of observed	95%	95%	100%	92%	98%	98%
Lysine, % MP	6.2	6.3	6.2	6.4	6.2	6.2
Methionine, % of MP	1.8	1.8	1.8	2.1	1.8	1.8
Lysine:Methionine	3.4	3.5	3.4	3.1	3.4	3.4

[1]TMR = total mixed ration, NE_L = net energy for lactation, and MP = metabolizable protein.