Nutritional Management for Transition Dairy Cows

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Introduction

The importance of a successful transition from late pregnancy to early lactation is well accepted. Health problems during the transition period can easily erase the entire profit potential for an individual cow in that lactation, through increased costs for veterinary treatment and lost production potential (Drackley, 1999). The incidence of health problems on US dairy farms today remains staggering. From epidemiological data and field observations, the combined incidence rate for dystocia, milk fever, retained placenta, metritis, ketosis, displaced abomasum, fatty liver, and lameness results in only 50% of all cows calving without health problems (Ferguson, 2001). Realistic goals for well-managed farms may be that 60% of cows calve without one or more of these problems (Ferguson, 2001). Because many, if not all, of these periparturient health problems are interrelated (Curtis et al., 1985; Markusfeld, 1987; Correa et al., 1993; Emanuelson et al., 1993; Peeler et al., 1994), using the categories of *healthy* and *problem* cows may provide a better indication of transition period management than focusing on a single disorder.

Less well documented, yet perhaps equally important, are the potential losses in peak milk yield and lactation persistency that are believed to result from sub-optimal transitions. Every 1 pound of milk lost from the cow's potential peak production represents a loss of 200 lbs of milk for the lactation. Problems during the transition period often result in the loss of 10 to 20 lbs of peak milk (e.g., Wallace et al., 1996), which translates into economic losses of $300 to $600 for that lactation. The occurrence of health problems during the transition is clearly a major complicating factor for subsequent reproductive performance (Ferguson, 2001), resulting in additional economic losses.

To maximize productivity and ensure successful reproduction, rations fed during this time need to be nutrient dense and often contain more expensive ingredients. Improper formulation of diets and poor feeding management can negate beneficial effects of these more costly rations (Drackley, 1998).

Therefore, a poor nutritional program during the transition period increases feed costs per unit of milk produced and decreases income through lost milk production, decreased reproductive efficiency, and increased incidences of metabolic disorders.

Interest in nutrition and management of dairy cows during the transition period has increased dramatically during the last decade as researchers and field nutritionists have recognized the importance of this critical 6-wk period (Drackley, 1999). To obtain maximum profits, nutritionists and veterinarians should work together with dairy producers to design practical strategies to help cows make smooth transitions, so that cows produce to their potential during early lactation. Most of the *metabolic upheaval* that cows will face during the transition from pregnancy during the late dry period to lactation has occurred by the first day after calving (Grummer, 1995). Consequently, management and nutrition during the pre-calving period assumes tremendous importance.

In this paper, I will examine several aspects of nutritional management that may be related to transition success. Furthermore, it is my contention that *stressors*, whether environmental, behavioral, or immunologic, play a very important role in transition success (Drackley et al., 2001). Because few data exist for this subject, discussion will be based on general principles of stress physiology and pertinent data from other species.

Metabolic Changes during the Transition Period

Signs of an inadequate transition program include cows that are slow to come onto feed after calving, an excessive incidence of metabolic and infectious disorders, cyclic feed intakes, and excessive loss of body condition after calving (Drackley, 1998). Poor reproductive success also may be linked back to problems in the transition period (Ferguson, 2001). To understand the origins of these signs and to implement nutritional

management recommendations for the transition period, it is helpful to understand the metabolic events that occur during this time (Drackley, 1998, 1999; Goff and Horst, 1997; Drackley et al., 2001).

As calving approaches, concentrations of progesterone in blood decrease and those of estrogen remain high or actually increase (Grummer, 1995). High circulating estrogen is believed to be one major factor that contributes to decreased dry matter intake (**DMI**) around calving (Grummer, 1993). During the last weeks of pregnancy, nutrient demands by the fetal calf and placenta are at their greatest (Bell, 1995), yet DMI may be decreased by 10 to 30% compared with intake during the early dry period.

After calving, the initiation of milk synthesis and rapidly increasing milk production greatly increases demand for glucose for milk lactose synthesis, at a time when feed intake has not reached its maximum. Because much of the dietary carbohydrate is fermented in the rumen, little glucose is absorbed directly from the digestive tract. Consequently, dairy cows rely almost exclusively on gluconeogenesis (synthesis of glucose) from propionate in the liver to meet their glucose requirements. Limited feed intake during the early postpartal period means that supply of propionate for glucose synthesis also is limited. Amino acids from the diet or from breakdown of skeletal muscle as well as glycerol from mobilized body fat contribute to glucose synthesis.

The total intake of energy by cows after calving usually is less than energy requirements, even in healthy cows (Bell, 1995). Negative energy balance results in a high ratio of growth hormone to insulin in blood of cows, which promotes mobilization of long-chain fatty acids from adipose tissue (body fat). Fatty acids released from adipose tissue circulate as nonesterified fatty acids (**NEFA**), which are a major source of energy to the cow during this period. The concentration of NEFA in blood reflects the degree of adipose tissue mobilization (Pullen et al., 1989); therefore, the greater the extent of negative energy balance, the more NEFA are released from body fat and the higher the concentration of NEFA in blood.

The liver of cows takes up NEFA from the blood that flows through it. As the concentration of NEFA in blood increases around calving or in early lactation, more NEFA are taken up by the liver (Emery et al., 1992). Once taken up by the liver, NEFA can be: 1) completely oxidized to carbon dioxide to provide energy for the liver, 2) partially

oxidized to produce ketone bodies that are released into the blood and serve as fuels for other tissues, or 3) reconverted to storage fat (triglycerides). Ruminants have an inherently low capacity for synthesis and secretion of very-low density lipoproteins to export triglyceride from the liver (Kleppe et al., 1988; Pullen et al., 1989), yet the rate of production of triglycerides in the liver is increased at the time of calving (Grum et al., 1996). Cows fed typical diets during the dry period and transition period have an increased concentration of triglyceride in the liver 1 day after calving (Skaar et al., 1989; Grum et al, 1996). If NEFA uptake by the liver becomes excessive, fatty liver may develop. Negative energy balance and carbohydrate insufficiency in the liver after calving leads to increased production of ketone bodies, which can result in ketosis.

Maintaining optimal liver function is central to the ability of cows to make a smooth transition into heavy milk production. As the degree of fatty infiltration increases, normal functions of the liver are affected adversely. In particular, fat infiltration impairs the ability of the liver to detoxify ammonia to urea (Strang et al., 1998). Blood ammonia concentrations were positively correlated with the degree of fat accumulation in the liver of cows shortly after calving (Zhu et al., 2000). In severe fatty liver, normal functions of the liver are severely depressed, which results in the condition of *fatty liver syndrome* or *clinical fatty liver* (Morrow, 1976). Feed intake and carbohydrate status of the cow are important in determining the extent of body fat mobilization, fatty liver, and ketone body production in the liver.

The sudden start of milk synthesis in the udder results in a tremendous demand for calcium. As a result, blood calcium concentrations can drop precipitously at calving, leading to milk fever. Smaller decreases in blood calcium, called subclinical hypocalcemia, are believed to be contributing factors in disorders, such as displaced abomasum and ketosis, by decreasing smooth muscle function, which is critical for normal function of the digestive tract (Goff and Horst, 1997). Hypocalcemia also leads to increased secretion of cortisol, which is believed to be a factor in increased incidence of retained placenta (Goff, 1999). Until the ability of the digestive tract to absorb calcium can increase, calcium must be obtained by breaking down bone. Metabolic acidosis caused by a negative dietary cation-anion difference (**DCAD**) favors mobilization of calcium from bone, whereas high dietary potassium concentrations and

positive DCAD suppress this process (Horst et al., 1997).

Function of the immune system is depressed during the transition period (Mallard et al., 1998). Decreased ability of the immune system to respond to infectious challenges likely is responsible for the high incidence of environmental mastitis around calving, as well as the high incidence of metritis. Reasons for the decreased immune function are not well understood. Vitamins A and E as well as a number of the trace minerals (selenium, copper, zinc) play a role in enhancing immune function. Recent evidence suggests that negative energy balance may be a major contributing factor (Goff, 1999). This finding relates well to the common observation that cows which seem to be the most stressed by nutrition and environmental factors, as judged by excessive loss of body condition, are the most likely to become ill.

In view of the dynamic nature of physiological changes during the transition period, goals of nutritional and environmental management during this period can be summed up as:

1) Maintain (or enhance) immune function.
2) Minimize the extent of body fat mobilization around calving.
3) Maintain blood calcium at and after calving.
4) Maximize the appetite of the cow at and after calving.

Aspects of Nutritional Management during the Transition

Optimal transition management views the period as consisting of three distinct phases for the cow: Phase 1 is the far-off dry period. This phase has relatively simple nutritional requirements but should not be ignored. Phase 2 is the close-up period, when many of the metabolic changes for lactation actually occur. Phase 3 is the fresh cow, which completes the transition into full lactation. The new National Research Council (**NRC**) publication *Nutrient Requirements of Dairy Cattle* (NRC, 2001) has incorporated much new information regarding the transition period, and has made recommendations for nutritional management of transition cows during these three phases. This new publication is a *must-read* for all professionals interested in the area.

Use of separate close-up and fresh cow rations, especially when fed as a total mixed ration (**TMR**),

should help cows come onto feed faster and more smoothly after calving, with a lower incidence of postpartum health disorders. The general concept of ration changes during the transition is that nutrient density is increased gradually from that fed to far-off dry cows to the higher nutrient density required for fresh cows. Because DMI of closeup cows declines by 10 to 30% during the last 7 to 14 days before calving, nutrient density must be increased to compensate. This allows maintenance of the same intake *amounts* (pounds or grams per cow per day) of key nutrients such as protein despite lower total feed intake. The typical decrease in DMI before calving results in the need to increase contents of crude protein (**CP**) and net energy of lactation (**NE$_L$**) by about 2 percentage units and 0.10 megacalories per pound (**Mcal/lb**) of DM, respectively, in the close-up diet. While the general concept of close-up rations has proven beneficial in the field, producers should be cautioned not to extend feeding of the close-up diet too long (see *Body Condition* below). Overfeeding high-starch rations (high in corn silage and grains) during the entire dry period is detrimental to cow performance. Our own research (Douglas et al., 1998) indicates that this appears to be true even if cows are not overconditioned, which is well known to be detrimental (Fronk et al., 1980; Van Den Top et al., 1995). The bottom line is that while a limited period (3 weeks) of close-up feeding is warranted, producers should not extend this more aggressive feeding program to the entire dry period.

Carbohydrates

The balance between structural carbohydrates (fiber) and nonstructural carbohydrates (grains or concentrate by-product feeds) in diets fed before and after calving is probably the most important dietary factor for transition success. Unfortunately, striking this balance in transition cows is difficult because of the lack of definitive research. Examination of the carbohydrate fractions of the transition ration and fresh-cow ration should be the starting point for trouble-shooting transition problems. Adequate fiber of sufficient particle size is needed to maintain rumen function, prevent acidosis and displaced abomasum, and achieve high DMI. On the other hand, excessive neutral detergent fiber (**NDF**) content may limit intake. Sufficient nonfiber carbohydrates (**NFC**) (sugars and starch provided by grains) must be present to provide adequate energy in the form of propionic acid for glucose synthesis and to suppress synthesis of ketone bodies.

Recently, considerable emphasis has been placed on increasing the starch content of close-up or pre-fresh groups (Grummer, 1995; Minor et al., 1998; VandeHaar et al., 1999). Starches promote ruminal production of propionate, which triggers insulin release and helps restrain body fat mobilization. Increasing starch also tends to improve total DMI over just forages alone (Grummer, 1995). Another benefit of additional grains in the prepartum diet is to adapt the ruminal tissues and the rumen microbial population to the type of diet that will be fed after calving (Goff and Horst, 1997). Grain feeding increases length of the rumen papillae in comparison to feeding only poorly digestible roughages (Dirksen et al., 1985). It has been proposed that rumen papillae elongate in the presence of increased concentrations of volatile fatty acids, thereby increasing the absorptive surface in the rumen and helping to prevent acidosis after calving. However, recent research has indicated that this may not be a large factor in transition success of cows fed more typical close-up diets (Andersen et al., 1999).

Other methods exist to increase energy intake by pre-fresh cows. Simply using higher-quality forages can have a major impact on ration energy density. High-fiber by-product feeds such as soy hulls, beet pulp, corn gluten feed, and wheat mids that are highly digestible also can improve total energy intake. While fermentation of fibrous feeds typically is thought to result in more acetate than propionate production in the rumen, greater fermentability still increases supply of propionate for glucose production. Relative effects of cereal grains and corn silage versus highly digestible fibrous concentrates and higher quality grass or legume forages is a topic of current research.

The proper particle size of chopped forages has not been well defined through research. Use of on-farm particle sizing devices, such as the Penn State Separator, has become prevalent but guidelines for transition cows have not been established. Illinois recommendations (Hutjens, 1997) for TMR are that more than 10% of the particles (by weight) should remain on the top screen and 30 to 50% should remain on the middle screen, resulting in less than 50% in the bottom pan. For transition cows, the amounts in the top and middle screen fractions may need to be 10 to 20% greater to ensure optimal rumen function and prevention of off-feed problems. If particle size is less than desired, such as when feeding all ensiled forages, it may be beneficial to add 1 to 2 lb of chopped straw to help maintain the rumen fiber

mat. Feeding 3 to 5 lb of high-quality long hay with the TMR after calving may help to ensure proper rumen function and avoid acidosis problems.

Protein

The requirements for protein by transition cows have been reviewed recently in the new NRC publication (NRC, 2001). An overall summary of the scientific literature as well as factorial calculation of protein requirements indicates that mature cows likely need less than 12% CP, as specified by the previous edition (NRC, 1989) for dry cows, during the closeup period. Accounting for all known metabolic needs for amino acids indicates that this amount should be more than sufficient for body needs (Bell, 1995). Research generally has demonstrated little benefit of greater amounts of dietary protein for mature close-up cows (NRC, 2001), but first-calf heifers may benefit from 15 to 16% CP (Van Saun et al., 1993; Santos et al., 2001) because of their lower DMI and higher amino acid requirements for growth.

Because microbial protein production is critically dependent on carbohydrate availability, CP is a poor predictor of the amount of amino acids actually available for absorption. The metabolizable protein system as predicted by various models (NRC, 2001; Cornell Net Carbohydrate and Protein System) is more useful for evaluating protein supply from diets. An example of the potential power of such systems is shown in Table 1. Putnam and Varga (1998) measured nitrogen balance in peripartum cows before calving. Cows fed diets that differed in CP intake by over 40% showed no differences in nitrogen retention. However, predicted metabolizable protein intake differed among treatments by less than 12%, because of corresponding changes in dietary carbohydrate composition. Likewise, an experiment by Putnam et al. (1999) showed differences of CP intake of 39%, yet predicted metabolizable protein supply was only 14% higher in cows fed the higher CP diet. Differences attributable to greater non-fiber carbohydrate content (starch) also may be confounded by resulting differences in metabolizable protein supply. For example, Minor et al. (1998) showed improvements in intake and lower NEFA when cows were fed a high (43.8% of DM) versus a standard (23.5%) NFC diet before calving. However, the predicted metabolizable protein supply was 32% greater for the high NFC group, which raises the question of whether at least a portion of the perceived benefits of the high NFC diet was actually attributable to an improved supply of metabolizable protein.

The rapidity of the increase in glucose demand for milk production at calving places a strain on the ability of the cow to provide that glucose. Feed intake, and therefore propionate supply, increases more slowly than milk production. During the first week after calving, we estimate that the supply of glucose from fermentation of dietary carbohydrates consumed may fall short of glucose demands by as much as 500 g/d (Drackley et al., 2001). Glucogenic amino acids likely contribute to making up this shortfall. In support of this idea, we have recently measured, by indirect methods, a three-fold increase in rate of muscle protein mobilization during the first week after calving compared with prepartum values (Overton et al., 1998). Likewise, the capacity of liver tissue to convert alanine, an important glucogenic amino acid, into glucose was 198% of prepartum (21 d before calving) values on d 1 after calving, whereas capacity for conversion of propionate to

glucose was increased by only 119% (Overton et al., 1998). In practical terms, this emphasizes the importance of protein nutrition and suggests that as much as 1 lb of protein per day may be needed to supply glucose needs in the immediate postcalving period.

Fat

Because of its high energy density, supplemental fat would seem to be a logical ingredient for minimizing the negative energy balance around and after calving, but increasing evidence indicates that cows may not respond as expected during the transition period. A summary of available research indicated that fat supplementation during early lactation decreased DMI by an average of 0.66 lb/day but the response was variable among studies. (Chilliard, 1993). Furthermore, supplemental fat appears to be ineffective at suppressing body fat mobilization in early lactation (Chilliard, 1993). Fat supplementation does not seem to increase milk yield until after the first few weeks of lactation (Grummer, 1995). Consequently, high amounts of supplemental fat are not recommended in the fresh cow ration. It is possible to implement this recommendation if a separate fresh cow group exists, but it is difficult in the absence of such a group.

Our research group has been interested in the potential use of supplemental fat during the dry period to restore body condition to thin cows and as a possible modifier of metabolism. We (Grum et al., 1996) attempted to add body condition to cows that

Table 1: Relationships between dietary supplies of crude protein (CP) and metabolizable protein (MP) predicted using CPM Dairy [1]

Experiment	CP			MP	
	% of Diet DM	g/d	% change	g/d	% change
Putnam and Varga, 1998	10.6	1166	....	1015	....
	12.7	1422	22.0	1083	6.7
	14.5	1638	40.4	1135	11.8
Putnam et al., 1999	13.3	1357	....	985	....
	17.8	1887	39.0	1121	13.8
Minor et al., 1998	14.4	1469	....	892	....
	13.2	1716	16.8	1177	32.0

[1]T. R. Overton, 2000 (personal communication)

dried off with body condition ≤3.5 on a 5-point scale.

During the dry period, cows (10 per group) were fed

one of three diets for ad libitum intake. The control diet contained 70% chopped grass hay and 30% concentrate and had a calculated NE_L of 0.58 (**Mcal**). The two high-energy diets contained 0.65 Mcal/lb, with the increased energy supplied either from fat (choice white grease, 6.5% of dietary DM) or additional concentrate. All cows were fed the same transition diet for the last 7 days before expected calving, consisting of 2/3 grass hay and 1/3 lactation TMR. Because of poor forage quality, we were not successful in increasing body condition during the dry period; cows fed fat during the dry period actually lost body condition because DMI was depressed (Grum et al., 1996).

Surprisingly, however, accumulation of triglyceride in the liver 1 day after calving was essentially abolished in cows fed the fat-supplemented diet during the dry period, averaging 7.3, 1.4, and 5.9% of wet weight for cows fed control, fat-supplemented, and high-grain diets, respectively. This decreased fat was accompanied by a smaller increase in plasma NEFA concentration around calving and changes in the ability of the liver to metabolize mobilized NEFA. Because nutrient intakes were decreased in the fat-supplemented group, we could not say with certainty that the fat supplementation was the cause of the altered fat metabolism. In a follow-up study (Douglas et al., 1998), cows were fed diets of equivalent energy density with or without supplemental fat, each at ad libitum or restricted intake. Results showed that feed intake during the dry period (ad libitum vs. restricted) had a greater effect than diet composition.

Other studies in which supplemental fat was fed at more typical levels before calving have not shown responses in DMI or milk production (Skaar et al., 1989; Allen et al., 1995; Salfer et al., 1995; Burhans and Bell, 1998). Feeding 1 lb/d of supplemental fat to feed-restricted nonlactating cows did not prevent fat accumulation in the liver (Bertics and Grummer, 1999). Although our results indicate that high rates of fat supplementation may trigger metabolic responses, results from other studies indicate that more typical and economically feasible supplementation rates likely will neither benefit nor harm cows during the transition period.

Body Condition

It is well known that overconditioned cows (>4.0 on a 5-point scale) are at greater risk for development of metabolic problems (Morrow, 1976; Fronk et al., 1980; Van Den Top et al., 1995). Overconditioned cows have poorer DMI after calving (Bines and Morant, 1983; Fronk et al., 1980) and readily break down their large stores of body fat. Obesity leads to increased susceptibility of the complex of metabolic disorders and infectious diseases known as the *fat cow syndrome* (Morrow, 1976) and should be avoided.

Ferguson and Otto (1989) concluded that cows whose body condition falls below 2.5 have decreased milk production and reproductive problems. They suggested that cows scoring 3 at calving would produce amounts of milk similar to cows scoring 4 at calving, but only if postpartum rations are of high quality and intake is truly ad libitum. These conditions often are not met in the field; consequently, milk production will drop if body energy reserves are insufficient. For most managers, a body condition score at calving of about 3.5 appears to be a suitable compromise between adequate and excessive body condition. Assuming that fresh cow management is good, a thinner cow should have a better appetite after calving than a heavier cow.

In a recent experiment (Douglas et al., 1998), we fed two diets during the dry period either at ad libitum intake or at restricted intake. Diets contained the same calculated energy density (NE_L of 0.65 Mcal/lb) and were either high fat or control. Cows fed ad libitum consumed about 157% of NRC (1989) requirements for dry cows and restricted cows were offered only enough feed to meet 80% of NRC recommendations. Body condition score at dry-off averaged about 3.0 (5-point scale). Cows fed either ration ad libitum gained about 0.2 body condition score units during the dry period, whereas restricted cows lost about 0.5 body condition units from dry-off to calving. Cows fed either ration in restricted amounts had less triglyceride in liver on day 1 after calving, and had faster rates of DMI increase after calving. Cows fed for ad libitum intake during the dry period produced about 4.5 lb/d less than restricted-fed cows (not significant). Of interest is that cows in both ad libitum and restricted groups reached the same body condition by about 5 wk after calving.

Results of this experiment indicated that under our controlled conditions, there was no advantage to feeding higher-energy diets during the dry period to try to add body condition to cows in moderately thin body condition going into the dry period. Earlier

research also supports this concept (Kunz et al., 1985). However, it must be noted that no close-up diets were fed in this experiment and that cows were housed individually in tie-stalls during the dry period.

Feeding Management

How transition cows are fed may be as important as what they are fed. Knowledge of factors impacting feeding behavior and DMI during the transition period lags behind other areas (Grant and Albright, 1995). Easy access to fresh and high-quality water is critically important for transition cows and becomes more so during heat stress conditions. Water is the single most important nutrient but often is the most neglected. Watering devices must be kept clean. Transition cows should not have to walk long distances to obtain water.

Feed intake under group-housing conditions should be truly ad libitum during the close-up and just-fresh periods. Producers must be aware that unless about 10% or more feed is left in the feed alley or bunk every day, cows will not be achieving maximal DMI. During the transition period, feeding to ensure 5 to 10% refusals will be worth the extra labor and cost. Likewise, all cows, including fresh cows, timid cows, and first-calf heifers, must have ample bunk space to eat whenever they want. Feed should be kept fresh, with feed alleys cleaned daily to prevent buildup of spoiled or moldy feed. This is especially important in hot climates where feed quickly goes out of condition. Grouping strategies are important to ensure that some cows are not deprived of feed due to social stresses from over-aggressive herdmates (Grant and Albright, 1995). Disruptions of social structure following introduction of new cows to groups and departure of others typically last less than 7 d (Stokes, 2001); however, the impact of social disruption in close-up groups where individuals are continually moved in and out may be much greater.

Cow Comfort and Environmental Stress

It is difficult to present scientifically defensible definitions and specifications for what constitutes *cow comfort*, but there is no doubt that good managers *know it when they see it*. The transition period and its metabolic challenges constitute a potentially stressful period for the dairy cow, if stress is defined as the impacts of external stimuli (physiological, environmental, psychological) that challenge homeostasis (Moberg, 1985). Cows face a major challenge to maintain homeostasis during the sudden and marked increase of nutrient requirements for milk production at a time when feed intake, and thus nutrient supply, lags far behind. The metabolic constraints imposed by decreased DMI as parturition approaches, coupled with the immunosuppression that occurs during this time (Mallard et al., 1998) and other stressors associated with calving and the start of lactation, likely contribute to the high incidence of infectious diseases and metabolic disorders encountered during the transition period. While many of the changes represent the concept of *homeorhesis* in adaptation to lactation (Bauman and Currie, 1980), these responses may be modulated by additional stressors encountered during the transition period.

In addition to the metabolic challenges and potential for nutritional stress if transition nutrition is sub-optimal, transition cows may face additional environmental stressors (Grant and Albright, 1995). These may include heat stress, overcrowding, infectious challenge, poor ventilation, poor footing, uncomfortable stalls, poor management of grouping and cow movement, and rough handling. The effects of heat stress on dairy cattle physiology and productivity have been well established. Periparturient cows may be unduly affected by heat stress conditions (Huhnke and Monte, 1976), leading to greater drops in pre-calving intake and slower increases of DMI after calving. Collier et al. (1982) studied the effects of heat stress during late gestation on calf birth weight and subsequent milk production. Dry cows provided with shade had heavier calves and produced more milk than cows not provided with shade. Investments in shading and cooling for transition cows (close-up and fresh groups) likely will pay large dividends in hot climates.

Biological response criteria to other forms of stress, such as crowding, poor ventilation, poor footing, and poor stall design, have not been well established for dairy cows. Furthermore, little is known in general about the effects of stress during the transition period. While overcrowding is common in free-stall barns, overcrowding should be avoided in the close-up and just-fresh pens (Grant and Albright, 1995). Every cow needs to have a comfortable stall to lie in. Cows naturally seek to isolate themselves from other cows as parturition approaches; in such animals the inability to do so in confinement constitutes a major social stress (Moberg, 2000).

The role of immune activation from the environmental pathogen load has generally been ignored in dairy production other than in relation to mastitis. In swine production, it is well known that pig growth and feed efficiency are higher in *clean* environments than in *dirty* environments. Pigs raised in a clean environment with minimal exposure to pathogens had greater rates of gain, improved feed efficiencies, and a greater lean-to-fat ratio than pigs raised in the presence of a high degree of pathogen exposure (Williams et al., 1997). Such responses are probably attributable both to increased nutrient demands by the immune system and to the anti-growth effects of cytokines produced by the activated immune system. Products of the activated immune system, such as the cytokines, can have marked impact on metabolic pathways of lipid, glucose, and amino acid metabolism that could be detrimental to adaptation to lactation (Johnson et al., 1997).

Stressors could impact dairy cows during the transition period in several ways. First, DMI may be decreased. Second, nutrients may be diverted away from the critical functions of fetal growth, lactogenesis, and preparation of support functions for lactation to support the stress response. Third, activation of the sympathetic nervous system and release of the stress hormones, such as glucocorticoids and epinephrine, generally are antagonistic to milk production. Fourth, hormones and cytokines associated with the stress response may decrease secretion of hormones important for lactogenesis, such as growth hormone. Fifth, many stressors result in activation of lipolysis and thus increase NEFA concentration, which leads to fat infiltration in the liver. Sixth, environmental or behavioral stressors may cause suppression of immune function, leading to increased susceptibility to infectious disorders. Finally, products of the activated immune system, such as the cytokines, lead to disruption of the normal metabolic adaptations to lactation and lead to wasting of muscle tissue, increased fat mobilization, and increased fat deposition in the liver (Johnson et al., 1997; Ingvartsen and Andersen, 2000).

The principles involved in response of animals to environmental stresses have been eloquently described by the late Gary Moberg (Moberg, 2000), who most recently defined stress as "the biological response elicited when an individual perceives a threat to its homeostasis". The stress response consists of recognition of a stressor, the biological defense against the stressor, and the consequences of the stress response. It is this last stage of the stress response that determines whether an animal's productivity is compromised (the stress becomes *distress*) or whether the event passes without impact. The stress response begins with the central nervous system perceiving a threat to homeostasis. Whether the stimulus is actually a threat is immaterial and the response depends on the sensory perceptions; in this way psychological stress may be detrimental (Moberg, 2000). In response to the stimulus, the organism mounts a response consisting of some combination of behavioral modification, the autonomic nervous system, the neuroendocrine system, and the immune system.

In many cases the expedient response of an animal is behavioral, by attempting to remove itself from the vicinity of a stressor. For example, a timid cow will move away from the perceived threat of a boss cow. When this behavioral response is prevented or limited, say by overcrowding in confinement housing, then the timid cow may be more likely to be negatively impacted from a physiological perspective. The neuroendocrine system responds with altered secretion of pituitary hormones in an attempt to restore homeostasis (Buckingham et al., 1997). Alterations in neuroendocrine function in response to a stressor affect nearly all functions of animal production, including metabolism, reproduction, lactation, immune competence, and behavior. These alterations include not only the classic neuroendocrine response to stress, the ACTH-mediated release of cortisol, but also may include changes in the pituitary secretion of prolactin, growth hormone, thyroid-stimulating hormone, and the gonadotropins (Moberg, 2000).

All of the systems invoked to deal with stress produce changes in biological function, and it is these changes that may directly affect the animal's well-being and productivity. The changes result in shifts of nutrients away from biological processes occurring before the stressor. For example, energy being used for growth in a first-calf heifer may be diverted to cope with the stressor. For many day-to-day stressors, this biological cost of the stress response is inconsequential. However, with prolonged or severe stress, or with multiple stressors, the biological cost of dealing with the stress becomes significant to the animal. The stress response may divert so many resources that the animal is placed at risk for developing various pathologies, such as infectious disease. A common example in animal production is the increased incidence of respiratory infection

(shipping fever) that results from long-haul transport of cattle (Blecha, 2000). Individual cows respond differently to stressors (Hopster et al., 1998) and the responses may vary with the extent, duration, and severity of the stressor (Hydbring et al., 1999).

It is now well accepted in the field of stress physiology that the cumulative effects of multiple stressors are additive. For example, calves grazing endophyte-infected fescue were affected by the toxin, as shown by significant decreases in plasma prolactin. When calves were challenged with endotoxin to simulate infection, responses in plasma cytokines and cortisol were significantly greater in the calves that were grazing the toxic fescue (Filipov et al., 1999). Thus, deficiencies in management that individually would not have major impact on dairy cow health and productivity (i.e., subclinical stressors) may sum to result in pronounced negative effects. For example, one might envision that the multiple stressors of overcrowding first-calf heifers with mature cows in the close-up pen of an uncooled barn during heat stress conditions might be disastrous for the heifers.

The emerging scientific field of *psychoneuroimmunology* recognizes that the immune system and the neuroendocrine system are tightly and intimately linked (Neveu, 1997). In this way, the central nervous system and neuroendocrine system can directly influence the immune system. Furthermore, activation of the immune system can impact central controls of metabolism and behavior. In turn, metabolic control mechanisms can impact the ability of the immune system to respond appropriately to infectious challenges (Johnson et al., 1997). Additionally, stressors can activate the immune system without the presence of infectious challenge (Faith et al., 1999). The potential roles of stress and immune challenge during the transition period in determining metabolic changes, postpartum feed intake (Ingvartsen and Andersen, 2000), and incidence of health disorders would seem to be of enormous importance, and should be investigated.

Conclusions

The transition period is a time of considerable metabolic adjustment for dairy cows. Sub-optimal nutrition during this time period may impart nutritional stress on the cows that may be manifested as one or more of the common periparturient disorders. Attention must be given to formulating appropriate diets for cows during the far-off and close-up dry periods and for the fresh cow. The

newly released NRC guidelines (NRC, 2001) provide a solid foundation for feeding close-up cows. Cows should not be fed high-starch diets throughout the entire dry period. In addition to ration formulation and monitoring, feeding management and grouping strategies may impact transition success. Finally, emerging concepts in stress physiology indicate that biological effects of multiple stressors are additive and may be a critical factor in the high incidence of health problems and poor transition success in some herds. Attention to keeping cows as comfortable as possible during the transition likely is as important as the nutritional management program.

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