New Concepts in Nutritional Management of Transition Dairy Cows

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The importance of managing cows for transition period success is unquestioned in the dairy industry. Large amounts of research have been conducted during the past 10 to 15 years regarding various aspects of transition period nutrition and health, including various dietary strategies and use of different additives and compounds designed to facilitate the cow’s adaptation to lactation (reviewed by Overton and Waldron, 2004). Despite this research and simultaneous outreach focus to the dairy industry, the transition period remains a problematic area on many commercial dairy farms, and metabolic disorders continue to occur at economically important rates (Burhans et al., 2003). Certainly, there are situations in which we have full understanding of the nutritional approaches required on a dairy farm, yet have difficulty with day to day implementation of sound management practices. However, we still lack substantial definitive understanding of certain aspects of transition biology (e.g., metabolic regulation, immune function, and stress biology) and their implications for transition cow success, together with potential interactions with nutritional management of dairy cows during this timeframe.

The dramatic metabolic changes in demands for macrominerals, glucose, amino acids, and fatty acids that occur during the transition period together with the adaptations that occur in metabolism of the liver, body fat, and other tissues in support of these metabolic demands have been well-reviewed over time (Grummer, 1993; Bell, 1995; Grummer, 1995; Goff and Horst, 1997; Drackley, 1999; Overton and Waldron, 2004). Rather than rehashing the contents of those reviews in this paper and other previous papers focused on comprehensive aspects of nutritional management of transition cows, we will focus on defining our emerging knowledge of key aspects of metabolic regulation in transition cows along with the implications that specific aspects of nutritional management have on this regulation. Furthermore, we will highlight specific recent research conducted by our research group and others with implications for macromineral nutrition of cows during the prepartum period.

Key aspects of metabolic regulation in transition cows

It is well-recognized that the dairy cows undergo important metabolic adaptations during late pregnancy to support fetal demands and at the onset of lactation to support milk production. These homeorhetic adaptations involved in the regulation of nutrient and energy partitioning during late pregnancy and early lactation occur in a variety of target tissues, and typically involve changes in responses of tissues such as adipose tissue and muscle to homeostatic signals such as insulin and epinephrine (Bauman and Currie, 1980; Bell, 1995). One major adaptation

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includes a large increase in glucose demand by the mammary gland that is supported by
dramatically increased glucose output by the liver (Reynolds et al., 2003). In addition, peripheral
tissues (primarily skeletal muscle) decrease their use of glucose for fuel (Bauman and Elliot,
1983; Petterson et al., 1993), thereby sparing glucose for use by the gravid uterus and lactating
mammary gland. Furthermore, increased mobilization of body fat stores facilitated by changes
in adipose tissue metabolism contributes to meeting increased whole-body needs for energy at
the onset of lactation (Petterson et al., 1994). The net result of these adaptations is coordinated
support of fetal needs and subsequent high milk production in the face of decreasing and
eventually insufficient dry matter intake (DMI) during late pregnancy and early lactation.

Insulin resistance in transition dairy cows

These changes in tissue metabolism that occur in dairy cows during the transition period are
mediated largely by changes in responses to hormonal signals such as insulin. Decreased
responses of these tissues to insulin are referred to in general terms as insulin resistance. As
referenced above, some aspects of insulin resistance (such as those related to skeletal muscle) are
very favorable for support of pregnancy and lactation because of glucose sparing for the fetus
and lactating mammary gland (Bell, 1995). At the same time, we believe that insulin resistance
in adipose tissue contributes to the increasing circulating concentrations of nonesterified fatty
acids (NEFA) and decreasing dry matter intake (DMI) as cows approach calving (Figure 1).
Allen et al. (2005) suggested that the increased circulating concentrations of NEFA during late
pregnancy and subsequent oxidation of these NEFA by the liver is the cause of the decreased
DMI as cows approach calving. Although direct evidence of this cause-effect relationship in
transition cows is lacking, this concept would help to explain the typical patterns of NEFA and
DMI measured in dairy cows as they approach calving. This relationship of NEFA and DMI is
associated with all periparturient health disorders with etiologies based in energy metabolism,
immune function, or both (displaced abomasum, ketosis, fatty liver, retained placenta, metritis,
and mastitis).

![Figure 1. Relationship between DMI and plasma NEFA concentration during the transition
period (Smith, 2004).](image-url)
Several years ago, we became interested in further understanding the nature and timing of insulin resistance, with specific focus on determining whether the relationships of NEFA and DMI could be modulated during the transition period. Initial research conducted in our lab (Smith, 2004) suggested that adipose tissue in periparturient dairy cows actually may be more refractory to insulin during the prepartum period than during the postpartum period. Subsequent work also generally supported the concept that insulin resistance may be greater during the prepartum period than the postpartum period (Smith et al., 2006).

As a result of this work and other circumstantial evidence that accentuated insulin resistance during the prepartum period contributes to lower peripartal DMI, elevated NEFA concentrations, and increased body condition score (BCS) loss during early lactation, we wanted to determine whether specific modulation of insulin resistance in adipose tissue during the prepartum period would decrease NEFA mobilization and change the patterns of DMI and NEFA during the transition period. Using an experimental approach, we administered compounds (thiazolidinediones; TZD) analogous to those used to treat Type II diabetes in humans to dairy cows during the prepartum period. In the first study, TZD administration tended to decrease circulating concentrations of NEFA and tended to increase DMI during the period from 7 days before calving until 7 days after calving (Smith et al., 2007). Importantly, TZD administration did not appear to interfere with the glucose sparing by peripheral tissues that is important for support of pregnancy and lactation.

In a second study (Smith, 2008) conducted using larger numbers of cows, we replicated the results of the first experiment in that TZD administration during the prepartum period decreased circulating NEFA concentrations and increased DMI during the immediate pre- and postpartum periods. In addition, TZD administration improved postpartum energy balance, decreased BCS loss, and decreased days to first ovulation in treated cows. These results suggested that specific modulation of insulin resistance in adipose tissue could have very positive effects on metabolic changes during the transition period and have substantial carryover effects on the dynamics of metabolism and performance during early lactation. It should be noted that this work was conducted as proof of concept relative to the mechanisms of metabolic regulation; TZD currently is not available in a form that can be used practically in the dairy industry and would require FDA approval before such use.

**Nutritional management during the prepartum period and its relationship to insulin resistance and health**

Although modulation of insulin resistance using pharmaceutical approaches is intriguing, it causes us to ask questions regarding which aspects of nutritional management may influence insulin resistance. During the past few years, energy nutrition of cows during the dry period has received substantial renewed attention (Drackley and Janovick-Guretzky, 2007) and an increasing body of information suggests that energy nutrition may interact with insulin resistance during the late prepartum period.

For many years, the emphasis of researchers and industry professionals was to maximize dry matter intake in order to ensure that cows consumed enough energy during the dry period. This strategy was supported in part by research that demonstrated that cows with lower NEFA
concentrations during the last two weeks before calving on commercial dairy farms had 
decreased incidence of most postcalving metabolic disorders (displaced abomasum, ketosis, 
retained placenta, mastitis; Dyk, 1995). Given that higher DMI typically results in lower 
circulating NEFA, the association between higher DMI and improved health and performance 
was implied. Our experience would suggest that many farms indeed had improved health and 
performance when management changes were implemented that increased DMI of cows, 
particularly during the close-up period.

On the other hand, increasing evidence suggests that plane of nutrition, in particular energy 
intake during the prepartum period, modulates the degree of insulin resistance and hence the 
relationships between NEFA and DMI during the immediate peripartal period. Mashek and 
Grummer (2003) reported that cows that had larger decreases in DMI during the prepartum 
period, generally because of higher DMI during weeks 3 and 4 before calving, had higher 
centrations of plasma NEFA and liver triglycerides during the postpartum period. More 
direct experimental evidence was provided by Douglas et al. (2006), who reported that cows fed 
at 80% of calculated energy requirements for the entire dry period had lower NEFA 
centrations during the postpartum period, lower concentrations of both circulating glucose 
and insulin during the prepartum period, and higher DMI during the postpartum period than 
cows consuming 160% of predicted energy requirements throughout the dry period. Similarly, 
Holcomb et al. (2001) reported that cows subjected to feed restriction during the late prepartum 
period had blunted NEFA curves during the periparturient period. In addition, Holtenius et al. 
(2003) determined that cows that were dramatically overfed (178% of calculated energy 
requirements) for the last 8 weeks before calving had higher concentrations of insulin and 
glucose during the prepartum period, greater insulin responses to glucose challenge during the 
prepartum period, and higher concentrations of circulating NEFA during the postpartum period 
than cows fed for 75 or 110% of calculated energy requirements. Furthermore, Agenas et al. 
(2003) reported that the same cows fed for 178% of calculated energy requirements prepartum 
had lower DMI and prolonged negative energy balance during the postpartum period compared 
with cows assigned to the other two prepartum treatments. Recently, Dann et al. (2006) 
demonstrated that overfeeding (150% of calculated energy requirements) during the far-off 
period may have exacerbated insulin resistance as cows approached calving, resulting in higher 
NEFA and BHBA and lower DMI and energy balance during the first 10 days postcalving.

This knowledge has led to an evolution in recommendations for energy nutrition of dairy cows 
during both the far-off and close-up periods during the past several years, with the goal of 
meeting, but not dramatically exceeding, energy requirements. In practice, this can be achieved 
by formulating diets during the far-off period to contain no more than 0.59 to 0.63 Mcal/lb of 
NEL in order to achieve the target NEL intake of approximately 16 to 18 Mcal during this 
timeframe. During the close-up period, conventional recommendations as described above have 
been to maximize DMI, and hence energy intake. Although this still applies in many herd 
situations, we believe that some well-managed herds in which close-up cows consume large 
amounts of feed (> 30 to 32 lb/day of dry matter in comingled cow/springing heifer groups) have 
increased rates of metabolic disorders because of excessive energy intake during the close-up 
period. Accordingly, some of these herds have had success in moderating energy intake during 
the close-up period in group-feeding situations by incorporating straw or other low potassium, 
low energy forage to lower overall dietary energy concentration. Our recommendations would
be to formulate the close-up diet at approximately 0.66 Mcal/lb of NEL if the group is a
commingled cow/heifer group and approximately 0.62 to 0.64 Mcal/lb of NEL if the group is
composed of mature animals and DMI is high. This lower energy diet also can be an acceptable
one-group dry cow approach if overall herd management dictates such an approach. Diets
formulated in these ranges will help to ensure adequate, but not excessive energy intake within
the dynamics of group-feeding and competition among animals.

Diets formulated using a combination of corn silage and straw to form the forage component of
the diet typically can have between 6 and 10 lbs of chopped straw, making feeding management
a critical component of implementation of bulky, low energy dry cow diets. As described by
Drackley (2007), the three key components of this implementation are 1) prevention of sorting,
2) ensuring continuous and non-crowded access to the TMR, and 3) careful monitoring of dry
matter content and attention to detail. Most of these diets will contain added water in order to
aid with prevention of sorting. A final point relative to these types of diets is that it is important
to account for the metabolizable protein requirements of the cow during late pregnancy. These
diets typically contain lower amounts of ruminally fermentable carbohydrate than those that have
been typically fed for the last ten to fifteen years, and therefore will supply less metabolizable
protein from ruminal bacteria. Inclusion of rumen-undegradable protein sources to result in total
metabolizable protein supply in the range of 1,100 to 1,200 g/d is critical for early lactation
performance and overall success.

Macromineral considerations for close-up cows

Most of the research conducted on macromineral nutrition of close-up cows has focused on
prevention of milk fever and related disorders. One of the more interesting relationships in the
epidemiological study of Curtis et al. (1985) was the lack of association of Ca content of the diet
fed prepartum with occurrence of milk fever. Indeed, the NRC (2001) effectively discounted the
potential that diets sufficiently low in Ca to prevent hypocalcemia could be fed during the
prepartum period. In turn, they focused attention on the approach of adjusting cation-anion
difference [[Na⁺ + K⁺] – [Cl⁻ + S⁻²]] to prevent metabolic alkalosis and perhaps induce a
metabolic acidosis. Horst et al. (1997) hypothesized that this correction of metabolic alkalosis
would prevent changes in the conformation of the receptor for parathyroid hormone on bone and
kidney and facilitate mobilization of Ca from bone and vitamin D synthesis. Prepartal diets with
a negative dietary cation-anion difference (DCAD) have repeatedly been shown to reduce
subclinical and clinical hypocalcemia in cows predisposed to milk fever (Block, 1984; Joyce et
al., 1997; Horst et al., 1997).

Currently, debate exists regarding whether sufficient alleviation of hypocalcemia can occur by
decreasing the cation (Na and K) content of the diet fed during the prepartum period alone
without adding anions through mineral or acid (HCl) based sources. Existing research in the
literature is equivocal about whether a reduction in dietary K and a moderate DCAD are
sufficient to avert milk fever or whether herds predisposed to milk fever might benefit from diets
with a DCAD of −10 to −15 meq/100 g of DM. Goff and Horst (1997) indicated a reduction in
dietary K to 1.1% DM was sufficient to avert clinical milk fever in multiparous Jersey cows;
however, the incidence of subclinical hypocalcemia was not reduced. Moore et al. (2000)
reported that cows fed a diet containing a DCAD of 0 meq/100g DM resulted in intermediate
indices of Ca metabolism relative to cows fed diets containing either –15 or +15 meq/100g DM; however, the feeding a diet with a 0 DCAD was not sufficient to prevent parturient hypocalcemia in Holstein cows. Many dairy herds in the Northeast and Upper Midwest have sufficient access to low potassium feeds such as corn silage and some other grass-based forages and thus can decrease dietary potassium concentrations in the close-up diet to 1.3% of DM or less.

We recently reported results of a study conducted to determine whether further reduction of the dietary DCAD in the context of low potassium prepartum diets would improve mineral status in transition cows (Ramos-Nieves et al., 2007). Beginning 21 d before expected calving, control cows were fed a diet with the forage component based on corn silage and wheat straw with dietary potassium level of 1.29% and a calculated DCAD of +10 mEq/100 g of DM. The cows assigned to the anionic supplement treatment were fed the same base diet with anions added as calcium sulfate and a commercially available anionic supplement based on chloride. Potassium levels in this diet also were 1.29%, but the addition of the anionic supplement decreased the calculated DCAD to -15 milliequivalents per 100 grams of dry matter. These diets were fed until calving and then all cows were fed the same lactation diet.

We sampled blood from each cow several times before calving, twice during the first 24 hours postcalving, and daily for the next 5 days after calving in order to fully characterize the effects of treatment on blood mineral status. Feeding the anionic supplements tended to increase blood calcium levels during the first 24 hours postcalving (8.0 vs. 7.1 mg/dL), but did not affect the proportion of cows categorized as clinically or subclinically hypocalcemic. However, feeding the anionic supplements increased blood phosphorus concentrations and decreased the proportion of cows categorized as clinically or subclinically hypophosphatemic during the first several days postcalving. Most previously conducted studies focused only on effects of DCAD blood calcium, but low blood phosphorus also leads to mineral-related down cow problems and so this finding is new and potentially important.

Recently, two meta analyses have been published which support some concepts relative to application of DCAD principles regarding prevention of milk fever and challenge some other concepts relative to macromineral nutrition during the prepartum period. It is important to remember that meta analyses are excellent tools to integrate literature and derive testable hypotheses, but it can be tenuous to use them as evidence of mechanistic biology. Charbonneau et al. (2006) determined, that of the many equations proposed over time to calculate DCAD, the equation discounting sulfur \([\left[\text{Na}^+ + \text{K}^+\right] - \left[\text{Cl}^- + 0.6 \text{S}^{2-}\right]\] (Goff et al., 2004) was the most highly associated with clinical milk fever and urinary pH (interestingly, the equation explained more variation in urine pH than it did in milk fever occurrence). Furthermore, the authors proposed a more modest target for urine pH (7.0) than that generally proposed (6.0 to 7.0) – this would be more in line with the approach of focusing on decreasing cations and then partially supplementing anions to the prepartum diet.

In the other meta analysis, Lean et al. (2006) supported the \([\left[\text{Na}^+ + \text{K}^+\right] - \left[\text{Cl}^- + \text{S}^{2-}\right]\] equation for application to milk fever, but proposed that increasing prepartum dietary Ca concentration to approximately that proposed in this paper (0.9 to 1.0% of DM) would actually increase milk fever incidence. Furthermore, increasing Ca concentration to very high concentrations (2.0 to 2.5% of DM) would result in very low milk fever incidence, similar to very low (unrealistically
low) Ca concentrations. Moore et al. (2000) determined that increasing Ca concentration while simultaneously decreasing DCAD resulted in improved DCAD status. Chan et al. (2006) reported that Ca concentrations of either 0.99 or 1.50% of the prepartum diet in conjunction with an anionic salt supplement maintained serum Ca at adequate levels around calving. Although this is an area that requires further study, we are comfortable with the recommendation of supplementing Ca to the prepartum diet, regardless of DCAD strategy.

Lean et al. (2006) also associated increasing Mg concentrations of the prepartum diet with sharply associated decreases in milk fever risk. Others (Jittakhot et al., 2004) have shown that high dietary K concentrations interfere with Mg absorption of the rumen, thus we would predict positive results from decreasing dietary K and supplementing Mg prepartum. Lean proposed that increasing dietary P concentrations from 0.3% to 0.4% of DM in the prepartum diet would increase risk of milk fever by 18%. This is consistent with data from Peterson et al. (2005), who determined that serum Ca was lower before calving through 2 d postpartum for cows fed 0.44% P compared to 0.21 or 0.31% P during the prepartum period.

Summary and conclusions

Success in transition cow programs depends upon excellent management in a number of different areas. Our understanding of the metabolic regulation underpinning the changes that occur in cows during the transition period is increasing, and with this understanding has come new potential opportunities for enhancing transition cow health and performance. Controlling energy intake of cows during the prepartum period (both far-off and close-up) is an important factor in nutritional management of transition cows, as is focus on macromineral aspects of prepartum rations. Although not a focus of this paper, management of nonnutritional factors (stocking density, grouping management, environmental control) is critical as a complement to dietary strategies for transition period success.

References


### General goals for diet formulation for closeup cows and one-group dry cow systems up to 40 days

<table>
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<th>Partial anionic</th>
<th>Full anionic</th>
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<td>NEL, Mcal/kg</td>
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<td>NFC, %</td>
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<td>Starch, %</td>
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<td>140</td>
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<td>Dietary Ca, %</td>
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<td>S, %</td>
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<td>Vitamin E (IU/d)</td>
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Prefer use of organic trace elements, including organic Se