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Impact of Changes in Organic Nutrient Metabolism on Feeding the Transition Dairy Cow[1]

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ABSTRACT: Pregnancy, decreased feed intake during late gestation, lactogenesis, and parturition have dramatic effects on metabolism in dairy cows during the transition period from 3 wk before calving to 3 wk after calving. Increases in plasma NEFA occur during the 10 d before calving and may precede the decrease in feed intake. Plasma NEFA concentrations are highest at calving and decrease rapidly after calving. Plasma glucose concentration decreases during the transition period except for a transient increase associated with calving. Hepatic glycogen is reduced and lipid is increased during the transition period. Feed intake is usually decreased 30 to 35% during the final 3 wk prepartum, but negative energy and protein balances are not as severe as during the week following parturition. Prepartum feed intake is positively correlated to postpartum feed intake; there-fore, efforts to maximize feed intake should begin before calving. Overconditioned cows may be more susceptible to a prepartum decrease in feed intake. Increasing nutrient density of the diet during the transition period may enhance feed intake. Feeding more fermentable carbohydrate during the prepartum transition period may acclimate the microbial population to lactation diets, promote development of ruminal papillae, increase absorptive capacity of the rumen epithelium, and reduce lipolysis by delivering more glucogenic precursor to the liver and enhancing blood insulin. Supplementing fat to transition diets does not seem to alleviate health problems associated with negative energy balance. Enhancing amino acid absorption by the prepartum cow may improve lactation performance and health, although mechanisms of action have not been identified.

Key Words: Dairy Cow, Transition, Stress, Feeding, Parturition, Feed Intake

Introduction

For the purposes of this review, transition period is defined as 3 wk prepartum until 3 wk postpartum. It is a period marked by changes in endocrine status to accommodate parturition and lactogenesis. These changes, which are much more dramatic than at any other time during the gestation-lactation cycle, influence tissue metabolism and nutrient utilization. A reduction in feed intake is initiated during the prepartum transition period, yet nutrient demands for support of conceptus growth and initiation of milk synthesis are increasing. Surprisingly, current feeding guidelines do not acknowledge the predicament of the cow during this time; feed intake and nutrient requirements are assumed to be constant throughout the nonlactating period (NRC, 1988).

Dairy scientists and dairy producers tend to neglect the transition cow, particularly prepartum. Very few research trials have investigated the influence of diet during the final 3 wk prepartum, the first 3 wk postpartum, or a combination of the two periods on subsequent health, lactation, and reproductive performance. Experiments to investigate prepartum nutrition usually begin during the preceding lactation or at dry-off. Trials examining postpartum nutrition typically begin 2 to 3 wk postpartum. Consequently, there is a very small literature base to make conclusions on how to feed the transition cow.

Metabolic Status of the Transition Cow

Plasma insulin decreases and growth hormone increases as the cow progresses from late gestation to early lactation, with acute surges in plasma concentrations of both hormones at parturition (Kunz et al., 1985). Plasma thyroxine (T_4) concentrations gradually increase during late gestation, decrease approximately 50% at calving, and then begin to increase (Kunz et al., 1985). Similar, but less pronounced,

changes occur in 3,5,3'-triiodothyronine (T_3). Estrogen, primarily estrone of placental origin, increases in plasma during late gestation but decreases immediately at calving (Chew et al., 1979). Progesterone concentrations during the dry period are elevated for maintenance of pregnancy but decline rapidly approximately 2 d before calving (Chew et al., 1979). Glucocorticoid and prolactin concentrations increase on the day of calving and return to near prepartum concentrations the following day (Edgerton and Hafs, 1973).

Both changes in endocrine status and decreases in DMI during late gestation influence metabolism and lead to mobilization of fat from adipose tissue and glycogen from the liver. A gradual decline in DMI begins 3 wk prepartum, with the most dramatic decrease occurring during the final week prepartum. The extent of this decrease varies, but a 30% reduction is typical in heifers and mature cows (Coppock et al., 1972; Hernandez-Urdaneta et al., 1976; Johnson and Otterby, 1981; Kunz et al., 1985; Bertics et al., 1992; Emery, 1993; Vazquez-Anon et al., 1994; Grummer et al., 1995). Causes for decreased prepartum DMI are not known but may be endocrine-related. For example, changes in blood estrogen or estrogen:progesterone ratio may influence feed intake (Grummer et al., 1990). Plasma NEFA increase approximately twofold between 17 d prepartum and 2 d prepartum, at which time the concentration increases dramatically until completion of parturition. How much of the initial increase in plasma NEFA (d -17 to -2) can be accounted for by changing endocrine status vs energy restriction resulting from decreased DMI is not known. Force-feeding cows during the transition period reduced the magnitude of NEFA increase but did not completely eliminate it (Bertics et al., 1992). An increase in plasma NEFA was observed before d -1 prepartum in cows that did not experience DMI depression until d -1 prepartum (Vazquez-Anon et al., 1994). These observations indicate at least part of the prepartum increase in plasma NEFA is hormonally induced. The rapid rise in NEFA at calving is presumably due to the stress of calving. Plasma NEFA concentrations decrease rapidly after calving, but concentrations remain higher than they were before calving. The liver is a major site for fatty acid removal from blood (Bell, 1980). Because ruminants do not efficiently export fatty acids as very low density lipoprotein triglyceride (Herdt et al., 1988; Kleppe et al., 1988; Pullen et al., 1988, 1989), a significant amount of the fatty acids taken up by the liver are esterified and stored. By 1 d after calving, the largest increase in hepatic triglyceride has occurred and concentration in the liver remains constant or increases slightly during the postpartum transition period (Skaar et al., 1989; Bertics et al., 1992; Studer et al., 1993; Vazquez-Anon et al., 1994). For unknown reasons, heifers seem to be less susceptible to fatty liver at 1 d postpartum (Grummer et al., 1995;

Christensen et al., 1995a). Plasma ketone concentrations mirror hepatic triglyceride concentrations and may increase during the postpartum transition period until clinical ketosis is experienced. Liver triglyceride:glycogen ratio at parturition may be an indicator of a cow's susceptibility to ketosis (Veenhuizen et al., 1991).

Plasma glucose concentrations remain stable or increase slightly during the prepartum transition period, increase dramatically at calving, and then decrease immediately postpartum (Kunz et al., 1985; Vazquez-Anon et al., 1994). The increase at calving may result from increased glucagon and glucocorticoid concentrations that promote depletion of hepatic glycogen stores. Although the demand for glucose by mammary tissue for lactose synthesis continues after calving, hepatic glycogen stores begin to replete and are increased by d 14 postpartum (Vazquez-Anon, 1994). This probably reflects an increased gluconeogenic capacity to support lactation.

Plasma alpha-amino nitrogen concentrations increase during the transition period except for a transient decrease at calving (Kunz et al., 1985). In the study of Kunz et al. (1985), albumin remained constant throughout the transition period, suggesting protein supply was adequate.

It is clear that the majority of metabolic upheaval associated with the transition period occurs by 1 d postpartum. Many of the undesirable metabolic outcomes among cows that experience turbulent transitions have either taken place by that time or may be "programmed" to take place in the following weeks. For example, hepatic triglyceride has increased, glycogen has decreased, and the magnitude of these changes may predispose cows to clinical ketosis several weeks later (Veenhuizen et al., 1991). If displaced abomasum is related to ruminal fill, then extent of prepartum DMI decrease may be an important factor determining whether the cow develops this disorder. Therefore, it seems logical that diet formulation during the prepartum segment of the transition period should be an important focus to minimize transition stress. Important goals should be to maximize energy intake, reduce fatty acid mobilization from adipose, and prevent excessive depletion of hepatic glycogen.

Nutritional Status of the Transition Cow

Estimates of DMI and nutrient requirements are constant for the entire nonlactating period according to the latest NRC (1988) for dairy cattle. To examine the energy status of transition cows, energy balance was calculated for 11 cows assigned to the control treatment in a previous trial (Bertics et al., 1992). Forage source for the experiment was 50% alfalfa, 50% corn silage. Forage:concentrate ratios were 100:0, 75:25, and 50:50 for the final 4 wk prepartum, d 1 or 2 to

d 5 postpartum, and d 6 to 28 postpartum, respectively. Energy content of the diets was estimated (NRC, 1988) to be 1.51, 1.60, and 1.69 Mcal of NE_l/kg of DM. Two estimates of energy requirements were calculated. One estimate was based on NRC (1988) and the other by a modification of the equation of Moe and Tyrell (1972): $NE_l[Mcal/kg \ BW^{.75}/d] = ((133 + .567e^{.0174t}) \times .6)/1{,}000$, where t is the day of gestation. The differences between the modified equation and Moe and Tyrell's (1972) original equation are that the intercept was changed from 100.8 to 133 to make the maintenance requirement consistent with the NRC (1988) and a multiplication factor of .6 was incorporated to convert from ME to NE_l. According to this equation, energy demands for conceptus growth and development increase as pregnancy advances. Energy requirements for support of gestation (excluding maintenance energy requirements) according to the two systems[2] are illustrated in Figure 1. According to Moe and Tyrell (1972), NRC (1988) underestimates energy requirements during late gestation. The impact of underestimating mean daily energy balance for transition cows in this study (Bertics et al., 1992) is shown in Figure 2a. Both estimates demonstrate that cows are in negative energy balance during the final week prepartum. However, using the model of Moe and Tyrell (1972), negative energy balance is more severe and begins 3 d earlier. These results agree with Zamet et al. (1979a), who observed negative energy balance beginning at 5 d prepartum. Cows in our study (Bertics et al., 1992) were consuming diets with a higher energy density than recommended by NRC (1988; 1.51 vs 1.27 Mcal of NE_l/kg of DM). Energy balance for these cows, assuming the same DMI but consuming diets with 1.27 Mcal of NE_l/kg of DM, is shown in Figure 2b. Negative energy balance is not encountered until the final week before parturition. If energy requirement estimates of Moe and Tyrell (1972) are used, cows are in negative energy balance for nearly the entire prepartum transition period, although the magnitude is quite small until the final week prepartum.

Calculated energy requirements (NRC, 1988), energy intake, and energy balance for the entire transition period are shown in Figure 3. Magnitude of negative energy balance is much greater during the early postpartum period relative to the prepartum transition period. Similar calculations for CP balance (Figure 4) indicate that cows were in a slight deficit for the final 3 d of the prepartum period and the most drastic imbalance occurred after calving.

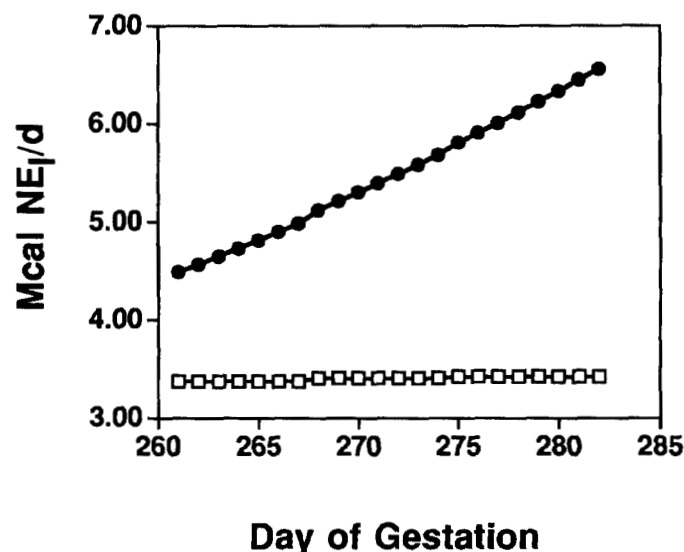Cows received diets containing 14% CP; therefore,

Day of Gestation

Figure 1. Estimated energy requirements for gestation, according to NRC (—□—) or Moe and Tyrell (1972) (—●—), for control cows in the study of Bertics et al. (1992) during the final 3 wk prepartum. The energy requirement for gestation according to Moe and Tyrell (1972) was calculated by the equation: $NE_l[Mcal/d] = ((.567e^{.0174t}) \times .6 \times kg \ BW^{.75})/1{,}000$, where t is the day of gestation. Multiplication of .6 is not in the original equation and was added to convert values from a ME basis to a NE_l basis. The energy requirement for gestation according to the NRC (1988) is .024 Mcal of NE_l/kg $BW^{.75}$/d.

CP balance for the prepartum period was calculated assuming cows had similar intakes but were consuming diets containing 12% CP as recommended by NRC (1988; Figure 5). In this scenario, cows would have reached negative CP balance 5 d before calving. Crude protein requirements were calculated according to NRC (1988) and assumed to be constant over the entire nonlactating period. This notion has been challenged (Van Saun, 1993; Van Saun et al., 1993); CP requirements to support conceptus development during late gestation are more poorly defined than energy requirements. Van Saun (1993) compared several models for estimating net protein requirements for gestation (Figure 6) and concluded that CP recommendations of NRC (1988) may be too low. Therefore, magnitude of prepartum negative CP balance (Figures 4 and 5) may be underestimated.

Estimated energy and CP balance of the control cow that experienced either the least or most severe decrease in DMI between d 21 and 1 prepartum (Bertics, 1992) are shown in Figures 7a and b. Dry matter intake of cow 723 decreased from 13.0 to 2.2 kg/d and DMI of cow 802 from 11.6 to 11.1 kg/d. These data imply that cows that avoid severe DMI decreases before calving have a favorable nutritional balance

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[2]The energy requirement for gestation according to Moe and Tyrell (1972) was calculated by the equation: $NE_l[Mcal/d] = ((.567e^{.0174t}) \times .6 \times kg \ BW^{.75})/1{,}000$, where t is the day of gestation. The energy requirement for gestation according to the NRC (1988) is .024 Mcal of NE_l/kg $BW^{.75}$/d.
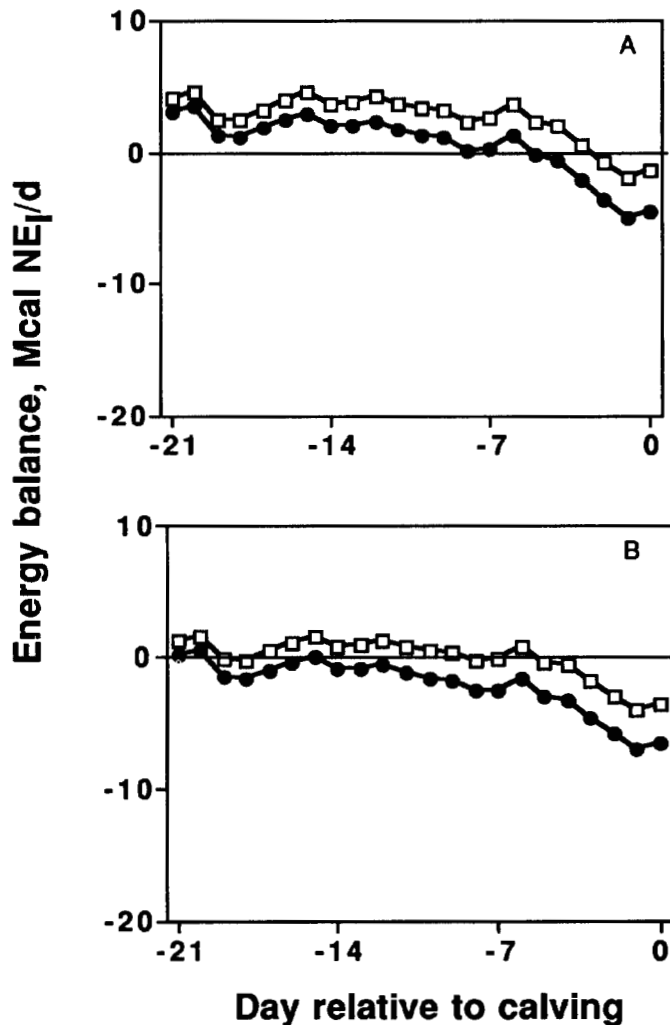
Figure 2. Estimated prepartum energy balance of control cows in the study of Bertics et al. (1992) when they consumed diets containing 1.51 Mcal of NE_l/kg of DM (A) or if they would have consumed an equal amount of DM that contained 1.27 Mcal of NE_l/kg of DM (B). Estimated energy requirements used for calculating energy balance were from NRC (1988) (—□—) or by a modification of the equation of Moe and Tyrell (1972; $NE_l[Mcal/kg\ BW^{.75}/d] = ((133 + .567e^{.0174t}) \times .6)/100$, where t = day of gestation) (—●—). The differences between the modified equation and Moe and Tyrell's (1972) original equation are that the intercept was changed from 100.8 to 133 to make the maintenance requirement consistent with the NRC (1988) and a multiplication factor of .6 was incorporated to convert from ME to NE_l.

before and after calving and those that go almost completely off feed experience an extended period of negative nutrient balance during the transition period.

The previous description of the metabolic and nutritional status of transition cows highlights a very

important point. Feed consumption by the typical transition cow decreases 30% before calving, leading to a negative nutrient balance. The relative magnitude of this reduction is small compared to that encountered during the 1st wk postpartum. The most dramatic changes in endocrine status, metabolism, and blood metabolite profiles are associated with parturition and the onset of lactogenesis and are experienced before the period of most severe negative nutrient balance. The magnitude of these changes probably plays an important role in determining the amount of stress a cow experiences during the transition period, as well as her health and productivity during the early postpartum period. The influence of nutrition on the magnitude of these changes is largely unknown.

Benefits from Increasing Dry Matter or Energy Intake During Transition

If transition feeding is important, then perturbations in nutrition during this period should affect lactation, health, and reproductive performance. Very few studies have specifically examined the influence of DM or energy feeding during the transition period on these parameters. Consequently, few data are available to document the importance of transition feeding.

Path analysis and logistic regression were used to examine relationships between energy feeding during the final 3 wk prepartum and metabolic and reproductive disorders of 1,374 multiparous Holstein cows in 31 commercial herds in central New York (Curtis et al., 1985). Feeding energy above NRC recommendations decreased the risk of displaced abomasum and dystocia. The authors speculated that benefits of increased prepartum energy feeding were attributable to microbial adaptation to higher concentrate feeding and fewer problems associated with acidosis rather than to a direct effect of higher energy on postabsorptive metabolism.

Liver triglyceride of cows force-fed via ruminal fistulas to maintain feed intake before calving increased only 75% between d 17 prepartum and d 1 postpartum compared with 225% for control cows allowed to experience feed intake decrease (Bertics et al., 1992). The correlation between DMI at 1 d prepartum and liver triglyceride was −.80. A time × treatment interaction ($P < .12$) for milk production was observed, which suggested force-fed cows were exhibiting an advantage in milk production as lactation progressed. Force-fed cows also produced milk with a higher fat percentage (4.22 vs 3.99, $P < .05$). Characteristics of the two control cows (723 and 802) from this experiment representing extremes in DMI decrease and nutrient balances (see previous discussion) were examined. In addition to having lower feed intake prepartum, cow 723 had higher liver triglyceride (35 vs 3%, DM basis) and NEFA (1,392 vs 667
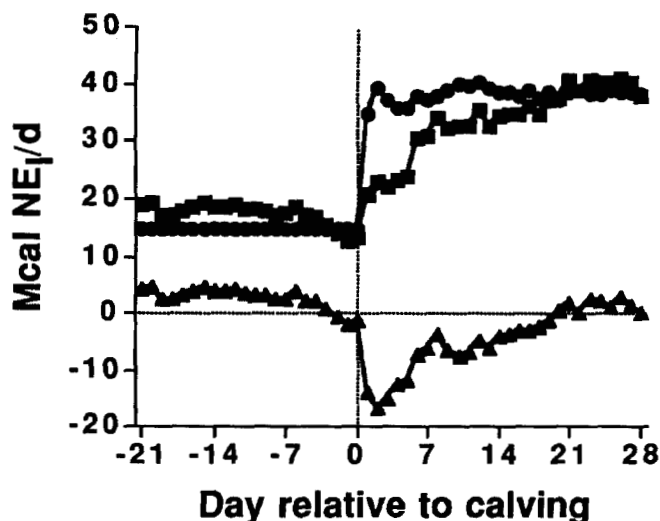
Figure 3. Energy requirement (—●—), intake (—■—), and balance (—▲—) of control cows in the study of Bertics et al. (1992) during the transition period. Energy requirements were obtained from NRC (1988).

μEq/L) and lower blood glucose (74 vs 55 mg/dL) at 1 d postpartum than cow 802. Neither cow was diagnosed as being clinically ketotic; however, at 14 d postpartum, cow 723 had higher plasma beta-hydroxybutyrate than cow 802 (15 vs 9 mg/dL).

A summary of data from five experiments (Skaar et al., 1989; Bertics et al., 1992; Studer, 1993; Studer et al., 1993; Vazquez-Anon et al., 1994) involving 78

cows on control treatments, or treatments that did not significantly alter cow response, indicated that DMI 1 d prepartum, expressed as a percentage of BW, was highly correlated to liver triglyceride (r = −.45; $P <$ .0001) and plasma NEFA (r = −.44; $P <$ .0001). Dry matter intake 1 d prepartum was also highly correlated with DMI 21 d postpartum (r = .53, $P <$ .0001; Figure 8). A priority in feeding the transition cow should be to maximize feed intake prepartum.

Zamet et al. (1979a) monitored 89 Holstein cows through the nonlactating period and first 30 days of lactation and categorized cows as being normal or abnormal. Abnormal (n = 45) cows were those with one or more partum or early postpartum disorders requiring treatment. Disorders included dystocia (n = 14), retained fetal membranes (n = 33), parturient paresis (n = 10), displaced abomasum (n = 7), fat cow syndrome (3), nephritis (1), and salmonella infection (1) (Zamet et al., 1979b). Feed intake during the final 27 d prepartum decreased from 1.8 to 1.2% of BW for normal cows and from 1.8 to .9% of BW for abnormal cows; DMI was significantly lower for abnormal cows from 3 d prepartum to 1 d postpartum ($P < .10$). Differences in feed intake between the two groups increased postpartum ($P < .05$) and normal cows produced more milk ($P < .01$). These data indicate that predisposition to disorders at and immediately after calving may be expected among cows with reduced DMI prepartum.
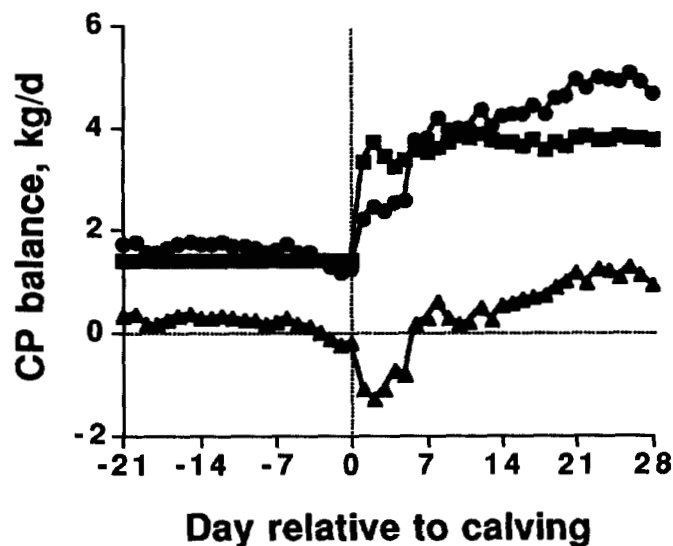

Figure 4. Crude protein requirement (—●—), intake (—■—), and balance (—▲—) of control cows in the study of Bertics et al. (1992) during the transition period. Crude protein requirements were obtained from NRC (1988).
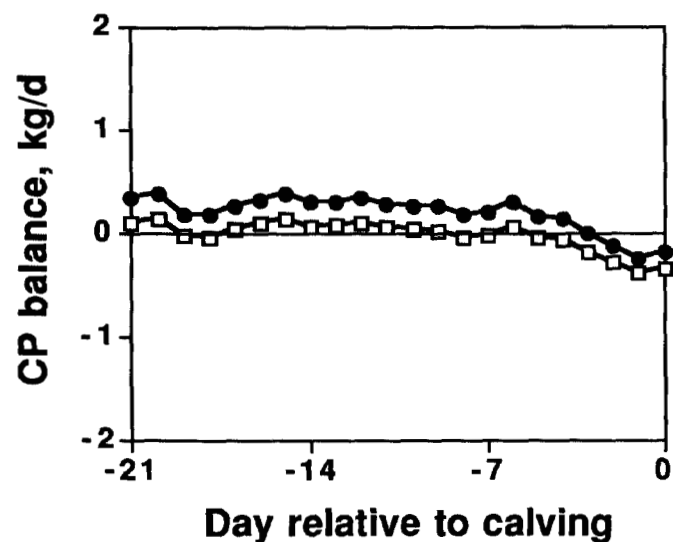

Figure 5. Estimated prepartum CP balance of control cows in the study of Bertics et al. (1992) when they consumed diets containing 14% CP (—●—) or if they would have consumed an equal amount of DM that contained 12% CP (—□—). Crude protein requirements were obtained from NRC (1988).
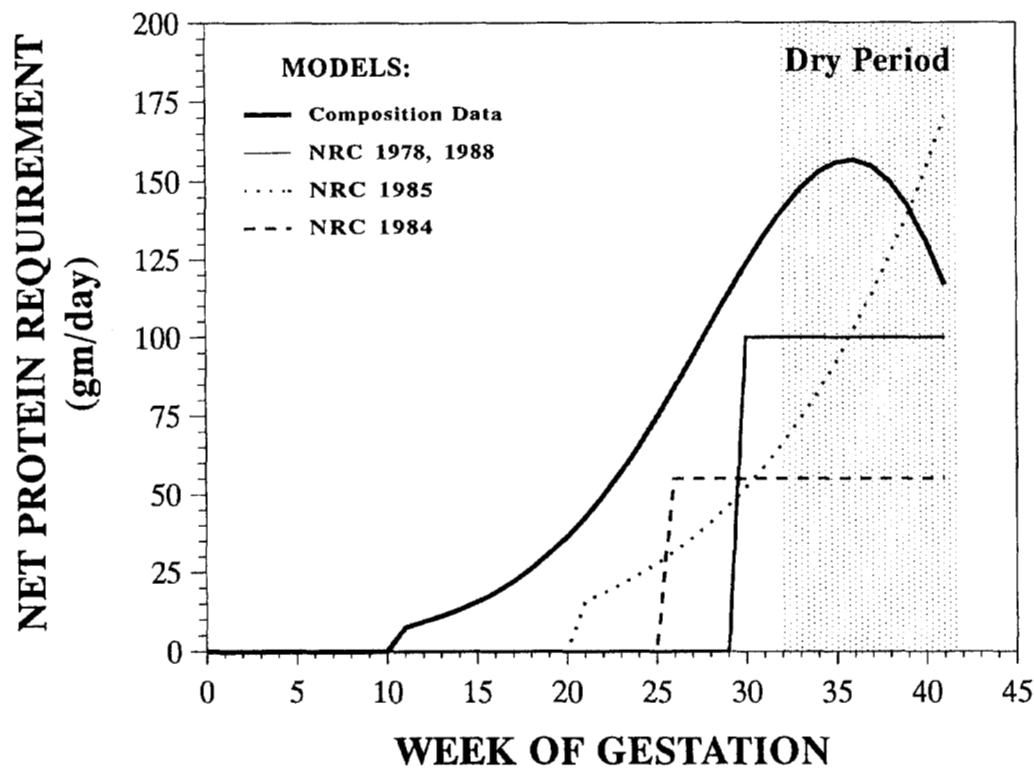
Figure 6. Estimates of net protein requirements for gestation from a composition model (Prior and Laster, 1979; Fox, 1990) (———), NRC (1984) (– – –), NRC (1985) (····), or NRC (1978 and 1988) (—) as compiled by Van Saun, 1993. Figure reprinted from Van Saun (1993) with permission from R. J. Van Saun.

Strategies for Enhancing Prepartum Dry Matter or Energy Intake

A decrease in prepartum intake seems unavoidable, but the magnitude and duration of decrease can vary (Coppock et al., 1972; Hernandez-Urdaneta et al., 1976; Johnson and Otterby, 1981; Kunz et al., 1985; Bertics et al., 1992; Emery, 1993; Vazquez-Anon et al., 1994; Grummer et al., 1995). Identification of factors that influence prepartum intake is important. Numerous studies have indicated that overconditioned cows are more likely to have poor appetites postpartum (Garnsworthy and Jones, 1987; Holter et al., 1990). Very little information is available to evaluate the influence of prepartum body condition on prepartum DMI. If postpartum DMI is related to prepartum DMI (Figure 8), then one can hypothesize that overconditioned cows would also consume less feed prepartum. Emery (1993) summarized DMI during the nonlactating period for 20 multiparous cows. The 10 cows with the highest body condition score (> 3.6; 1 = thin, 5 = obese) consumed DM at approximately 1.5% of BW and the 10 cows with the lowest body condition score (≤ 3.6) consumed DM at 2% of BW. Interestingly, overconditioned cows had a higher incidence of health problems within 75 d postpartum. The data were confounded because a different proportion of cows in

each group were treated with somatotropin during the previous lactation. Zamet et al. (1979b) reported lower prepartum DMI for cows diagnosed with fat cow syndrome compared to "normal" cows that did not have postpartum complications.

We examined the relationship between body condition score at 17 d prepartum and DMI at 1 d prepartum or 21 d postpartum for 40 cows that represented the control treatments from three experiments (Bertics et al., 1992; Studer, 1993; Studer et al., 1993). The correlation coefficient between prepartum body condition score and DMI at 1 d prepartum and 21 d postpartum was −.25 ($P < .12$) and −.45 ($P < .006$). Although these data and those of Emery (1993) and Zamet et al. (1979b) suggest a relationship between body condition score and prepartum feed intake, they do not imply cause and effect. For example, to categorize cows on the basis of body condition score may also categorize cows into two different genetic groups with different characteristics, many of which could influence feed intake.

Diet composition and nutrient content may influence prepartum DMI. Dry matter intake increased 30% when dietary NE_l was increased from 1.3 to 1.54 Mcal/kg of DM and CP from 13 to 16% at 3 wk prepartum (Emery, 1993). The improvement in DMI was lost as cows experienced feed intake decrease
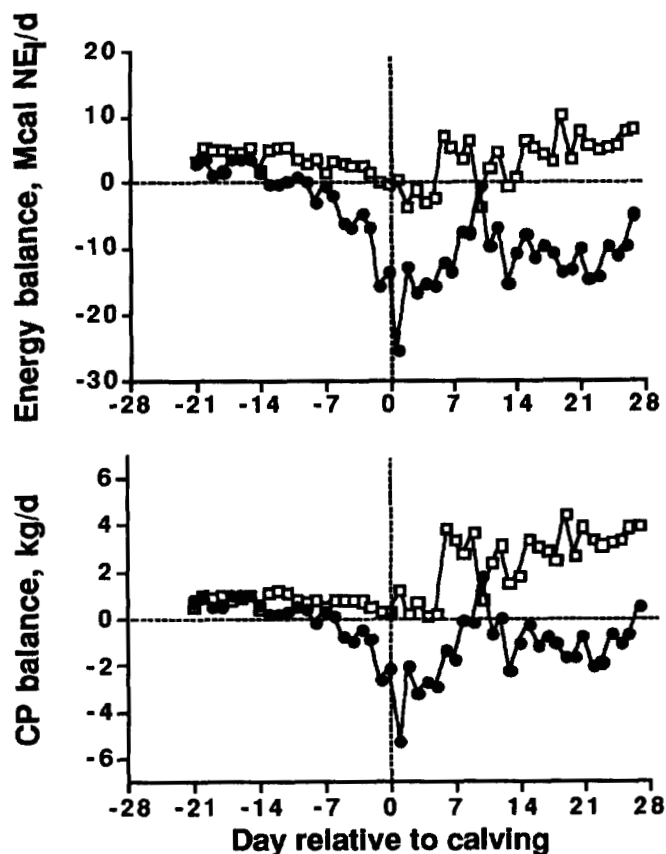
Figure 7. Estimated energy and CP balance of a transition cow (723) that experienced a severe decrease in DMI prepartum (—●—) or a cow (802) that experienced virtually no decrease in DMI prepartum (—□—).
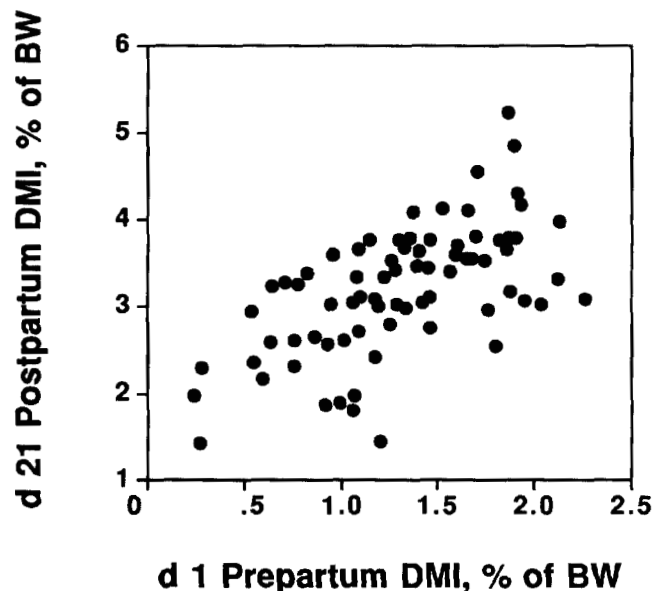

Figure 8. Relationship between DMI as a percentage of BW at 1 d before calving and 21 d postpartum. Data are from five studies (Skaar et al., 1988; Bertics et al., 1992; Studer, 1993; Studer et al., 1993; Vazquez-Anon et al., 1994) and represent 75 cows from control treatments or treatments that had no effects on prepartum DMI and liver triglyceride. Correlation coefficient (r) = .54, $P <$ .0001.

during the final week prepartum, but cows were still consuming 12.5 kg of DM/d at calving. Body weight of cows was not reported; however, this feed intake (1.8% of BW) would be quite satisfactory for a 700-kg cow.

Cows consuming diets containing 20% concentrate during the final 28 d prepartum had greater feed intake than those consuming 5% concentrate (Hernandez-Urdaneta et al., 1976). However, the advantage began to decrease at 11 d prepartum, and by calving there was no difference in DMI between the two groups. Similar results were obtained by Johnson and Otterby (1981) for cows fed all alfalfa-grass hay or corn silage-alfalfa silage-based diets containing 12 or 47% high-moisture corn beginning at 30 d prepartum. Increasing high-moisture grain in the diet increased DMI from d 28 to 13 prepartum ($P < .001$) but not from d 12 prepartum to d 31 postpartum. Coppock et al. (1972) fed four diets varying from 75 to 30% forage during the final 28 d before calving. Although significant treatment differences were not noted, feed intake was highest for cows receiving the

two diets with the most grain. Regression analysis indicated significant intake decrease ($P < .01$) as parturition approached for all treatments except the one containing the highest forage.

Several studies suggest that reducing forage:concentrate ratio increases DMI during 14 to 28 d prepartum. However, the higher intake seems to be accompanied by a more severe decrease in DMI during the final week before calving (Coppock et al., 1972; Hernandez-Urdaneta et al., 1976; Johnson and Otterby, 1981; Kunz et al., 1985). Consequently, DMI at calving may be no greater when feeding high-concentrate diets, but energy intake is still improved. In contrast to results from these studies (Coppock et al., 1972; Hernandez-Urdaneta et al., 1976; Johnson and Otterby, 1981), replacement heifers fed 6% concentrate during the final 5 mo before first calving had higher feed intake during the final 10 d prepartum than cows fed 39% concentrate during the same period (Grummer et al., 1995). Total digestible nutrient intakes during the final 10 d prepartum were similar, suggesting energy intake of heifers is regulated. The relative importance of DM or energy intake before DMI decrease, the severity of the decrease, or the level of intake following the decrease on health and productive performance of the transition cow has not been determined.

Extra-Caloric Effects of Increasing Fermentable Carbohydrate

Increasing prepartum energy intake, particularly by increasing intake of fermentable carbohydrate, may provide benefits beyond provision of calories. Dirksen et al. (1985) demonstrated that reduction of fiber percentage in the prepartum diet promotes development of ruminal papillae and increases the capacity for VFA absorption. They speculated that development of the ruminal papillae was essential to minimize ruminal VFA accumulation, reduction of ruminal pH, and the likelihood of acidosis that may occur when high-grain lactation diets are introduced postpartum. Papillae development may be a more important benefit of lead feeding than adaptation of ruminal microflora to high-starch diets. Because development of the ruminal papillae takes 4 to 6 wk (Dirksen et al., 1985), concentrate must be increased during the prepartum transition period to benefit the cow postpartum.

Increasing intake of fermentable carbohydrate will increase ruminal propionate production. This in turn will increase hepatic glucose production and may minimize glycogen depletion during transition. Propionate, and glucose to a lesser extent, are insulin secretagogues (Harmon, 1992). If cows are responsive to insulin near calving, lipid mobilization from adipose tissue and glycogen depletion from the liver may be curtailed. This may reduce the severity of hepatic triglyceride accumulation and decrease the incidence of ketosis (Grummer, 1993).

Increasing concentrate intake from .9 to 7.9 kg/d during the final 4 wk prepartum, while forage intake remained constant, resulted in 100 to 300% increases in serum insulin ($P < .01$; Holtenius et al., 1993). Serum insulin also was increased ($P < .01$) when energy intake was held constant during the transition period but concentrate was increased from 5 to 60% of ration DM. Prepartum concentrate feeding did not influence serum glucagon concentrations.

Enhancing carbohydrate status and increasing plasma insulin does not need to be accomplished by feeding additional concentrate. Administration of 1 L of propylene glycol (**PG**) as an oral drench once daily during the final 9 d prepartum increased blood glucose and insulin and decreased NEFA, beta-hydroxybutyrate, and liver triglyceride (Studer et al., 1993). Although cows may become insulin-resistant as parturition approaches, these data indicated that adipose tissue responded to elevated blood insulin because NEFA elevation was lower among PG-treated cows than among control cows. An oral drench of 296 mL of PG/d was almost as effective as 887 mL/d in lowering blood NEFA in heifers that were between 30 and 90 d from first calving (Grummer et al., 1994). It is not known whether 296 mL PG/d would be effective in mature cattle approaching parturition that may be developing insulin resistance. We compared the effectiveness of providing PG as an oral drench, in a totally mixed diet, or with 3 kg of grain in a single offering separate from forage (Christensen et al., 1995b). Feeding PG as part of a totally mixed diet was not as efficacious as providing PG as an oral drench or mixed with 3 kg of grain, probably because a sufficient quantity was not consumed quickly enough to trigger the metabolic changes required to reduce lipid mobilization from adipose tissue.

Although not approved for lactating dairy cows, ionophore supplementation may act similar to grain feeding or PG for reducing stress associated with the transition period. Monensin enhances propionate production in the rumen (Prange et al., 1978; Rogers and Davis, 1982). Sauer et al. (1989) fed monensin at approximately 0, 100, or 200 mg/d from 1 wk prepartum until 3 wk postpartum. Feeding 200 mg/d monensin lowered feed intake 1.2 kg/d but reduced blood beta-hydroxybutyrate from 7.2 to 3.9 mg/100 mL ($P < .05$). Incidence of ketosis was 1 out of 12 for cows receiving the high dose of monensin compared with 6 out of 12 for cows not receiving monensin. Milk yield for 16 wk postpartum was similar among groups. Similar results were obtained by Thomas et al. (1993), who fed 0, 150, 300, or 450 mg of monensin/d starting 2 to 4 wk prepartum through 84 d postpartum. Feed intake by cows fed monensin was not affected prepartum but was decreased .7 to 2.5 kg/d during the 84 d postpartum period; the difference was significant ($P < .05$) for cows receiving 150 mg/d monensin. Plasma NEFA and beta-hydroxybutyrate were reduced ($P < .05$) by all levels of monensin. Prepartum blood NEFA, beta-hydroxybutyrate, and glucose were reduced when cows 50 d before expected calving were dosed with a bolus designed to release 300 of mg monensin/d into the rumen for 100 d (Stephenson et al., 1994). Lasalocid supplementation reduced alimentary ketogenesis in sheep (Heitmann et al., 1994; Housewright et al., 1994).

Ironically, data suggesting improved health or lactation performance resulting from prepartum grain consumption are difficult to find. Feeding cows a 47% high-moisture grain diet during the final 30 d prepartum increased udder edema score compared with feeding an all-hay diet (Johnson and Otterby, 1981; 1.22 vs 2.27; 1 = slight edema, 3 = severe edema). Heifers, but not cows, had more udder edema when consuming grain ad libitum than those consuming no grain during the final 28 d prepartum (Emery et al., 1969). Decreasing forage:concentrate ratio may predispose cows to displaced abomasum (Coppock et al., 1972). A trial involving 156 cows indicated that supplementation of an all-forage diet with grain at 1% of BW during the last 3 wk prepartum did not affect postpartum DMI, milk yield, or composition (Nocek et al., 1986). These results were similar to those of Emery et al. (1969) and Johnson and Otterby (1981).

It has been suggested that instead of increasing prepartum grain intake, it might be advantageous to restrict prepartum energy intake in an attempt to stimulate the type of metabolism experienced immediately postpartum. Cows (n = 8) consuming a diet formulated to provide 67% of energy requirements (NRC, 1988) from 30 to 10 d before parturition had lower plasma insulin concentrations than cows (n = 8) fed a diet intended to provide 100% of energy requirements (Lotan et al., 1988). The authors considered lowered insulin to be beneficial, suggesting it indicated reduced insulin resistance and less lipogenesis. Milk production and plasma glucose, NEFA, and beta-hydroxybutyrate were not affected by treatment. In a second trial (Lotan et al., 1988) involving 70 pairs of cows, energy was fed at 51 or 84% of requirement during the final 30 d of gestation. Cows fed the low-energy diet lost 7 kg BW and those fed the high-energy diet gained 14 kg BW ($P < .01$) prepartum. No significant production differences were observed postpartum.

In an elegant study by Kunz et al. (1985), cows were feed-restricted to meet energy requirements or were allowed to consume forage ad libitum with some concentrate during the entire dry period. Dry matter intake increased slightly faster whereas energy deficiency and weight loss during the first weeks of lactation were reduced for feed-restricted cows. Milk production for 125 d postpartum was similar between groups, although the shapes of the lactation curves were different; feed-restricted cows produced less milk initially but were more persistent. Cows that were feed-restricted did not experience a decrease in DMI prepartum and had higher blood glucose postpartum and lower blood NEFA and beta-hydroxybutyrate postpartum. Body weight gain during the nonlactating period was slightly greater for cows fed forage ad libitum than for feed-restricted cows (approximately 40 vs 55 kg). Body condition scores were not monitored; therefore, it is difficult to determine whether treatment differences were due to direct effects of diet or indirect effects that may have resulted from differences in body condition score. Results similar to those of Kunz et al. (1985) were obtained when cows were fed to achieve low vs high body condition scores at calving (for reviews, see Broster, 1971; Garnsworthy, 1988). Unfortunately, in most trials examining the influence of prepartum energy intake on postpartum health and lactation performance, treatments began before or at dry-off and body condition scores were not monitored.

are, in contrast to NEFA, metabolized predominantly by extrahepatic tissues. However, plasma NEFA concentrations almost always increase when supplemental fat is fed (Grummer and Carroll, 1991; Chilliard, 1993). Supplemental fat fed to cows from 17 d prepartum through 15 wk postpartum did not affect liver triglyceride or plasma beta-hydroxybutyrate from parturition until 5 wk postpartum (Skaar et al., 1989).

Numerous trials have indicated little increase in milk yield or decrease in BW loss from feeding fat during the first 5 wk postpartum (Ruegsegger and Schultz, 1985; Jerred et al., 1990; Hoffman et al., 1991; Schingoethe and Casper, 1991; Chilliard, 1993; Grummer et al., 1995). The lag period before a production response to supplemental fat has been documented for heifers and multiparous cows, for a wide variety of fat sources, and when feeding 2 to 5% supplemental fat. Cows seem to respond best to fat at approximately the time they reach positive energy balance. It has not been determined whether one must feed fat during the first weeks of lactation to obtain the benefit later on, or whether one could start feeding fat 5 to 7 wk postpartum and get the response immediately without a lag phase. Seymour et al. (1994) fed multiparous cows no added fat for d 1 to 100 of lactation (dietary fat = 4.3%), no added fat for d 1 to 49 and 7% dietary fat for d 50 to 100, 5.5% dietary fat for d 1 to 49 and 7% dietary fat for d 50 to 100, or 7% dietary fat for d 1 to 100. They concluded that 5.5% dietary fat was "optimal" during d 1 to 49 of lactation and 7% dietary fat was most beneficial during d 50 to 100 of lactation.

An extensive review of the literature (Chilliard, 1993) indicated feeding supplemental fat in early lactation did not reduce BW loss or influence body condition score during early lactation. There is some evidence that feeding supplemental fat may increase NEFA release from adipose tissue (Grummer and Carroll, 1991; Chilliard, 1993). This may be due to increased basal lipolysis, decreased reesterification of fatty acid, or both. Feeding fat accelerated gain of cows after they reached positive energy balance (Skaar et al., 1989). The lack of responses to fat in early lactation may be related to a decrease in feed intake (Eastridge and Palmquist, 1988; Seymour et al., 1994) that would offset the advantage of increasing energy density of the diet by adding fat. Clearly, feeding supplemental fat during the postpartum transition period is not as beneficial as one might predict considering the severe negative energy balance cows experience during that time.

Supplemental Fat During the Transition

Kronfeld (1982) speculated feeding supplemental fat would reduce fatty acid mobilization from adipose tissue and potentially reduce the incidence of ketosis. This strategy assumes dietary fatty acids are incorporated into intestinally synthesized lipoproteins and

Influence of Transition Diet Protein on Health and Lactation Performance

Path and regression analysis of data from the field trial by Curtis et al. (1985) involving 1,374 multiparous Holsteins on 31 New York farms indicated feeding protein above NRC recommendations during

the final 3 wk prepartum was correlated with decreased risk of retained placenta and uncomplicated (primary) ketosis. Two theories have been forwarded to explain why improving amino acid status of the transition cow may affect performance. First, protein requirements listed by NRC (1988) may be underestimated. As a result, underfeeding protein may cause maternal reserves to be depleted, leading to compromised lactation, health, and reproduction (Van Saun et al., 1993). Second, improving the amino acid status of the prepartum cow may beneficially influence endocrine physiology and enhance lactation performance (Chew et al., 1984a).

Intravenous infusion of 0 or .1 g of arginine/kg of BW over a 5-min period each day for the final 7 d prepartum increased blood prolactin, insulin, and growth hormone ($P < .001$; Chew et al., 1984a). Milk yield for 23 wk postpartum was increased 10% for cows receiving arginine ($P < .10$). Little information is available describing the influence of feeding undegradable protein during the transition period on endocrine status. Arginine injection into the jugular vein of lactating cows increased plasma growth hormone and insulin, but abomasal infusion of similar amounts of absorbable arginine did not (Vicini et al., 1988). Increasing dietary UIP from 6 to 9% of DM from 2 wk prepartum to 16 wk postpartum increased plasma IGF-I and decreased growth hormone ($P < .07$) during the postpartum period (Komaragiri et al., 1994). Dietary CP was increased from 16 to 19% CP as UIP was increased, so it could not be determined whether the treatment effects were specific to UIP.

Increasing dietary CP of corn silage or predominantly corn silage diets from 8 to 15% by addition of soybean meal during the dry period increased the incidence of postpartum disease from 7.14 (2/27) to 69.2% (18/26; Julien et al., 1977). Cows receiving the 15% CP diet suffered a variety of disorders. Perhaps most striking was the large number (n = 8) of downer cows, including six that died. Blood parameters measured did not indicate an obvious cause for downer cows. Cows on the trial were overconditioned. Shaver (1993) speculated that the liver's ability to detoxify ammonia resulting from ruminal soybean protein degradation may have been compromised. Accumulation of triglyceride by bovine hepatocytes cultured in vitro decreases ureagenesis (Strang et al., 1995). Significant inhibition of ureagenesis was observed at hepatic triglyceride concentrations common in fresh cows. Chew et al. (1984b) fed 80 or 100% of NRC recommendations for CP during the entire dry period. Urea was used to increase CP of the corn silage and alfalfa grass hay diets. Cows consuming the 100% treatment consumed more DM (+.1% of BW; $P < .10$) prepartum and produced more milk (4,558 vs 5,485 kg; $P < .06$) during the first 200 d of lactation. Perhaps feeding urea prepartum enhances urea cycle activity and increases the cow's ability to transition from low- to high-protein diets after calving.

Heifers fed 13% CP diets for the final 60 d of gestation produced more milk (11,720 kg vs 10,807 kg; $P < .05$) during lactation than those fed 9% CP diets (Hook et al., 1989). Blood meal was used to increase CP from 12.4 to 15.3% in diets fed to heifers for the final 3 wk of gestation (Van Saun et al., 1993). Undegradable protein was increased from 27 to 39% of CP. Heifers fed the high UIP diet maintained a higher body condition score (3.24 vs 3.03, scale = 1 to 5; $P < .07$). However, because heifers fed high UIP started the experiment at a higher body condition, and a covariate was not used for statistical analysis, this probably does not represent a treatment effect. Heifers fed the high-UIP diet produced milk with a higher protein concentration (3.18 vs 2.96%; $P < .02$) and had fewer services per pregnancy (1.2 vs 2.1; $P < .10$). In a follow-up study (Van Saun, 1993) multiparous cows were fed diets near NRC specifications (approximately 12% CP, UIP = 32% of CP) or with elevated CP and UIP (approximately 13.5% CP, UIP = 42% of CP). Cows fed the high-UIP diet had a lower incidence of ketosis (0 vs 16.7%; $P < .01$) and had fewer days open (72 vs 90; $P < .04$).

Feeding ruminally protected lysine and methionine to dairy cows consuming diets containing 12.6% CP and high UIP during the final 3 wk prepartum reduced the incidence of metabolic disorders at parturition (4/16 vs 5/11; Rode et al., 1994). Methionine serves as a methyl donor for phospholipid synthesis and is required for the synthesis of apolipoproteins. In nonruminants, insufficient phospholipid or apolipoprotein synthesis impairs triglyceride export from the liver. Use of lipotrophic compounds such as methionine to influence hepatic lipid metabolism in dairy cattle has been investigated, but results have been inconclusive. Socha et al. (1994, personal communication) indicated prepartum feeding of ruminally protected methionine or protected methionine plus lysine did not influence hepatic triglyceride content at calving. However, cows may not have been deficient in these amino acids because the transition diet contained 16% CP and 38% of CP was UIP. Torralba (1980) fed control or methionine-hydroxy analog-supplemented diets to dairy cows beginning 3 wk prepartum and examined liver tissue obtained by biopsy 3 wk prepartum and 1 d postpartum. Through histological examination, liver tissue was classified as being normal or having slight, moderate, or severe fat infiltration. Liver fat content did not seem to be reduced by feeding methionine-hydroxy analog. Insufficient replication and the use of a qualitative rather than a quantitative measure of liver fat probably minimized the likelihood of detecting a treatment effect.

Using radiotracer techniques, Pullen et al. (1989) examined the effects of dietary methionine-hydroxy

analog on endogenous triglyceride synthesis in early lactation cows. They did not observe treatment effects; however, animal numbers were probably insufficient to detect a response. Intravenous infusion of lysine plus methionine to lactating dairy cows increased net hepatic very low density lipoprotein balance (Durand et al., 1992). Because the trial involved only two animals and accurate measurement of transhepatic triglyceride differences is extremely difficult, results need confirmation.

There is evidence to support the concept of increasing protein content of diets fed to nonlactating cows above NRC (1988) recommendations to deliver additional absorbable amino acids. Additional supportive data from applied trials as well as more basic research to delineate mechanisms for improved health and performance are needed.

Effects of Postpartum Nutrition on Performance of Overconditioned Cows

Early lactation cows are in negative energy balance and body reserves are an important fuel supply to assist the cow in reaching her genetic potential for milk synthesis. However, adipose tissue reserves can become too large, and when a decrease in feed intake occurs, BW loss is accentuated. This can result in metabolic disorders and poor lactation performance (Morrow, 1976; Garnsworthy, 1988; Emery, 1993).

Labile protein reserves are limiting relative to lipid reserves. Increasing dietary UIP may enhance utilization of mobilized lipid by extra-hepatic tissues. Increasing UIP in postpartum diets fed to overconditioned cows increased negative energy balance because milk yield increased and DMI did not change (Garnsworthy and Jones, 1987; Jones and Garnsworthy, 1988). Health parameters were not monitored. Seymour and Polan (1986) did not observe effects of postpartum dietary UIP on performance of cows fed high- or low-energy diets during the nonlactating period, but protein treatments were not initiated until 3 wk postpartum.

Boisclair et al. (1986) hypothesized that sodium bicarbonate may promote appetite by overconditioned cows during the early postpartum period. They theorized that greater feed intake would reduce mobilization of fatty acids from adipose and reduce the incidence of health problems such as ketosis and fatty liver in overconditioned cows. In their study, cows were fed diets varying in energy density during the nonlactating period to obtain groups with body condition scores varying from 3.2 to 4.0 (scale = 1 to 5). Sodium bicarbonate in the early postpartum diet did not influence postpartum performance (Boisclair et al., 1986) or health parameters (Boisclair et al., 1987) and there were no differences in postpartum DMI among groups of cows with different body condition scores.

Palmquist (1993) proposed that feed intake and efficiency of energy utilization may be improved, and metabolic disorders minimized, if cows calved in moderate body condition (2.5, scale = 1 to 5). To compensate for a moderately conditioned cow having less energy to mobilize from adipose tissue than a cow with more condition, he suggested feeding fat during early lactation. Variation in the ability of overconditioned cows to cope with the stress of parturition and lactation may be explained by energy content of postpartum diets (Jones and Garnsworthy, 1989). Cows were fed for 12 wk before calving to achieve body condition scores of 3.23 or 1.98 (scale of 1 to 4; Jones and Garnsworthy, 1989). Half the animals in each group were fed a low- (2.34 of Mcal ME/kg of DM) or high- (3.11 Mcal of ME/kg of DM) energy diet postpartum. Increasing energy density improved BW replenishment and lactation performance of thin cows ($P < .05$) but had very little effect on overconditioned cows, probably because ME intake of overconditioned cows was not increased as much as that of thin cows. Blood NEFA concentration was increased (.27 vs .20 meq/L; $P < .05$) when the high-energy diet was fed to the overconditioned cows. A second study (Garnsworthy and Hugget, 1992) with a similar design examined the response of thin and overconditioned cows to postpartum diets that contained 0 or 2.6% supplemental fat and were fed for equal energy intake. Results were similar to those of the first study; feeding diets with fat seemed to be more beneficial for thin cows than for overconditioned cows. Overconditioned cows fed supplemental fat tended to lose less body condition than overconditioned cows that were not fed fat, but the differences were not significant. Both studies suffered from inadequate replication, but considered together, it seems that dietary energy density has a greater influence on performance of thin cows than on that of overconditioned cows, and the feeding regimen proposed by Palmquist (1993) merits further investigation.

Conclusions

Nutrient requirements of the nonlactating cow, particularly during the transition period, are poorly defined. Research is needed to determine the most effective means to meet the nutrient demands of the prepartum transition cow and her rapidly growing fetus during a period of decreasing feed intake. There is a paucity of high-quality, applied nutrition research that specifically addresses cows from 3 wk prepartum to 3 wk postpartum. The cost of this research is often prohibitive because the amount of animal variation during this period dictates that extremely large numbers of animals be used in trials, particularly those attempting to detect treatment differences for discrete variables such as incidence of metabolic disorders.

Although the greatest organic nutrient imbalances occur immediately postpartum, the greatest fluctuations in organic nutrient metabolism occur at or immediately before parturition. The magnitude of the fluctuations probably has a major impact on the amount of stress a cow encounters during the transition period. There is evidence to suggest that amount of DM consumed and nutrient composition of the feed may modify organic nutrient metabolism near the time of calving. Increasing DMI and protein density of prepartum transition diets may enhance lactation, health, and reproductive performance of the cow following parturition. Effects may be brought about by changes in endocrine status or other signals that influence metabolism rather than by alleviating a nutrient deficiency per se. For example, high priority should be placed on determining ways to reduce fatty acid mobilization from adipose tissue and prevent hepatic lipid accumulation and glycogen depletion.

The importance of external inputs such as diet vs the inherent characteristics of the animal on determining the tranquillity of the transition period has not been determined. For example, transition cows that are in the same environment vary considerably in the magnitude of DMI decrease immediately before calving. Why? Blood concentrations of estrogen, and progesterone that has anti-estrogenic activity, change rapidly as calving approaches (Henricks et al., 1972). Estrogen administration to dairy cows reduces feed intake (Grummer et al., 1990). Perhaps the estrogen: progesterone ratio in blood, or a multitude of other factors not directly related to nutrition, play a critical role in determining the amount of difficulty a cow experiences during the transition period. A combination of nutritional and physiological manipulations of the cow may ultimately be necessary to provide the least stressful transition.

Implications

Dry matter intake during the final days before calving is related to postpartum animal health, dry matter intake, and lactation performance. Very few factors that influence prepartum dry matter intake have been identified. Increasing nutrient density of the prepartum diet may stimulate dry matter intake and enhance postpartum performance. When establishing feeding strategies for the transition cow, nutrient demands of the dam and conceptus must be considered as well as effects of diet on ruminal environment and organic nutrient metabolism.

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