Feed Additives for the Transition Cow

R. R. Grummer[1], R. D. Shaver[2*], and S. Gunderson[3]

Department of Dairy Science
University of Wisconsin – Madison[1,2]

Manitowoc County Extension[3]
University of Wisconsin – Extension[2,3]

Introduction

The transition period discussed in this paper is the period two weeks prepartum through two weeks postpartum. This period is characterized by intake depression prepartum (Bertics et al., 1992) and slow intake ascent postpartum (Kertz et al., 1991). Prepartum intake depression and slow intake ascent postpartum are major risk factors in the etiology of metabolic and digestive disorders, such as milk fever, ketosis, fatty liver, left-displaced abomasum, and ruminal acidosis. Numerous feed additives are targeted to transition cows by nutritionists for prevention of metabolic disorders and improvement of lactation performance. The purpose of this paper is to review the research base behind this practice for some of the common feed additives.

Additives for Ketosis/Fatty Liver

There is a gradual decline in dry matter intake (DMI) starting two weeks prepartum followed by a precipitous drop 3-5 days prepartum (Bertics et al., 1992). Decline of DMI is about 30% over the last week prepartum causing increased liver triglyceride immediately postpartum (Bertics et al., 1992). Numerous feed additives are positioned for the prevention of fatty liver and ketosis.

* Contact at: 1675 Observatory Drive, Room 280 Animal Sciences Building, University of Wisconsin, Madison, WI 53706, (608) 263-3491, FAX (608) 263-9412, Email: rdshaver@facstaff.wisc.edu.

Propylene glycol

Bertics et al. (1992) theorized that administration of glucose precursors prepartum to increase blood glucose may elicit an insulin response and reduce fatty acid mobilization from adipose. Propylene glycol (PG) drenched orally once daily (32 oz) starting ten days prepartum until calving increased plasma glucose and insulin prepartum and reduced total liver lipids and plasma nonesterified free fatty acids (NEFA) immediately postpartum (Studer et al., 1993).

Grummer et al. (1994) compared 0, 10, 20 and 30 oz PG drenched orally once daily for five days in feed-restricted springing heifers. Increasing dose of PG had positive linear effects on plasma glucose and serum insulin concentrations and negative linear effects on plasma NEFA and beta-hydroxy-butyrate (BHBA) concentrations. Quadratic effects of PG on plasma glucose, NEFA and BHBA concentrations were also observed; the 10 oz dose was nearly as effective as the 30 oz dose for reducing lipid mobilization.

Because of the difficulty of drenching cows orally for several days prepartum, there is interest in adding PG directly to the steam-up ration. Christensen et al. (1997) administered 12 oz PG once daily as an oral drench, in 6-7 lb of concentrate, or in a total mixed ration (TMR) for seven days in feed-restricted springing heifers and cows. Administering PG mixed with concentrate was nearly as effective as the oral drench for lowering plasma NEFA concentrations. Administering PG in a TMR was not effective. Whether or not using a larger dose when administering PG in a TMR would improve efficacy can not be determined from this trial. This, however, would increase the cost of administering PG and it is unlikely that administering PG in several small sub-doses throughout the day (TMR) would be as effective as pulse dosing PG (oral drench or mixed with concentrate).

Use of PG as a ration additive for early lactation cows has been shown to reduce milk ketones (Fisher et al., 1973) and plasma NEFA and BHBA (Sauer et al., 1973). It does not appear that PG limits concentrate consumption for concentrates containing up to 10% PG (Christensen et al., 1997; Fisher et al., 1973). This suggests that use of PG as a ration additive at 10-20 oz per cow per day for early lactation cows should not depress feed intake as inclusion rates would range from 3-6% and 1.5-3.0% (DM basis) for concentrate and TMR, respectively.

Propionate

Similar to PG, propionate is a precursor for glucose synthesis. Sodium propionate fed at the rate of 4 oz per cow per day for the first six weeks of lactation increased glucose and reduced ketone concentrations in blood (Schultz, 1958). There is interest within the feed industry in using calcium propionate as a ration additive for transition cows. Research is needed to evaluate the efficacy of propionate salts in transition diets. Research (Christensen et al., 1997; Grummer et al., 1994) indicating ruminal conversion of PG to propionate suggests the potential for comparable efficacy between PG and propionate salts. Palatability may be a concern with propionate salts when fed at similar rates as PG (Littledike et al., 1981); research is needed. High cost of supplementation likely limits the use of PG and propionate salts to transition diets.

Niacin

Interest with transition cows relates to its role in preventing ketosis and fatty liver, which could be due to reduced fat mobilization or altered glucose metabolism (Drackley, 1993). Although a common additive in transition diets, the evidence for its benefit is equivocal (Skaar et al., 1989). Skaar et al. (1989) found no positive effects of niacin supplementation at 12 grams per day from 17 days prepartum through 105 days postpartum. Niacin supplementation did not influence plasma glucose, NEFA or BHBA or lactation performance. Niacin supplementation tended to increase total liver lipids slightly at calving and at five weeks postpartum. Evidence was cited from the human literature suggesting that niacin may reduce fat export from the liver. Supplementation of 12 grams niacin per day from 19 days prepartum through 36 weeks postpartum did not influence plasma glucose or NEFA or liver triglyceride around parturition or lactation performance (Minor et al., 1998). A summary of 14 treatment comparisons in which niacin was fed (Grummer, unpublished) indicated plasma nonesterified fatty acids were significantly reduced once, increased twice, and not altered 11 times. If restricted to studies in which niacin was fed prepartum or within two weeks postpartum, plasma nonesterified fatty acids were significantly reduced once, increased twice, and not altered 8 times. In 10 comparisons (9 of which niacin treatment began prepartum or prior to two weeks postpartum) plasma ketones were significantly reduced 4 times and not affected 6 times. However, three of the four comparisons in which significant reductions were observed were from a single experiment and corresponded to contrasts between three different doses of niacin to a control treatment (Dufa et al., 1983).

Rumen–protected amino acids

Methionine is often mentioned as an amino acid that may enhance export of fat from of the liver. Methionine is a methyl donor and plays a role in the synthesis of phospholipids. Phospholipids are an important constituent of lipoproteins, the particles that carry fat away from the liver. Methionine also is required for the synthesis of the protein fraction of lipoproteins. Because lipoprotein export is inherently slow in ruminants, several researchers have speculated that it is due to methionine deficiency. French researchers were the first to demonstrate that methionine supplementation may increase lipoprotein production by the ruminant liver, however, the increase was small and probably biologically insignificant (Bauchart et al., 1998). Feeding 20 g rumen-protected L-methionine/day to cows fed corn silage based diets from 7 to 28 days of lactation did not reduce liver fat. However, when the same amount was fed with 30 g rumen-protected lysine/d, liver fat was reduced 35% (Bauchart et al., 1998). Lysine was not fed alone, therefore, we do not know if this was a lysine effect or a complimentary effect of feeding methionine and lysine. We fed 13 g liquid methionine-hydroxy analogue to far-off dry cows that were restricted to 25% of ad libitum feed intake (to mimic feed intake depression at the time of calving) and did not prevent fatty liver (Bertics and Grummer, 1997). In a second experiment, the same amount of methionine-hydroxy analogue was provided to cows fed ad libitum following feed restriction (Bertics and Grummmer, 1998). Supplementation did not hasten depletion of fat from the liver. At this time, there is insufficient evidence to support the use of rumen-protected methionine to prevent fatty liver or ketosis.

Ruminally-protected choline

Feeding ruminally-protected choline (RPC; 33 grams choline) increased milk yield and milk fat percent (Erdman, 1994). However, interest with transition cows relates to its role in the formation of lipoproteins that function to export triglyceride from the liver (i.e., prevention of fatty liver). Choline serves as a precursor for phospholipids, an essential component of lipoproteins. Choline might spare methionine (both are methyl donors in metabolism); methionine is required for the synthesis of proteins, which are essential for lipoprotein synthesis. Di Costanzo et al. (1995) evaluated RPC (0, 15, 30 and 45 grams per day) supplementation in 40 mature Holstein cows (8 cows per treatment) from 20 days prepartum through 100 days postpartum. There were no treatment effects ($P > .05$) on plasma NEFA, BHBA, or glucose or lactation performance. Piepenbrink and Overton (2000) fed 0, 45, 60, or 75 g/d protected choline to cows from 3 weeks prior to calving until 9 weeks postcalving. Dry matter intake, milk yield, and milk fat percentage was not affected by treatment. There was a trend ($P < .15$) for increased fat and 3.5% fat corrected milk yield (93.5, 105.6, 94.1 and 100.5 lb FCM/day; 3.44, 3.95, 3.44, and 3.79 lb fat/day) from cows fed protected choline. In vitro studies with liver tissue sampled from these cows provided some evidence that protected choline might reduce triglyceride accumulation in the liver. However, analysis of liver biopsies indicated that there was no beneficial effect of treatment on reducing triglyceride in the liver. More research with larger numbers of cows and cows with varying body condition score (BCS) at calving is needed to evaluate the efficacy of "lipotropic" agents in transition cows.

Ionophores

Addition of ionophores to the diet increases the proportion of gram positive bacteria and decreases the proportion of gram negative bacteria. As a result, there is a shift in fermentation end-products. Methane production is decreased and the molar proportion of acetate and butyrate are decreased while the molar proportion of propionate is increased. Increased propionate production and gluconeogenesis may spare amino acid catabolism and reduce fat mobilization from adipose and ketone production by the liver. An increase in plasma glucose, decrease in plasma nonesterified fatty acids, decrease in blood beta-hydroxybutyrate, or combinations of the above have been attributed to ionophore feeding on several occasions (Sauer et al., 1989; Thomas et al., 1993; Lean and Wade, 1997; Phipps et al., 1997). Thomas et al. (1993) fed monensin at 0, 150, 300 or 450 mg per cow per day from 2-4 weeks prepartum through twelve weeks of lactation. Serum NEFA and BHBA were reduced for multiparous cows during the first four weeks postpartum with 300 and 450 mg per day monensin. Sauer et al. (1989) fed monensin at 0, 200 or 400 mg per cow per day for the first three weeks of lactation. Blood BHBA concentration was reduced for cows fed the high level of monensin. During the first three weeks postpartum, 50% of the control cows had clinical or subclinical (blood ketones > 9 mg/100 ml) ketosis. Incidence rates in the low and high monensin groups were 33 and 8%, respectively. More research is needed to evaluate the efficacy of ionophores as anti-ketogenic agents in transition diets, but initial research looks promising. In the United States, ionophores are approved for use only in dairy replacement rations at this time.

Chromium

Chromium (Cr) is an essential nutrient for humans and animals. Its primary role is to potentiate the action of insulin as part of the glucose tolerance factor (GTF); an organometallic compound comprised of Cr^{+3}, nicotinic acid, glutamic acid, glycine, and cysteine. Absorption coefficients for inorganic forms of Cr in ruminants is not known, but it ranges from 0.5 to 2% in humans and laboratory animals (NRC, 1997). Efficiency of absorption is affected by numerous factors, consequently the total chromium content of the diet is probably not highly related to available chromium in the diet. Organic forms of Cr are more available than inorganic forms. About 10-25% of chromium in brewer's yeast (a naturally-occurring organic complex) is absorbed. There has been recent interest in supplementing organic forms of Cr to livestock. Examples of organic Cr include Cr-picolinate, Cr-nicotinate Cr-amino acid chelates, and high-chromium yeast.

Some of the initial studies conducted with chromium supplementation of recently shipped beef calves indicated a reduction in "stress" and improved performance (average daily gain and average daily gain/DMI). This observation along with the potential of Cr to potentiate insulin action generated interest in feeding Cr to transition dairy cows. Supplementing Cr has reduced blood cortisol concentrations and increased measures of immunological activity in transition dairy cows (Burton et al., 1993; Mallard, 1994; Chang et al., 1996). Canadian researchers (Subiyatno et al., 1996; Yang et al., 1996) fed 0.5 ppm organic chromium and observed improved glucose tolerance and milk yield and decreased blood cortisol, NEFA and BHBA in primiparous but not multiparous cows. They suggested that differences in response may be due to greater "stress" experienced by primiparous cows. Hayirli et al. (2001) fed 0, 0.03, 0.06 or 0.12 mg of Cr as Cr-methionine per day/kg $BW^{.75}$ to multiparous cows (12/treatment) from 28 days prior to calving to 28 days post calving. Prepartum and postpartum dry matter intake increased linearly and milk yield increased quadratically with Cr supplementation. Milk composition was not affected. Plasma nonesterified fatty acid (NEFA) concentration was decreased linearly prepartum (but not postpartum) with Cr supplementation. Liver triglyceride content was not affected. Although there were some treatment effects noted during pre- and postpartum glucose tolerance tests, plasma glucose concentrations were not affected during the 56 day trial.

Anionic Salts for Milk Fever

Anionic salts, such as ammonium chloride and sulfate, calcium chloride and sulfate**,** and magnesium sulfate**,** are used in steam-up diets to alter dietary cation-anion difference (DCAD) for preventing clinical and subclinical milk fever. Feeding anions reduces blood pH and counteracts the alkalizing effect of dietary potassium and sodium. Low blood pH favors calcium mobilization from bone and perhaps calcium absorption from the intestine. Numerous formulas have been forwarded for quantitating DCAD (e.g. $[Na^{+} + K^{+}] – [Cl^{-} + S^{--}]$ or $[0.15\ Ca^{++} + 0.15\ Mg^{++} + Na^{+} + K^{+}] – [Cl^{-} + 0.2\ S^{--} + 0.3\ P^{---}]$). An alternative approach is to provide dietary guidelines for minerals that will result in a reasonable DCAD. Dietary magnesium should be set at 0.4%. Magnesium sulfate or magnesium chloride can be used, the latter is a better acidifying agent. Dietary phosphorous should be set at 0.4%. Excessive phosphorous can induce milk fever. Dietary sulfur should not exceed 0.4%, particularly since sulfates are not the most effective acidifying agents. Dietary chlorine can be added to achieve an appropriate level of acidification in the diet. Chlorine can be added to 0.5% of the diet without adverse effects on dry matter intake. Most diets will contain 0.6% chlorine for effective prevention of milk fever. Feeding above 0.6% chlorine increases the likelihood of feed intake depression and should be avoided. Urinary pH can be used as an indicator of acid-base balance in the cow. Urine pH between 6.0 to 6.5 is necessary for successful control of milk fever. Urinary pH of 8.0 is not unusual in herds with milk fever problems. Removal of high potassium forages from transition diets should be the first step in milk fever prevention because anionic salts are expensive and sufficient reduction in urinary pH may not be obtainable through anionic salt supplementation alone. Although data is limited, most researchers recommend high dietary calcium (1.2-1.3% of DM) when using anionic salts.

Bio-Chlor (Biovance Technologies, Oskaloosa, IA), is being marketed as an alternative source of anionic salts. It is a by-product of the manufacture of monosodium glutamate and contains 8.6% chloride and 2.4% sulfur (DM basis). Each pound of the supplement provides 1.5 equivalents of anionic salts. The recommended feeding rate is 2.5 pounds per cow per day, but feeding rates will vary depending on the DCAD. Preliminary results suggest better palatability and similar efficacy for acidifying blood and urine relative to traditional anionic salts. Feedback from the field has been positive. There have been reports of higher prepartum intakes. More controlled research is needed.

Hydrochloric acid is also being used as a source of anions. It yields an acid taste to the diet rather than a salt taste and may be more palatable. Hydrochloric acid is an excellent acidifier and should be less expensive than anionic salts. Direct use on the farm is dangerous and not recommended, however, by-product feeds can serve as a carrier and hydrochloric acid is available commercially in the US through the feed product SoyChlor®.

Digestion Additives

Direct-Fed Microbials

Hutjens (1992) suggested that the transition period is the optimum time to feed yeast products to stabilize the rumen environment as cows shift from low to high energy diets. Research data on this feeding strategy are limited.

Robinson (1995) fed 57 grams (2 oz) yeast culture (Diamond V Mills, Cedar Rapids, IA) from 14 days prepartum through 14 days postpartum. Lactation performance was monitored on 27 multiparous Holstein cows (13 in control and 14 in treatment groups) through 28 days postpartum. Pre- or post-partum intakes of DM and milk or component yields were not affected by treatment. Cows fed yeast culture lost less ($P<.01$) BCS prepartum with a numerically higher weight gain. Postpartum loss of body weight and BCS tended to be less for cows fed yeast culture. Similar trends were observed in a follow-up study (Robinson, personal communication).

Wohlt et al. (1991) supplemented 24 primiparous Holstein cows on corn silage-based diets with either 0 or 10 grams of yeast (Chr. Hansen's, Milwaukee, WI) from 30 days prepartum through 18 weeks postpartum. Cows supplemented with yeast peaked earlier and higher and had higher average milk yields over the 18 week study. Intakes of DM prepartum and through the first 6 weeks postpartum tended to be higher for cows supplemented with yeast.

Wohlt et al. (1995) supplemented 36 multiparous Holstein cows on corn silage-based diets with either 0 or 10 grams yeast (Chr. Hansen's, Milwaukee, WI) from 30 days prepartum through 4 weeks postpartum and then 0, 10, or 20 grams yeast during weeks 5-18 postpartum. Yeast supplementation did not improve DMI or body weight prepartum or through 4 weeks postpartum. Milk and component yields through 4 weeks postpartum were not improved by yeast supplementation. Milk yield and DMI during weeks 5-18 were increased by yeast supplementation in both supplemented and unsupplemented transition groups.

Yeast culture (Diamond V, Cedar Rapids, IA) was fed to Jersey cows from 14 days prior to expected calving until 140 days postpartum (McCoy et al., 1997). Dry matter intake was increased by feeding yeast during the last 7 days prepartum (9.8 vs 7.7 kg/day) and during the first 42 days postpartum (13.7 vs 11.9 kg/day). Cows fed yeast produced more milk (50.5 vs 47.0 kg/day) with higher fat test (4.44 vs 4.27%) but these differences were not statistically significant.

Numerous products containing bacterial direct-fed microbials are targeted to transition cows. These generally contain lactobacillus or streptococcus organisms and are available in several forms including powders for feed incorporation, pastes, boluses, or liquids (Hutjens, 1992). More research is needed.

Buffers

Dietary buffers are used widely in dairy feeding programs. They can improve milk yield and milk fat test (Hutjens, 1992). Feeding recommendations (Hutjens, 1992) for commonly used ingredients are sodium bicarbonate or sesquicarbonate (.25-.50 lb per day) and magnesium oxide (.10-.20 lb per day). Use in early postpartum cows relates to their role in maintaining high ruminal pH and fiber digestion, minimizing off-feed problems, and improving feed intake. Sodium bicarbonate or sesquicarbonate and potassium bicarbonate or buffer packs that contain these ingredients should not be used in steam-up diets because they will increase the DCAD. Be cautious of this in herds that feed milking cow ration to steam-up cows.

Nutritive Additives

Fat supplements

Supplemental fat has been used to increase the energy density of diets for early postpartum cows. In theory, this should increase energy intake resulting in higher milk yield or less body weight loss. However, Jerred et al. (1990) observed that early postpartum cows fed supplemental fat had lower dry matter and similar energy intakes. A milk production response to supplemental fat was not observed until week six postpartum. Shaver (1993) noted several studies reporting delayed early postpartum milk production response to supplemental fat. This raises questions about the level of fat addition to early postpartum diets.

Seymour et al. (1994) reported lower DMI for cows fed a ration containing 7% total fat during days 1-49 postpartum relative to cows fed rations containing 4.3% or 5.5% total fat. Supplemental fat was a 50:50 blend of calcium salts of long chain fatty acids (Church & Dwight Co., Princeton, NJ) and tallow. Milk yield during days 1-49 postpartum was highest for the ration containing 5.5% total fat. Milk yield during days 50-100 postpartum was highest for cows fed rations containing 5.5% and 7% total fat during days 1-49 and 50-100 postpartum, respectively. Feeding rations containing 7% total fat did not adversely affect DMI during days 50-100 postpartum. It is recommended that early postpartum rations be restricted to 2-3% supplemental fat or 5-6% total fat (DM basis).

There is little research on the addition of fat to steam-up diets. Skaar et al. (1989) reported a trend for higher total liver lipids at calving and at five weeks postpartum for cows fed 5% prilled fat in the total ration dry matter from 17 days prepartum through 105 days postpartum. Salfer et al. (1995) saw no benefit to the prepartum addition for 14 days of hydrogenated tallow (Alifet USA, Cincinnati, OH) at 1% of total ration dry matter when evaluating performance during the first 151 days postpartum of cows fed lactation rations containing 2% hydrogenated tallow (DM basis). Grum et al., (1996) increased energy density of diets fed to cows for the entire dry period by increasing concentrate:forage or by feeding supplemental fat. Feeding supplemental fat during the entire dry period reduced plasma NEFA concentrations and liver fat at calving; increasing concentrate:forage had no effects. Milk production was not affected by fat supplementation during the dry period. Allen et al. (1995) utilized a 2 x 2 factorial design to examine the effects of fat supplementation during prepartum, postpartum, or pre- and postpartum on health, production and reproduction. Prepartum diets were isocaloric and 75% forage and 25% concentrate. Prepartum treatments were corn-soy vs. wheat middling-fat based concentrates (1.5% of total dry matter as fat). After calving, one-half of the animals from each prepartum treatment were fed 0 or 4% animal fat. Feeding fat prepartum did not affect dry matter intake but did increase plasma NEFA. Feeding fat after calving increased plasma NEFA and beta-hydroxybutyrate concentrations, decreased plasma glucose, dry matter intake and milk yield, and increased the incidence of ketosis. There were no prepartum by postpartum treatment interactions which indicated that fat supplementation during the transition period did not help acclimate cows to fat supplementation postpartum.

Ruminally-protected amino acids

Garthwaite et al., (1999) recently summarized lactation responses to rumen-protected amino acids when supplementation began prepartum and continued postpartum. Average responses were + 1.1 lb/day DMI, + 3.7 lb/day milk, + .06 percentage units milk protein, + 79 g/day milk protein, + 0.10 percentage units milk fat, and + 85 g/day milk fat. Negative results were obtained in three of the nine experiments summarized. The authors speculated that negative results may have been due to excessive amino acid supplementation relative to requirements during the prepartum period. Amino acid requirements for maintenance plus pregnancy have not been defined. However, Putnam et al. (1996) indicated that transition cows fed diets containing 10.5, 12.6, or 14.5% CP and restricted to a DMI of 1.5% of body weight were all in positive nitrogen balance during the transition period. Therefore, over-supplementation is possible during the transition period, particularly if rumen-protected amino acids are fed at the rates recommended for the lactation period.

Use of Feed Additives in Transition Diets fed in Wisconsin

Gunderson (1998, unpublished) surveyed ten of the top dairy herds for use of feed additives in transition and immediate post-fresh diets. Herd sizes ranged from 44 to 585 cows; average was 194. Rolling herd average ranged from 25,111 to 31,539 lb; average was 29,872 lb. DMI ranged from 54 to 58 lb/day; average was 55.9. Results of the survey were as follows:

Feed Additive	Amount/cow/day	Number of Farms Using Additive
Pre-fresh		
Propylene Glycol	8 oz.	1
Yeast	2-4 oz.	3
Anionic Salts	8 oz.- 2 lb*	4
Chelated Mineral	---	1
Post-fresh		
Propylene Glycol	4 oz.	1
Yeast	2-4 oz.	4
Chelated Mineral	---	2
Sodium Bicarbonate	6-8 oz.	2

*varies according to product and carrier

References

Allen, S. K., D. J. Carroll, and B. A. Barton. 1995. The effects of supplemental energy pre- and postpartum on lactation and reproductive performance of dairy cattle. J. Dairy Sci. 78(Suppl. 1):164 (Abstr.).

Bauchart, D., D. Durand, D Gruffat, and Y. Chilliard. 1998. Mechanism of liver steatosis in early lactation cows-effects of hepatoprotector agents. Pages 27-37 in Proceedings of the Cornell Nutrition Conference

Bertics, S.J., R.R. Grummer, C. Cadorniga-Valino and E.E. Stoddard. 1992. Effect of prepartum dry matter intake on liver triglyceride concentration and early lactation. J. Dairy Sci. 75:1914.

Bertics, S. J., and R. R. Grummer. 1997. The effects of fat and methionine on liver triglyceride of dry cows during feed restriction. J. Dairy Sci. 80(Suppl. 1):252 (Abstr.).

Bertics, S. J. and R. R. Grummer. 1998. Effects of dietary fat and methionine on depletion of liver triglyceride. J. Dairy Sci. 81(Suppl. 1):311 (Abstr.).

Burton, J. L., B. A. Mallard, and D. N. Mowat. 1993. Effects of supplemental chromium on immune response of periparturient and early lactation dairy cows. J. Anim. Sci. 71:1532-1539.

Chang, G. X., B. A. Mallard, and D. N. Mowat. 1996. Effects of supplemental chromium on health status, blood neutrophil, and in vitro lymphocyte blastogenesis of dairy cows. Vet. Immunol. Immunopath. 52:37-47.

Christensen, J. O., R. R. Grummer, F. Rasmussen, and S. J. Bertics. 1997. Method of propylene glycol delivery influences metabolites of feed-restricted cattle. J. Dairy Sci. 80:563.

Di Costanzo, A. and J.N. Spain. 1995. Effect of rumen protected choline or methionine on lactational performance and metabolites of periparturient Holsteins. J. Dairy Sci. 78(Suppl. 1):188 (Abstr.).

Dufva, G. S., E. E. Bartley, A. D. Dayton, and D. O. Riddell. 1983. Effect of niacin supplementation on milk production and ketosis of dairy cattle. J. Dairy Sci. 66:2329.

Drackley, J.K. 1993. Fatty liver and ketosis in dairy cows. Proc. 4-State Applied Nutr. Conf. La Crosse, WI.

Erdman, R.A. 1994. Production responses in field study herds fed rumen protected choline. J. Dairy Sci. 77(Suppl. 1): 186 (Abstr.).

Fisher, L.J., J.D. Erfle, G.A. Lodge and F.D. Sauer. 1973. Effects of propylene glycol or glycerol supplementation of the diet of dairy cows on feed intake, milk yield and composition, and incidence of ketosis. Can. J. Anim. Sci. 53:289.

Garthwaite, B. D., C. G. Schwab, and B. K. Sloan. 1999. Low crude protein diets may work in prepartum cows. Feedstuffs, Vol. 71, No. 2, Page 11.

Grum, D. E., J. K Drackley, R. S. Younker, D. W. Lacount, and J. J. Veenhuizen. J. 1996. Production, digestion, and hepatic lipid metabolism of dairy cows fed increased energy from fat or concentrate. Dairy Sci. 79:1836.

Grummer, R.R., J.C. Winkler, S.J. Bertics and V.A. Studer. 1994. Effect of propylene glycol dosage during feed restriction on metabolites in blood of prepartum Holstein heifers. J. Dairy Sci. 77:3618.

Hayirli, A., D. R. Bremmer, S. J. Bertics, M. T. Socha, and R. R. Grummer. 2001. Effect of Chromium supplementation on production and metabolic parameters in periparturient dairy cows. J. Dairy Sci. 84:1218-1230.

Hutjens, M.F. 1992. Selecting feed additives. In: Large Dairy Herd Management. Ed: H.H. Van Horn and C.J. Wilcox.

Jerred, M.J., D.J. Carroll, D.K. Combs and R.R. Grummer. 1990. Effects of fat supplementation and immature alfalfa to concentrate ratio on lactation performance of dairy cattle. J. Dairy Sci. 73:2842.

Kertz, A.F., L.F. Reutzel and G.M. Thomson. 1991. Dry matter intake from parturition to mid lactation. J. Dairy Sci. 74:2290.

Lean, I. J., and L. Wade. 1997. Effects of monensin on metabolism, production, and health of dairy cattle. Proceedings of a symposium: Usefulness of ionophores in lactating dairy cattle. Ontario Veterinary College. June 25-26, 1997. Pages 50-70.

Littledike, E.T., J.W. Young and D.C. Beitz. 1981. Common metabolic diseases of cattle: Ketosis, milk fever, grass tetany, and downer cow complex. J. Dairy Sci. 64:1465.

Mallard, B. A., D. N. Mowat, K. Leslie, X. Chang, and A. Wright. 1994. Immunomodulatory effects of chelated chromium on dairy health and production. Pages 69-76 *In* Natl. Mastitis Counc. Annual Mtg. Proc., Harrisburg, PA. Natl. Mastitis Counc., Inc., Arlington, VA.

McCoy, G. C., J. K. Drackley, M. F. Hutjens, and J. E. Garret. 1997. Effect of yeast culture (Saccharomyces cerevisiae) on prepartum intake and postpartum intake and milk production in Jersey cows. J. Dairy Sci. 80(Suppl. 1):262 (Abstr.).

Minor, D. J., S. L. Trower, B. D. Strang, R. D. Shaver, and R. R. Grummer. 1998. Effects of nonfiber carbohydrate and niacin on periparturient metabolic status and lactation of dairy cows. J. Dairy Sci. 80:189.

National Research Council. 1997. The Role of Chromium in Animal Nutrition. National Academy Press. Washington, D. C.

Phipps, R. H., B. A. Jones, J. I. D. Wilkinson, and M. E. Tarrant. 1997. The influence of monensin on milk production of Friesian dairy cows in the United Kingdom. J. Dairy Sci. 80(Suppl. 1):208 (Abstr.).

Piepenbrink, M. S., and T. R. Overton. 2000. Liver metabolism and production of periparturient dairy cattle fed rumen-protected choline. J. Dairy Sci. 83(Suppl. 1):257 (Abstr.).

Putnam, D. E., G. A. Varga, T. W. Cassidy, J. E. Vallimont. 1996. Increasing dietary protein density increases N balance in late gestation Holstein cows. J. Dairy Sci. 79(Suppl. 1):207 (Abstr.).

Robinson, P.H. 1995. Effect of yeast on the adaptation of cows to diets post-partum. J. Dairy Sci. 78(Suppl. 1):267 (Abstr.).

Salfer, J.A., J.G. Linn, D.E. Otterby and W.P. Hansen. 1995. Early lactation responses of Holstein cows fed a rumen-inert fat prepartum, postpartum, or both. J. Dairy Sci. 78:368.

Sauer, F.D., J.D. Erfle and L.J. Fisher. 1973. Propylene glycol and glycerol as a feed additive for lactating dairy cows: An evaluation of blood metabolite parameters. Can. J. Anim. Sci. 53:265.

Sauer, F.D., J.K.G. Kramer and J. Cantwell. 1989. Antiketogenic effects of monensin in early lactation. J. Dairy Sci. 72:436.

Schultz, L.H. 1958. Use of sodium propionate in the prevention of ketosis in dairy cattle. J. Dairy Sci. 41:160.

Seymour, W.M., J.E. Nocek and J. Siciliano-Jones. 1994. The effect of dietary fat level on performance of dairy cows at different stages of lactation. J. Dairy Sci. 77(Suppl. 1):344 (Abstr.).

Shaver, R.D. 1993. TMR transition strategies for transition feeding of dairy cows. Proc. MN Nutr. Conf. Bloomington, MN.

Skaar, T.C., R.R. Grummer, M.R. Dentine and R.H. Stauffacher. 1989. Seasonal effects of prepartum and postpartum fat and niacin feeding on lactation performance and lipid metabolism. J. Dairy Sci. 72:2028.

Studer, V.A., R.R. Grummer, S.J. Bertics and C.K. Reynolds. 1993. Effect of prepartum propylene glycol administration on periparturient fatty liver in dairy cows. J. Dairy Sci. 76:2931.

Subiyatno, A., D. N. Mowat, and Z. W. Yang. 1996. Metabolic and hormonal responses to glucose and propionic acid infusions in periparturient cows supplemented with chromium. J. Dairy Sci. 79:1436-1445.

Thomas, E.E., S.E. Poe, R.K. McGuffey, D.H. Mowrey and R.D. Allrich. 1993. Effect of feeding monensin on milk production and serum metabolites during early lactation. J. Dairy Sci. 76(Suppl. 1): 280 (Abstr.).

Wohlt, J.E., T.T. Corcione and P.K. Zajac. 1995. Improvements in performance and nutrient digestibility when corn silage based diets fed to dairy cows were supplemented with yeast. J. Dairy Sci. 78(Suppl. 1):267 (Abstr.).

Wohlt, J.E., A.D. Finkelstein and C.H. Chung. 1991. Yeast culture to improve intake, nutrient digestibility, and performance by dairy cattle during early lactation. J. Dairy Sci. 74:1395.