FATS AND PROTEINS RESEARCH FOUNDATION, INC.

Director's Digest

FRED D. BISPLINGHOFF, D.V.M.
Director Technical Services

7150 ESTERO BLVD. • APT. 906
FT. MYERS BEACH, FL 33931
AREA CODE 813 — 463-4744

June, 1992 No. 238

UTILIZATION OF FAT IN DAIRY CATTLE RATIONS

Ric R. Grummer, Ph. D.
University of Wisconsin, Madison
Dairy Science Department

INTRODUCTION

Immediately after calving, dairy cattle are in negative energy balance. This results because energy intake is insufficient to meet the cow's energy requirement for maintenance and copious milk secretion. Weight loss is expected during early lactation, however, if excessive, maximum milk production, health, and reproductive performance of dairy cow will not be obtained. Consequently, maximizing energy intake during early lactation is essential. Energy intake is dependent on level of feed intake and energy density of the diet. Energy content of the diet can be increased by feeding supplemental fat or by increasing the proportion of the diet that is grain. The latter option is often practiced following calving, however, there are upper limits to the amount of grain that can be fed to ruminant animals. Excessive grain feeding results in depressed fiber digestion, decreased ruminal pH, and a low ratio of acetate:propionate, the two major volatile fatty acids formed during fermentation of feedstuffs. Low ruminal pH and low acetate:propionate will lead to acidosis, founder, and milk fat depression. Supplementing fat is a means by which energy density of the diet can be increased without reducing fiber levels below that required for optimal rumen fermentation. Fat, relative to protein and carbohydrate-rich feeds, has greater than three times the net energy of lactation.

The concept of feeding fat to dairy cattle dates back to the 1800's. It did not become popular until the latter 1970's and 1980's when a more complete appreciation of the effects of various fat sources on rumen fermentation were realized and feeding strategies were developed. Genetic potential of cows to produce milk has increased dramatically during the past 3 to 4 decades. It is safe to assume that the task of meeting the energy needs of cattle will not become easier as genetic potential of cows continues to increase and as new technologies (e.g. administration of bovine somatotropin) to enhance lactation performance are developed. The continuing challenge for dairy nutritionists will be to feed lactating cows to maintain health and maximize milk yield while minimizing cost of the diet. Undoubtedly, fat will play an increasingly important role in feeding dairy cows.

DIGESTION AND ABSORPTION OF FAT

Prior to reviewing the various fat sources available for incorporation into dairy rations, it is important to understand the digestion and absorption of fat in ruminant animals. Dietary sources of fat are usually long chain fatty acids in free or esterified form. Triglycerides and galactolipids are the primary forms of esterified fatty acids, the former being in greatest abundance in cereal grains and the latter being in greatest abundance in forage plants. Supplemental fats may be free fatty acids, esterified fatty acids, or mineral salts of fatty acids. Esterified fatty acids are rapidly hydrolyzed to free form by lipolytic microorganisms within the rumen. Following hydrolysis, unsaturated fatty acids are hydrogenated by ruminal microorganisms, but extent of hydrogenation is dependant on the degree of unsaturation of fatty acids and level and frequency of feeding. If excessive amounts of polyunsaturated fatty acids are fed, capacity of the ruminal microorganisms to hydrogenate (saturate) fatty acids may be exceeded. This is undesirable because unsaturated fatty acids are toxic to ruminal microorganisms. Estimates for ruminal hydrogenation of PUFA range from 60 to 90% (Bickerstaffe et al., 1972; Mattos and Palmquist, 1977). Because of hydrogenation in the rumen, C18:0 and and C18:1 are the major fatty acids leaving the rumen. Long chain fatty acids are not degraded in the rumen. Since fatty acids are hydrophobic, they associate with particulate matter and pass to the lower gut. Digestion coefficients for total fatty acids within the rumen are negative which reflects microbial synthesis of fatty acids. The majority of fatty acids synthesized by rumen microbes are incorporated into phospholipids. Approximately 85 to 90% of the fatty acids leaving the rumen are free fatty acids and approximately 10 to 15% microbial phospholipids.

Although little triglyceride reaches the small intestine of ruminants, bile and pancreatic secretions are required for lipid absorption. If triglycerides are fed at moderate levels in a form which protects them from ruminal hydrolysis (e. g. formaldehyde protected casein-fat emulsion), there appears to be sufficient pancreatic lipase for triglyceride hydrolysis (Noble, 1981). However, pancreatic lipase does not appear to be inducible (Johnson et al., 1974) and may become limiting if large quantities of triglyceride are presented to the small intestine. In the absence of substantial amounts of monoglyceride reaching the small intestine, ruminants are dependant on lysolecithin and the monounsaturate, oleic acid, for fatty acid emulsification. Lysolecithin is formed by pancreatic phospholipase activity on lecithin which may be of microbial or hepatic origin. Monounsaturated fatty acid is predominantly from digesta leaving the rumen. Therefore, it is critical that fatty acids supplemented to the diets of ruminants are not completely saturated and a portion of the unsaturated fatty acids avoid complete hydrogenation by ruminal organisms. Fatty acid emulsification and micelle formation in the small intestine is critical for efficient fat digestion and absorption.

SOURCES OF FAT FOR DAIRY DIETS

A wide variety of fat supplements are available for dairy cattle diets and include oilseeds, rendered fats such as tallow or yellow grease, and specialty fats that are manufactured to have a high degree of ruminal inertness, i.e., do not interfere with rumen fermentation. Specialty fats include hydrogenated tallow, relatively saturated long chain fatty acids, and calcium salts of long chain fatty acids.

To maximize ruminal fiber digestion, milk fat percentage, and animal health, it is essential to feed fats which minimize interference with ruminal fermentation. Oilseeds, relatively saturated fats, and mineral salts of fatty acids are desirable fats for dairy rations. Oilseeds may contain 15 to 35% fat, predominantly in the triglyceride form. Oilseed fat is highly unsaturated, which may seem undesirable. However, the fat within the seed is slowly released into the rumen as the seed is being degraded by ruminal microorganisms. Therefore, at any point in time, only small amounts of the fat are present in "free" form in the rumen. Feeding a totally mixed ration or heat treated oilseeds may further minimize the amount of fat released into the rumen at any particular moment. The negative impact of the unsaturated fat is reduced under these conditions, largely because the bacteria in the rumen are able to convert modest amounts of unsaturated fat to less toxic saturated fat. Recent research at the University of Wisconsin (Knapp et al., 1991) indicated that whole roasted soybeans can be fed at 24 % of ration dry matter in a total mixed ration without any adverse effects on fiber digestion, rumen fermentation, and fat test. However, recommendations for oilseed feeding levels are usually lower than this to insure against the possibility of overloading the rumen with polyunsaturated oil or overfeeding protein.

Saturated fats are believed to be relatively inert in the rumen because of their high melting point and consequently low solubility in fluid bathing the rumen. Reducing solubility of fat in rumen fluid presumably reduces interaction of fat with rumen microorganisms. The fatty acid composition and ratio of unsaturated fatty acids to saturated fatty acids of several fat sources is in the Table 1. Tallow is solid at room temperature and is considerably more saturated than vegetable oils and greases. This probably accounts for the lack of interference with rumen fermentation when feeding a pound or more of tallow to high producing cows even if oilseeds are present in the diet (Grummer et al., 1992). Research from the University of California at Davis (DePeters et al., 1987) indicated that supplementing 3.5% yellow grease, which is more unsaturated than tallow, had minimal effects on diet digestibility and enhanced lactation performance when incorporated into dairy rations containing whole cottonseeds.

Table 1. Fatty acid composition of fat supplements.

	Fatty acid content, g/100g fatty acid							
Source	C14:0	C16:0	C16:1	C18:0	C18:1	C18:2	C18:3	U/S[1]
Soybean oil	---	10	---	4	23	51	7	5.64
Poultry	1	24	10	5	43	17	1	2.44
Yellow grease	1	18	2	10	46	21	1	2.33
Choice white grease	2	24	4	12	45	11	3	1.70
Animal-vegetable	2	26	2	18	34	16	2	1.17
Tallow	3	27	5	21	41	2	1	0.96
Part. hyd. tallow[2]	4	26	3	35	32	---	---	0.54
Hyd. relatively[3] sat. fatty acids	2	47	---	36	14	1	---	0.18

[1]U/S = Ratio of saturated to unsaturated fatty acids.
[2]Alifet; Alifet USA, Inc. (Cincinnati, Ohio).
[3]Energy Booster 100; Milk Specialties, Inc. (Dundee, Illinois).

To reduce the level of unsaturation in tallow, it may be hydrogenated. Many of the commercially available specialty fat sources are hydrogenated tallow or hydrolyzed and hydrogenated tallow. The degree of hydrogenation of these types of products is important. If the product is overhydrogenated, the fat may actually become too hard for efficient digestion in the lower tract. In other words, there still should be some C18:1 remaining after hydrogenation. The minimum acceptable level has not been clearly defined, but it should probably be at least 10 to 15 % C18:1. Tallow that has not been hydrogenated is approximately 40 % C18:1.

Encapsulated tallow is another product designed to render tallow more inert in the rumen. Sodium alginate treatment is used to physically coat tallow to prevent it from influencing rumen fermentation. There is no difference in fatty acid makeup between this product and tallow. Consequently, to be effective, the encapsulation process must be relatively complete. Further research is needed to document the degree of protection provided by alginate treatment.

Mineral salts of long chain fatty acids are inert in the rumen because they are relatively insoluble in ruminal fluid. Once the complex is delivered to the acidic conditions of the abomasum and small intestine, the complex is broken and the fatty acid is available for digestion. The product has been extensively researched and is inert in the rumen when included at 4 % of ration dry matter.

EFFECTS OF FAT SUPPLEMENTATION ON PERFORMANCE OF DAIRY CATTLE

An extensive review of the literature on fat supplementation of dairy cattle diets was presented by Shaver (1990) and a summary of his findings regarding animal performance is in Table 2.

Table 2. Performance of cattle fed various fat sources

		Change from control				
Source (n)	Suppl. fat, % of DM	DMI lb/d	Milk lb/d	FCM lb/d	Fat %	Protein %
Roasted SB (5)	2.5-3	.2	4.2	4.1	.06	-.08
Cottonseeds (4)	3-3.5	-.7	.5	2.9	.28	-.09
Megalac (10)	2-3	-1.1	3.1	4.0	.11	-.08
Tallow (5)	4-5	1.0	3.8	4.3	.11	-.15

Adapted from Shaver, 1990

In general, milk increases 3 to 4 lb per day when supplementing fat at 2 to 4% of ration dry matter; greater responses have been observed. Milk yield response tends to be lower when supplementing cottonseeds. However, fat percentage is usually increased more when cottonseed is supplemented. Milk protein percentage almost always is decreased when feeding fat, but total protein synthesized by the mammary gland usually remains constant. In other words, the decrease in milk protein percentage reflects a dilution of protein because of enhanced milk yield.

Milk protein premiums have been increasing and probably will continue to increase in the future. Feeding strategies to alleviate depression in milk protein percentage have not been identified. Numerous reports have suggested that feeding niacin, additional undegradable protein, or ruminally protected amino acids may alleviate the depression (Horner et al., 1986; Canale et al., 1990; DePeters and Palmquist, 1990). Research results have been inconsistent, but in several trials, milk protein percentage was increased using these feeding strategies. However, in almost all cases, the increase in milk protein is independent of fat being in the diet.

It is very clear from the literature that heifers respond differently to fat supplementation than mature cows (Mattias, 1982; Robb and Chalupa, 1987; Ferguson et al., 1988; Pitcher et al., 1991a, 1991b; Table 3). Increases in milk and fat-corrected milk yields were 4.9 and 6.1 lb per day for multiparous cows and 1.8 and 2.9 lb per day for heifers when fat was fed in five research and field trials. Little difference was observed in the milk fat percentage responses between heifers and mature cows. Energy supplied to heifers is used for growth in addition to maintenance and lactation. Therefore, a lower proportion of the energy supplied by fat may be available for milk production in heifers. The lower milk response by heifers relative to mature cows may be economically important because heifers may constitute 35 to 40% of the herd. However, one should be cautioned against making the decision of whether to feed fat to heifers based solely on predicted milk responses. Fat supplementation may enable heifers to better withstand the stress of the first lactation, maintain better body condition, and consequently perform better during the second lactation.

Table 3. Responses of heifers and mature cows to supplemental fat[1].

	Milk	FCM	FAT
Heifers	+1.8 lb	+2.9 lb	+.1 %
Mature	+4.9 lb	+6.1 lb	+.1 %

[1]Mattias, 1982; Robb and Chalupa, 1987; Ferguson et al., 1988; Pitcher et al., 1991a, 1991b.
[2]Fat-corrected milk.

Numerous trials have indicated that there was little benefit from feeding fat during the first 5 to 7 weeks postpartum (Ruegsegger and Schultz, 1985; Jerred et al., 1990; Hoffman et al., 1991). In essence, there seems to be a lag time prior to obtaining a milk response (Figure 2). Surprisingly, cows seem to best respond to fat near the time they reach positive energy balance. Similarly, body weight loss may not be reduced by feeding additional fat (Skaar et al., 1989). However, gain usually is accelerated once the cow reaches positive energy balance. The lack of an early lactation response seems to be related to a depression in feed intake which offsets any advantage that may be gained by increasing the energy density of the diet. Adding fat at 3% of diet dry matter increases energy density by about 7 to 8%, therefore, a similar percentage decrease in feed intake will offset the benefit of supplementing fat to the diet. It has not been determined whether one must feed fat during the first weeks of lactation to obtain the benefit later on, or if one could start feeding fat at 6 to 7 weeks postpartum and get the response immediately without experiencing a lag phase. The latter is a more likely scenario. The early lactation cow that is rapidly mobilizing a lot of body fat seems to be "metabolically programmed" to consume a given amount of energy. It has been known for years that cows are slow to increase feed feed intake following calving and recent evidence suggests that factors beyond gut fill limit feed intake in early lactation (Johnson and Combs, 1991). Physiological regulation of feed intake in lactating cows is poorly understood. Ideally, fat should probably be left out of the diet immediately postpartum. However, management factors may preclude doing so.

Field trials conducted in Pennsylvania (Chalupa and Ferguson, 1990) and university trials conducted at South Dakota State University (Schingoethe and Casper, 1991) indicated that milk yield advantages from feeding fat during the first half of lactation are maintained even when fat is withdrawn at mid lactation (Figure 1). This probably should be expected if cows are in positive energy balance at the time fat is removed from the diet. Pennsylvania and South Dakota research did not address whether cows could have produced additional milk if fat would have been left in the diet for the remainder of the lactation. Once again, logic says that cows would not respond to fat supplementation if they were in positive energy balance. However, numerous trials indicated that lower milk producing cows (<60 lb per day), presumably in positive energy balance, respond to fat supplementation (Shaver, 1990). The reason for the milk response is not known, however, fat supplementation may increase availability of glucose to milk producing cells. Glucose is a precursor for lactose synthesis and the amount of lactose synthesized is a major determinant of milk volume produced by the mammary gland.

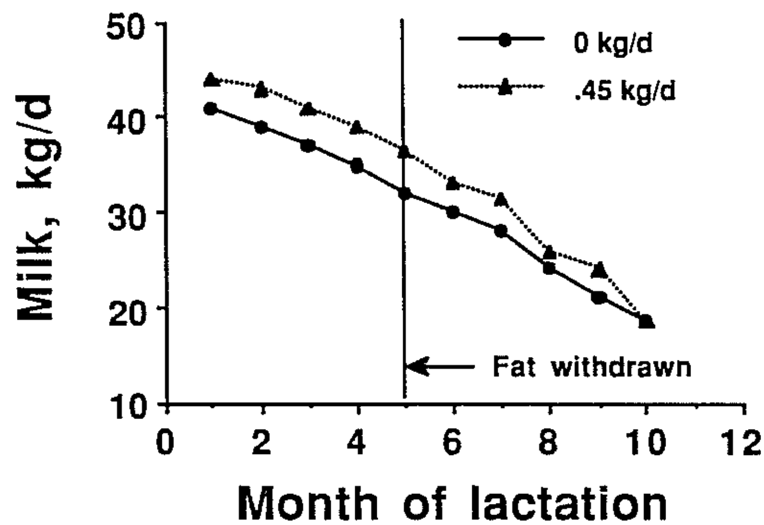

Figure 1. The "carry over" effect when fat is withdrawn from the diet of mid lactation cows. Chalupa and Ferguson, 1990.

Fat supplementation may be particularly beneficial when environmental temperature and humidity are high and cows are heat stressed. Digestion and metabolism of feed nutrients causes heat production. If an animal is heat stressed, it reduces feed intake to reduce the heat load and energy expenditures associated with dissipating heat. It has been shown in numerous species of animals that less heat is generated during the digestion and metabolism of fat relative to proteins and carbohydrates. Therefore, fat feeding during heat stress may serve a dual function. It may lessen the heat load and it will increase the energy density of the diet during periods when feed intake is likely to be depressed. In a recent lactation trial we conducted (Skaar et al., 1989), cows fed fat supplemented diets had improved lactation performance during the warm weather months but not during the cool weather months (Figure 2). Based on these results, we conducted a study (Knapp and Grummer, 1991) to examine the seasonal effects on fat feeding under more controlled conditions. Cows were housed in environmentally controlled chambers where they were subjected to thermoneutral or heat stress environments. No differences in response to supplemental fat was noted between cows kept in the two environments. This may have been due to our experimental design, to the limited number of cows that we were able to use in the experiment, or to the absence of an effect. Although research results are inconsistent, biological principles argue in favor of fat supplementation during heat stress conditions.

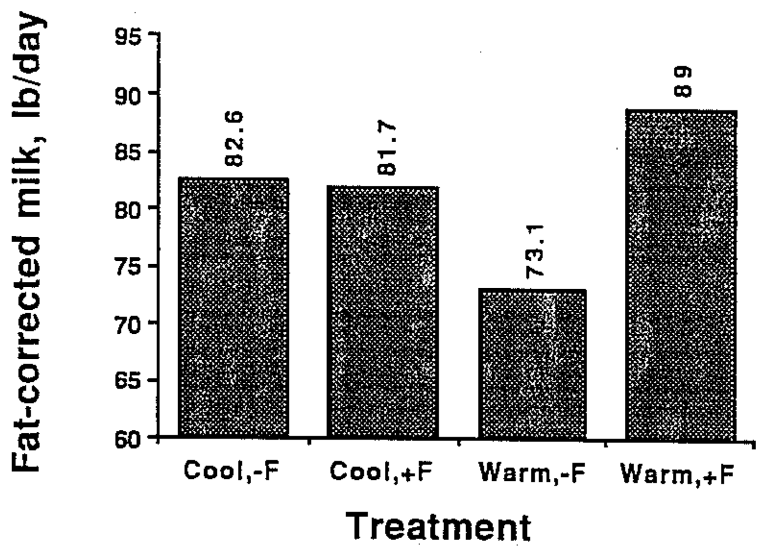

Figure 2. Lactation response to supplemental fat during cool and warm seasons. Skaar et al., 1989

Other potential benefits from feeding fat to lactating cows may be improvement in body condition, reproductive performance, and metabolic status, although documentation of these effects is limited. Improvement in reproductive performance due to fat supplementation may be the consequence of improved energy status, provision of essential fatty acids, or stimulation of progesterone production by the corpus luteum (Grummer and Carroll, 1991). The majority of studies have not shown an improvement in reproductive performance of cattle fed supplemental fat, however, this is probably the consequence of insufficient animal numbers on trial to detect a response. Ferguson et al., (1990) observed an improvement in first service conception rate and a decrease in services per conception, while Sklan et al. (1991) noted a decrease in days open and an increase in pregnancy rate when feeding supplemental fat.

Supplemental fat is primarily metabolized by extrahepatic tissues, but fatty acids mobilized during negative energy balance may be utilized by the liver. Consequently, a potential benefit from feeding fat to dairy cattle may be to reduce fatty acid mobilization and decrease the amount of fatty acids taken up by the liver, which could result in less fat deposition in the liver and lower ketone production. However, fat supplementation beginning at 17 days prepartum and lasting through early lactation did not reduce liver fat content and the positive influence on blood ketone levels was relatively small (Grummer and Carroll, 1991).

ENERGY VALUE OF SUPPLEMENTAL FATS IN DAIRY RATIONS

There are no methane or urinary energy losses associated with fat supplementation. Therefore, energy content of supplemental fat is related to it's digestibility and efficiency of conversion of metabolizable energy to net energy. Although digestibility of fat in nonruminants is influenced by the ratio of unsaturated:saturated fatty acids (Palmquist, 1988), little is known about the comparative digestibility of saturated and unsaturated fats in ruminants and differences in digestive physiology between nonruminants and ruminants make extrapolation risky. Apparent digestibility of fat in the basal diet of ruminants is low due the high concentration of endogenous lipids relative to dietary lipid and the high content of low digestibility non-fatty acid, but ether extractable material in feeds. Supplemental fat fed to late lactation cows at 3.5 % or less of the ration dry matter had an apparent digestion coefficient of approximately 85 % (Grummer, 1988). The 1989 dairy NRC assumes a digestion coefficient of approximately 79 % for both animal and vegetable fat. It is peculiar that NRC uses 1.87 Mcal DE/lb TDN from fat but uses 2.00 Mcal DE/lb TDN from other feed sources in the 1989 feed tables. Using this factor (1.87) results in low calculated DE (3.31 Mcal/lb), ME (3.31 Mcal/lb), and NEl (2.65 Mcal/lb). Several other lines of evidence point to the 2.65 Mcal NEl/lb or 3.31 Mcal ME/lb cited by the 1989 dairy NRC as being low. Davis (1988) estimated fat to contain 3.13 Mcal NEl/lb. He assumed supplemental fat to be 90 % digestible, 2.00 Mcal DE/lb TDN, DE = ME, and efficiency of conversion of ME to NEl to be 82.4 %. The latter value was based on the assumption that supplemental fat would enter the same fatty acid pool in the body as fatty acids mobilized from body stores and therefore be used at a similar metabolic efficiency. Metabolic efficiency of dietary fat utilization may actually be greater than mobilized fatty acids since they are more likely to be utilized directly by the mammary gland and less likely to be metabolized by the liver. The 1989 dairy NRC uses 80 % ME to NEl conversion efficiency which is higher than the 70 % value used in the 1978 NRC. Palmquist and Conrad (1978) estimated NEl of blended animal-vegetable fat to be 2.91 Mcal NEl/lb. This value is very close to what NRC NEl values would be for fat if 2.00 Mcal/lb TDN would have been used rather than 1.87 Mcal DE/lb TDN. Recent evidence from the University of Maryland and USDA-Beltsville (Andrew et al., 1991) indicates fat fed as calcium salts of long chain fatty acids to cows contains greater than the 3.31 Mcal ME/lb listed by NRC.

REFERENCES

Andrew, S. M., H. F. Tyrell, C. K. Reynolds, and R. A. Erdman. 1991. Net energy for lactation of calcium salts of long-chain fatty acids for cows fed silage-based diets. J. Dairy Sci. 74:2588.

Bickerstaffe, R., D. E. Noakes, and E. F. Annison. 1972. Quantitative aspects of fatty acid biohydrogenation, absorption and transfer of milk fat in the lactating goat, with special reference to the cis- and trans-isomers of octadecenoate and linoleate. Biochem. J. 120:607.

Canale, C. J., L. D. Muller, H. A. McCahon, T. J. Whitsel, G. A. Varga, and M. J. Lormore. 1990. Dietary fat and ruminally protected amino acids for high producing dairy cows. J. Dairy Sci. 73:135.

Chalupa, W., and J. D. Ferguson. 1990. Immediate and residual responses of lactating cows on commercial dairies to calcium salts of long chain fatty acids. J. Dairy Sci. 73 (Suppl. 1):244 Abstr.

Davis, C.L. Value of oilseeds in dairy diets contested. (Letter to the Ed.) Feedstuffs, Dec. 26, 1988.

DePeters, E. J., and D. L. Palmquist. 1990. Effect of fish meal and calcium salts of long chain fatty acids on the nitrogen content of milk. J. Dairy Sci. 73 (Suppl. 1):242 Abstr.

DePeters, E. J., S. J. Taylor, C. M. Finley, and T. R. Famula. 1987. Dietary fat and nitrogen composition of milk from lactating cows. J. Dairy Sci. 70:1192.

Ferguson, J. D., J. Torralba, P. L. Schneider, B. Vecchiarelli, D. Sklan, D. S. Kronfeld, and W. Chalupa. 1988. Response of lactating cows in commercial dairies to calcium salts of long chain fatty acids. J. Dairy Sci. 71(Suppl. 1):254 Abstr.

Ferguson, J. D., D. Sklan, W. V. Chalupa, and D. S. Kronfeld. 1990. Effects of hard fats on in vitro and in vivo rumen fermentation, milk production, and reproduction in dairy cows. J. Dairy Sci. 73:2864.

Grummer, R. R, and D. J. Carroll. 1991. Effects of dietary fat on metabolic disorders and reproductive performance of dairy cattle. J. Anim. Sci. 69:3838.

Grummer, R. R., M. L. Luck, and J. A. Barmore. 1992. Effects of incremental addition of tallow to diets containing roasted soybeans on rumen fermentation and lactation performance of high producing diary cows. J. Dairy Sci. 75:(Abstract submitted).

Grummer, R.R. 1988. Influence of prilled fat and calcium salt of palm oil fatty acids on ruminal fermentation and nutrient digestibility. J. Dairy Sci. 71:117.

Hoffman, P. C., R. R. Grummer, R. D. Shaver, G. A. Broderick, and T. R. Drendel. 1991. Feeding supplemental fat and undegraded intake protein to early lactation dairy cows. J. Dairy Sci. 74:3468.

Horner, J.L., C.E. Coppock, G.T. Schelling, J.M. LaBore, and D.H. Nave. 1986. Influence of niacin and whole cottonseed on intake, milk yield, and composition, and systemic responses of dairy cows. J. Dairy Sci. 69:3087.

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 nutrient utilization and lactation performance of dairy cattle. J. Dairy Sci. 73:2842.

Johnson, T. O., G. E. Mitchell, R. E. Tucker, and G. T. Schelling. 1974. Pancreatic lipase secretion by sheep. J. Anim. Sci. 39:947.

Johnson, T. R., and D. K. Combs. 1991. Effects of prepartum diet, inert rumen bulk, and dietary polyethylene glycol on dry matter intake of lactating dairy cows. J. Dairy Sci. 74:933.

Knapp, D. M., and R. R. Grummer. 1991. The response of lactating dairy cows to fat supplementation during heat stress. J. Dairy Sci. 74:2573.

Knapp, D. M., R, R. Grummer, and M. R. Dentine. 1991. The response of lactating dairy cows to increasing levels of whole roasted soybeans. J. Dairy Sci. 74:2563.

Mattias, J. E. 1982. Effect of feeding animal fat to dairy cows in early lactation. M. S. Thesis, University of Wisconsin, Madison.

Mattos, W., D. L. Palmquist. 1977. Biohydrogenation and availability of linoleic acid in lactating cows. J. Nutr. 107:1755.

Noble, R. C. 1981. Digestion, absorption, and transport of lipids in ruminant animals. Page 57 in Lipid metabolism in ruminants. W. W. Christie, Ed. Pergamon Press, Oxford.

Palmquist, D.L. 1988. The feeding value of fats. Page 293 in Feed Science. E.R. Orskov, Ed. Elsevier Science Publishers, Amsterdam.

Palmquist, D.L., and H.R. Conrad. 1978. High fat rations for dairy cows. Effect on feed intake, milk and fat production, and plasma metabolites. J. Dairy Sci. 61:890.

Pitcher, P. M., J. D. Ferguson, D. T. Galligan, and W. Chalupa. 1991a. Responses of primiparous cows to calcium salts of long chain fatty acids. J. Dairy Sci. 74 (Suppl. 1):253 Abstr

Pitcher, P. M., J. D. Ferguson, D. T. Galligan, and W. Chalupa. 1991b. Responses of multiparous cows to calcium salts of long chain fatty acids. J. Dairy Sci. 74 (Suppl. 1):253 Abstr.

Robb, E. J., and W. Chalupa. 1987. Lactation responses in early lactation to calcium salts of long chain fatty acids. J. Dairy Sci. 70 (Suppl. 1):220 Abstr.

Ruegsegger, G. J., and L. H. Schultz. 1985. Response of high producing dairy cows in early lactation to the feeding of heat-treated whole soybeans. J. Dairy Sci. 68:3272.

Schingoethe, D. J., and D. P. Casper. 1991. Total lactational response to added fat during early lactation. J. Dairy Sci 74:2617.

Shaver, R. D. 1990. Fat sources for high producing dairy cows. In: Proc. 51st Minnesota Nutrition Conference, September 18-19, 1990, Bloomington, Mn.

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

Sklan, D., U. Moallem, and Y. Folman. 1991. Effect of feeding calcium soaps of fatty acids in production and reproductive responses in high producing lactating cows. J. Dairy Sci. 74:510.