Director's Digest

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THE ROLE OF FAT IN MAXIMIZING MILK YIELD IN HIGH PRODUCING DAIRY COWS

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Introduction

If .5 kg of corn in the ration of a dairy cow is replaced by .5 kg of fat, the increase in energy intake should be sufficient to support 2.8 kg of additional milk containing 3.5% fat (NRC, 1989). This value may be low because the NRC energy value for fat may be underestimated by as much as 10 to 15%. However, research results indicate that the milk response is rarely ever that large. The challenge for research and applied dairy nutritionists is to identify factors that influence the magnitude of response to supplemental fat and to convey to the producer the conditions that provide for the greatest response. There are numerous factors that influence how cows respond to supplemental fat. Type and level of supplemental fat, characteristics of the basal diet, and physiological state of the anima are among the most important. The objective of this paper is to discuss the relationship between these factors and lactation performance.

Influence of Fat Source on Energy Utilization and Cow Performance

Effects of Fat Source on Rumen Fermentation. A wide variety of fat supplements are available for dairy cattle diets and include oilseeds, liquid fats such as tallow or grease, and granular fats that are manufactured to have a high degree of ruminal inertness, i.e., do not interfere with rumen fermentation. Granular fats include hydrogenated tallow, relatively saturated long chain fatty acids, and calcium salts of long chain fatty acids.

To maximize feed intake, ruminal fiber digestion, milk yield, milk fat percentage, and animal health, it is essential to feed fats which minimize interference with ruminal fermentation. Elevated concentrations of unsaturated nonesterified fatty acids in the rumen should be avoided (Jenkins, 1993). Unsaturated free fatty acids reduce microbial digestion of fiber. Most dietary fat is in triglyceride form; three fatty acids esterified to glycerol. Feeding triglyceride does not avoid the presence of free fatty acids in the rumen because triglycerides may be hydrolyzed by ruminal bacteria. Once hydrolyzed, bacteria can hydrogenate fatty acids. However, if large amounts of unsaturated fatty acids are present, the capacity for biohydrogenation is exceeded. Concentration of unsaturated fatty acids in the rumen is largely dependent on the amount and type of fat fed, but is also influenced by the rates of triglyceride hydrolysis, fatty acid hydrogenation, fatty acid incorporation into microbial lipid, formation of calcium salts, and adherence to feed particles (Jenkins, 1993).

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 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.

Saturated fats are believed to be relatively inert in the rumen because of their high melting point and consequently low solubility in rumen fluid (Chalupa et al., 1984). There is limited evidence to suggest that triglycerides are less detrimental to rumen fermentation than fatty acids (Chalupa et al., 1984). Rate of triglyceride hydrolysis may be slower for saturated fats (Palmquist and Kinsey, 1993). Reducing solubility of fatty acids in rumen fluid may reduce interaction with rumen microorganisms. The fatty acid composition and ratio of unsaturated fatty acids to saturated fatty acids of several fat sources is in Table 1. Tallow is solid at room temperature and is considerably more saturated than vegetable oils and greases.

Mineral salts of long chain fatty acids are inert in the rumen because they are relatively insoluble in ruminal fluid (Chalupa, 1984). 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 (Shaver, 1990).

Digestibility of the Fat Sources. In addition to the effects of fats on rumen fermentation, digestibility of fats must also be considered when selecting a fat source. The single most important factor in determining the energy value of a fat is the amount absorbed by the intestine versus excreted in the manure. Recently, Davis (1993) concluded that physical form, degree of unsaturation, and structure (fatty acid vs triglyceride) may be important factors dictating postruminal absorption of dietary fat. Postruminal fat digestion and absorption is dependent on fat solubilization. Unfortunately, the low solubility characteristic that provides for rumen inertness may be a hindrance to postruminal fat digestion. Pertinent literature in this area is summarized in Table 2 and was recently reviewed by Firkins and Eastridge (1994).

Fats that are solid at room temperature are usually sold as flakes or prills, the latter representing particles that are formed during spray drying and cooling. Size of prill can vary. Granular fats are less digestible if they are flaked rather than prilled or liquefied prior to feeding (Macleod and Buchanan-Smith, 1972; Eastridge and Firkins, 1992; Elliot et al., 1994). A 6 to 20% reduction in digestibility has been observed, presumably due to a reduction in surface area available for enzymatic digestion and (or) solubilization.

Hydrogenation of tallow or yellow grease appears to reduce dietary fatty acid digestibility (Jenkins and Jenny, 1989; Eastridge and Firkins, 1992; Eastridge et al., 1993; Pantoja et al., 1994). The degree of hydrogenation of tallow that is necessary to cause a reduction in digestibility has not been identified. Varying degree of unsaturation by blending prilled triglycerides with canola oil resulted in a quadratic or cubic response in fatty acid digestibility; maximum digestibility occurred with a 67:33 blend (Jenkins and Jenny, 1992). Effect of saturation on digestibility of fatty acids (as opposed to triglycerides) is not well documented. Drackley et al., (1992) did not measure significant differences in total fatty acid digestibility when a saturated, unsaturated, or blend of saturated and unsaturated fatty acid mixtures were infused into the abomasum. Diarrhea was a problem when infusing high levels of unsaturated fatty acids which agrees with observations of (Grummer et al., 1987, Gagliostro and Chilliard, 1991) following postruminal infusion of >500 ml soybean oil/day. It is important to note that interpretation of (Drackley et al., 1992) is difficult because degree of unsaturation was confounded by chain length of the infused fatty acids. It is generally believed that palmitic acid (C16:0) is more digestible than stearic acid (C18:0). For example, fatty acid digestibility of diets containing hydrogenated palm oil was greater than for diets containing hydrogenated tallow of a similar iodine value (Eastridge et al., 1993). Very little is known regarding the relative digestibility of fatty acids vs triglycerides in the small intestines, or if degree of unsaturation affects the digestibility of nonesterified (free) fatty acids differently than esterified fatty acids (triglycerides). Eastridge and Firkins (1991) did not observe differences in the fatty acid digestibility of diets containing hydrogenated tallow triglycerides vs hydrogenated tallow fatty acids. In general, digestibility of calcium salts of fatty acids and relatively saturated (free) fatty acids has been acceptable (e.g. Grummer, 1988).

Concentration of fat in the diet may also affect postruminal fat digestion (Zinn, 1989; Palmquist, 1991; Wu et al., 1991; Chandler, 1993). Increasing supplemental fat (yellow grease or animal-vegetable blend) from 1 to 2.5 g/kg body weight in beef diets decreased digestibility of the added fat from 80 to 60% (Zinn, 1989, 1994). Fatty acid digestibility was decreased 2.2%/100g fatty acid as intake of supplemental fat was increased from 200 to 1400 g/day (Palmquist, 1991). Chandler (1993) indicated that digestibility of tallow was only 45 to 65% when added to diets that contained supplemental fat from vegetable sources. Factors limiting postruminal fat digestion have not been identified but need to be.

Influence of Dietary Fat Concentration on Lactation Performance

In the US, oilseeds are almost always used as the first source of supplemental fat. For example, cottonseeds and soybeans are excellent sources of fiber and (or) protein in addition to fat. Fat from oilseeds typically represents approximately 2.5% of ration dry matter. It usually is the most economical source of supplemental fat assuming the fiber and protein supplied by the oilseeds are required by the cow and, therefore, have value. Once oilseeds are incorporated into the diet to balance the protein and (or) fiber needs of the cow, one must decide if there should be additional fat in the diet. One criteria for assessing whether more fat should be fed is effects on lactation performance. Characteristics of the second increment of fat is critical because there is more potential to interfere with rumen fermentation, lower gut digestibility, and lactation performance as the amount of fat in the diet is increased.

A summary of research trials in which a second increment of supplemental fat was added to diets already containing supplemental fat from oilseeds is in Table 3. Most studies have insufficient animal replication to identify treatment differences for milk yield, therefore, data from numerous studies have been compiled. Average milk yield of control cows fed a single fat source was 35 kg/day. Studies were divided into those in which the second source of fat was granular fat or liquid fat. Average amount of supplemental fat prior to addition of the second source of fat was 2.3% for trials in which granular fats were fed and 2.2% for trials in which liquid fats were fed. Average level of supplementation for the second source was 2.2% for granular fats and 2.6% for liquid fats. Daily dry matter intake was reduced .37 kg/day when feeding granular fats and .06 kg/day when feeding liquid fats. Milk yield response was relatively similar when feeding granular vs liquid fats (.78 kg/day vs .66 kg/day) but feeding granular fats resulted in approximately 1kg/day FCM response advantage over feeding liquid fats (1.09 vs .13 kg/day). This was the result of granular fats causing an increase in milk fat percentage (+.08) and liquid fats causing a decrease in milk fat percentage (-.1). Milk protein percentage depression was similar when feeding granular or liquid fats as the second source of fat.

Feeding high levels of supplemental fat should be avoided. Feeding total supplemental fat at 6% or more of ration dry matter caused reductions in dry matter intake and/or milk yield (Schauff et al., 1992; Elliot et al., 1993; Wu et al., 1993b). Very few studies have been conducted to compare various fat sources as a second increment of fat in dairy diets. Wu et al.(1993a), added 2.5% tallow, calcium salts of long chain fatty acids, or prilled hydrogenated tallow fatty acids to diets containing 2.4% whole cottonseed. Fat supplementation resulted in greater milk and FCM yield, and decreased milk protein; however, there were no significant differences between fat sources.

Results in Table 3 indicate that use of a second source of fat can not be justified economically on the basis of milk response alone. Milk yield responses diminish as the amount of supplemental fat increases (Palmquist, 1988). This does not mean a second source of supplemental fat should not be fed. To obtain optimum health and reproductive performance of dairy cattle, one must avoid extreme losses in body condition. Lost body condition should be replenished by the end of the lactation to increase the likelihood of optimal performance during the following lactation. If cows are routinely loosing more than 1.0 in body condition score (1=thin to 5=obese) and(or) are not reaching a body condition score of 3.5 by the time they are dried off, higher energy diets may be justified.

Results in Table 3 also indicate that it may be difficult to justify the extra cost of granular fats compared to liquid fats based on superior animal performance. Although tallow and grease are not as inert in the rumen as granular fats, they are relatively saturated in comparison to soybean oil which has an unsaturated:saturated ratio of 5.6 (Table 1). Tallow is the most saturated with a unsaturated:saturated fatty acid ratio of .96 while yellow grease has a ratio 2.44.

Interactions Between the Basal Diet and Supplemental Fat

Characteristics of the basal diet may also affect the animal response to supplemental fat. I have summarized recent peer reviewed articles, and abstracts from 1992 and 1993, that describe trials to examine interactions between fat and other dietary factors on lactation performance. All experiments were conducted using a factorial arrangement of treatments. This is an important aspect of this summary because a factorial arrangement of treatments allows one to examine the response to varying levels of factor A (i.e. fat) at varying levels of factor B (e.g. undegradable intake protein). This design is used to determine if there is an interaction between factor A and B.

Interaction implies that the animal responds differently to factor A depending on the level of factor B. The different response may be in the opposite direction or in the same direction but of a different magnitude. All summaries are a compilation of data from a minimum of five studies.

Fat by Protein Interactions. Feeding supplemental fat typically reduces milk protein by approximately .1 percentage unit. Because protein content influences cheese yield from milk, considerable efforts have been made to identify ways to maintain milk protein percentage during fat supplementation. Numerous investigators have hypothesized that supplemental fat reduces milk protein by reducing the amount of protein that reaches the small intestine for absorption. This could occur if fat reduces the amount of organic matter that is fermented in the rumen. A reduction in fermentable organic matter can result if fat (nonfermentable) is incorporated into the diet at the expense of a readily fermented feed such as corn, if fat adversely affects rumen microbes such that fermentation is reduced, or both. Providing additional undegradable intake protein (UIP) or ruminally protected amino acids (rpAA) to the cow are ways to compensate for potential reductions in microbial flow to the intestine.

Factorial experiments to examine responses to supplemental fat when incorporated into diets with or without rpAA were summarized (Table 4). If the control (no fat) diets provide a sufficient supply of absorbable essential amino acids to the small intestine but the fat supplemented diets do not, one might predict an interaction. Feeding fat increased milk fat percentage by an average of .09 or .12 percentage units on diets without or with rpAA which resulted in corresponding increases in FCM yield. Feeding rpAA increased milk fat percentage .08 or .09 percentage units when added to diets without or with added fat and increased milk protein percentage .07 percentage units when added to diets without fat. Rumen protected amino acids had virtually no effect on protein percentage when added to diets with fat. The pooled data is in disagreement with results of Canale et al. (1990) that indicated an increase in milk protein when rpAA were supplemented to control and fat supplemented diets. Milk protein yield was increased approximately 45 g/d with the addition of rpAA to diets with or without fat. Feeding fat did not decrease milk protein yield. Pooled data in Table 4 provide little evidence for fat by rpAA interactions and the same was true for individual studies.

Studies to examine fat by dietary UIP interactions are summarized in Table 5. Responses to fat were similar to that in Table 4. Increasing UIP did not affect milk or FCM yield. There was a slight decrease (-.07) in milk fat percentage when UIP was increased in diets without supplemental fat and a slight increase (+.06) when UIP was increased in diets with supplemental fat. Although this suggests an interaction, none of the individual studies detected a statistically significant fat by UIP interaction on milk fat percentage. In these five studies increasing UIP did not affect milk protein percentage or protein yield. Neither the pooled data or individual studies indicated an increase in protein yield from cows fed fat and additional UIP versus those fed fat without additional UIP.

Fat by Carbohydrate Interactions. Another strategy to compensate for a reduction in microbial protein synthesis due to fat feeding is to increase the fermentable carbohydrate in the diet. Doing so may stimulate incorporation of ammonia into microbial protein. A positive relationship between intake of fermentable carbohydrate and milk protein content and yield is long established (Emery et al., 1978). Two feeding strategies to increase fermentability of the diet are to decrease forage:concentrate ratio or feed rapidly fermentable concentrates containing ingredients such as barley and processed grains. A summary of trials examining the latter strategy are in Table 6. Fermentability of the concentrate was manipulated by inclusion of whey (Casper et al., 1990), wheat (Gallegos et al., 1992), soybean hulls (Elliot and Drackley, 1993), and barley and starch grits (LaCount et al., 1993), or by steam flaking (Simas et al., 1992). Supplemental fat increased milk yield by less than 1 kg/d and no improvement in FCM was noted because of slightly lower milk fat percentage. The decrease in milk fat percentage was mainly accounted for by the study of Casper et al., (1990) who used extruded soybeans as the fat source. Milk fat depression is common when feeding extruded soybeans because processing releases some of the polyunsaturated fat which can interfere with rumen fermentation. In these studies, there was a depression in milk protein of .11 to .12 percentage units due to feeding fat but the severity of depression was not influenced by the fermentability of the concentrate. As predicted, increasing fermentability of the diet reduced milk fat percentage; the magnitude of depression was slightly greater when fat was in the diet (-.06 vs -.15). Increasing fermentability of the diet did not influence milk protein percentage but did cause a slight increase in protein yield when feeding diets without (+26 g/day) and with supplemental fat (+37 g/day). The increase reflected slightly higher milk production from cows fed more fermentable diets. Steam flaking sorghum increased milk protein from 2.93 to 3.00% when fed with control diets and from 2.79 to 2.99% when fed with fat supplemented diets (Simas et al., 1992). The abstract did not indicate if this was a significant interaction; the pooled data (Table 6) does not support a fat by fermentable carbohydrate interaction on milk protein percentage.

Interactions between forage:concentrate ratio and supplemental fat are summarized in Table 7. Increasing concentrate will provide additional fermentable organic matter to the rumen and may stimulate microbial protein synthesis if ammonia is not limiting. Palmquist (1980) speculated that fiber content of the diet should be high to minimize the potential for adverse effects of fat on rumen fermentation. Decreasing forage in the diet had the predicted response of increasing milk yield, decreasing milk fat percentage, and slightly increasing milk protein percentage (Table 7). Fat increased milk production only when fed in conjunction with high forage diets. However, affects of fat on FCM were not apparent because of a slight decrease in milk fat percentage when adding fat to high forage diets and an increase in milk fat percentage when adding fat to low forage diets. Added fat decreased milk protein percentage .12 units regardless of forage to concentrate ratio. Milk protein yield was greatest from cows fed low forage diets. Fat supplementation did not affect protein yield when high forage diets were fed but did result in a slight decrease in protein yield (-26 g/day) when low forage diets were fed.

Fat by Forage Type Interactions. I know of only one study that has examined fat by forage type interactions through a trial using factorial arrangement of treatments (Smith et al., 1993). Feeding whole cottonseeds decreased milk fat percentage on corn silage-based diets but increased milk fat percentage when a portion of the corn silage was replaced with alfalfa hay. Similarly, tallow supplementation did not alter milk fat percentage when corn silage was fed and increased milk fat percentage when a portion of the corn silage was replaced with alfalfa hay. Milk production was decreased when whole cottonseeds were supplemented to corn silage-based diets but was not affected in diets containing some alfalfa hay. In contrast, tallow tended to increase milk production more when cows were fed all corn silage diets vs corn silage/alfalfa hay diets. Examination of nutrient digestibility data led the authors to conclude that fats may have a more negative effect on fermentation when diets are based on corn silage as the only forage. Smith and Harris (1993) compiled data from lactation trials in which various fat sources were fed with either corn silage, alfalfa, or corn silage/alfalfa-based diets. They concluded that there was a greater likelihood of decreased milk and (or) milk fat percentage when extruded soybeans, whole cottonseeds, and rendered animal fats were fed with corn silage-based diets as compared to alfalfa-based diets. Response to granular fats that are designed to be ruminally inert were not affected or inconsistently affected by forage type. Mechanisms by which fat may be more detrimental to fermentation on corn silage based diets have not been identified.

Fat by Niacin Interactions. Horner et al., (1986) reported that feeding niacin could reverse milk protein depression caused by feeding whole cottonseeds. They hypothesized that the increase was mediated through increases in microbial protein synthesis or blood insulin concentrations. A summary of six studies indicated niacin had very slight negative effects on milk production regardless of whether fat was in the diet or not (Table 8). The drop in FCM yield due to niacin supplementation was greater when fat was in the diet (-1.2 vs -.2 kg/day). Feeding niacin did not alter milk protein percentage when cows were fed diets without fat but did cause an increase of .09 percentage units when fat was in the diet. Milk protein yield was not altered by fat or niacin supplementation. In other words, the improvement in milk protein percentage due to niacin supplementation of fat supplemented diets did not result in greater protein yield because of a corresponding slight (-.8 kg/day) decrease in milk production. Based on lactation performance, an argument can be made for exclusion of niacin from fat supplemented diets.

Physiological State of the Cow

Stage of Lactation. Numerous trials have indicated that there was little benefit from feeding fat during the first 5 to 7 weeks postpartum (Hoffman et al., 1991; Jerred et al., 1990; Ruegsegger and Schultz, 1985; Grummer et al., 1993). Seymour et al (1994) fed cows a 50:50 tallow:calcium salts of long chain fatty acid mixture and found that 5.5% total dietary fat was optimal in early lactation and 7% total dietary fat was optimal in later lactation. Contrary to logic, cows seem to respond best to fat beyond the time at which they encounter the most severe energy balance. Similarly, body weight loss may not be reduced by feeding additional fat, but gain usually is accelerated once the cow reaches positive energy balance (Skaar et al., 1989). The lack of an early lactation response may be related to a depression in feed intake. Depressed feed intake may offset any advantage that is gained by increasing the energy density of the diet. Cows are slow to increase 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. 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 5 to 7 weeks postpartum and get the response immediately without experiencing a lag phase. The latter scenario is most likely, therefore, 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. This is not surprising 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. Cows would not be expected to respond to fat supplementation if they were in positive energy balance. However, numerous trials have indicated that mid to late lactation cows with low milk production (<27 kg/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 synthesized by the mammary gland.

Heifers vs Multiparous Cows. Heifers respond differently to fat supplementation than mature cows (Mattias, 1982; Robb and Chalupa, 1987; Ferguson et al., 1988; Pitcher et al., 1991a, 1991b). Increases in milk and fat-corrected milk yields were 2.2 and 2.8 kg/day for multiparous cows and .8 and 1.3 kg/day for heifers when fat was fed in five research and field trials. Improvement in milk fat percentage was similar between heifers and mature cows (+.1 percentage units). Grummer et al. (1993) speculated that response to supplemental fat by heifers may be dependent on body condition at calving but results did not support the hypothesis. 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 not make 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.

Heat Stress. 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. 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. 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 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.

Areas of Needed Information

Research from the past 15 years has led to identification of fat sources and feeding strategies that minimize interference with ruminal fermentation. Even though it is possible to avoid interference with ruminal fermentation, the concentration of fat that can be included in the diets of ruminants is much lower than that for nonruminants. High levels of fat supplementation to dairy cows will result in depressed feed intake, especially in early lactation, and low fat digestibility in the lower gut. As level of milk production continues to increase, pressure to increase the energy density of lactation diets will continue. Identifying why feed intake is affected by high levels of fat supplementation and what limits postruminal fat digestion should be a priority research area if supplemental fat is going to be the vehicle by which nutritionist continue to increase dietary energy density.

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
Tallow	3	27	5	21	41	2	1	0.96
Poultry	1	24	10	5	43	17	1	2.44
Choice white grease	2	24	4	12	45	11	3	1.70
Yellow grease	1	18	2	10	46	21	1	2.33
Animal-vegetable	2	26	2	18	34	16	2	1.17
PHT[2]	4	26	3	35	32	--	--	0.54
SLFA[3]	2	47	--	36	14	1	--	0.18

[1] U/S = Ratio of saturated to unsaturated fatty acids.

[2] PHT: partially hydrogenated tallow; Alifet; Alifet USA, Inc. (Cincinnati, Ohio).

[3] SLFA: relatively saturated long chain fatty acids; Energy Booster 100; Milk Specialties, Inc. (Dundee, Illinois).

Table 2. Effect of fat structure, form and composition on dietary fatty acid digestibility*.

Study§	Treatments	Fatty acid profile C16:0/18:0/18:1/PUFA	Dietary FA dig.	Comments
1	Control		47.2d	IV of hyd tallow=.6 Trt means with unlike superscripts differ (P<.05).
	5% flaked hyd tallow	30/66/NR/NR	34.8c	
	5% liquid hyd tallow	30/66/NR/NR	42.2cd	
2	Control		65.0	Specifics of statistical analysis not reported.
	5% 14.4 IV flaked hyd. tallow	27/52/12/1	36.7	
	5% 14.5 IV prilled hyd. tallow	27/51/15/0	45.7	
	5% 25.8 IV prilled hyd. tallow	26/40/27/0	45.0	
	5% 62 IV "tallow"	24/12/47/10	53.3	
3	Control		67.9	Digestibility of prilled FA > prilled hyd. tallow (P<.05).
	5.0% 14.4 IV prilled FA	40/41/12/1	68.1	
	5.6% 8.3 IV prilled hyd. tallow	30/53/9/0	49.7	
	5.0% 14.1 IV flaked FA	40/40/12/1	63.6	
4	Control		73.2	Control vs fat diets (P<.01). Y grease vs hyd. Y grease (P<.05).
	5% Y grease	26/15/43/10	67.8	
	3% hyd Y grease	22/76/0/1	53.6	
	5% hyd Y grease	22/76/0/1	47.4	
5	Control		69.5	Digestibility of hyd. tallow < control or tallow
	4% 41 IV tallow	26/24/38/2	67.2	
	4% 16 IV hyd. palm oil	53/27/17/0	57.8	
	4% 13 IV hyd. tallow	26/54/14/0	45.4	
6	Control		70.1	Tendancy (P<.10) for linear effect of fat IV.
	5% 17 IV triglyceride	27/53/14/0	46.9	
	5% 54 IV triglyceride	25/15/44/5	66.5	
	5% 92 IV triglyceride	15/10/50/5	67.3	
7	Control		62.6	Quadratic/cubic effect of replacing PHTG with canola oil (P<.05).
	100% prilled hyd. TG (PHTG)	29/48/13/5	59.1	
	67% PHTG:33% canola oil	21/33/29/13	62.3	
	33% PHTG:67% canola oil	13/18/46/21	57.7	
	0% PHTG:100% canola oil	5/3/62/28	49.7	
8	Control		69.6	NSD
	454g abomasal sat FA	39/40/12/1	70.5	
	454g abomasal unsat FA	10/24/3/62	65.9	
	454g abomasal sat/unsat blend	27/24/19/56	77.8	
9	Control		78.1	IV of supplements=15 to 20. Control vs fat diets (P<.05). 2 vs 5% fat diets (P<.05). TG vs FA, NSD
	2% hyd tallow FA	29/53/11/NR	64.2	
	5% hyd tallow FA	29/53/11/NR	50.0	
	2% hyd tallow TG	22/59/16/NR	60.0	
	5% hyd tallow TG	22/59/16/NR	53.9	

* FA=fatty acid; PUFA=18 carbon polyunsaturated fatty acids; dig.=digestibility; sat=saturated; unsat=unsaturated; hyd=hydrogenated; IV=iodine value; NR=not reported; TG=triglyceride; Y grease= yellow grease; NSD=no significant differences.

§ Studies: 1-Macleod and Buchanan-Smith, 1972, 2-Eastridge and Firkins, 1992, 3-Elliot et al., 1994, 4- Jenkins and Jenny, 1989, 5- Eastridge et al., 19936-Pantoja et al., 1994, 7-Jenkins and Jenny, 1992, 8-Drackley et al., 1992, 9-Eastridge and Firkins, 1991.

Table 3. Lactation responses from a second source of fat.

Amount of added fat (%) from:			Response Relative to Control				
1st fat	2nd fat	Total fat	DMI kg/d	Milk kg/d	FCM kg/d	Fat %	Protein %
2nd fat = Granular (13 studies)							
2.3	2.3	4.6	-.37	.78	1.09	.09	-.07
2nd fat = Liquid (10 studies)							
2.4	2.6	5.0	-.06	.66	.13	-.10	-.06

Note: In every study, either soybeans or cottonseeds provided the first source of fat. Granular fats were either relatively saturated prilled long chain fatty acids or calcium salts of long chain fatty acids. The liquid fat was tallow in 8 of the 10 studies; in one study it was safflower oil and in one study it was soapstock.

Table 4. A summary of studies (Schingoethe et al., 1988; Kincaid and Cronrath, 1993; Chow et al., 1990; Canale et al., 1990; Goodling et al., 1992) utilizing factorial arrangement of treatments to examine potential interactions when feeding fat and ruminally protected amino acids (rpAA)[a].

Treatment		DMI kg/day	Milk kg/day	FCM[b] kg/day	Fat %	Protein %	Protein g/day
Control	**ave.**	**21.5**	**29.5**	**27.3**	**3.44**	**3.19**	**967**
	range	17-25	21-35	23-32	2.9-4.6	2.9-3.7	792-1130
	SD	3.7	5.2	3.2	.67	.34	127
Control+rpAA	**ave.**	**21.8**	**30.0**	**28.0**	**3.52**	**3.26**	**1016**
	range	16-26	21-35	23-32	3.2-4.5	2.9-3.8	813-1150
	SD	3.7	5.5	2.9	.59	.35	173
Fat	**ave.**	**21.9**	**30.9**	**28.7**	**3.53**	**3.11**	**989**
	range	18-25	22-36	25-32	3.3-4.7	2.9-3.6	810-1290
	SD	3.1	5.5	2.8	.74	.33	127
Fat+rpAA	**ave.**	**22.1**	**31.2**	**30.0**	**3.64**	**3.12**	**1027**
	range	17-26	22-34	25-33	2.7-4.8	2.9-3.6	799-1300
	SD	3.5	6.0	3.8	.77	.28	180

[a] All studies supplemented methionine and lysine except (Schingoethe et al., 1988) which supplemented methionine. All studies used encapsulated amino acids except (Kincaid and Conrath, 1993) which used Zn methionine and lysine. All studies used Holsteins except (Goodling et al., 1992) which used Jerseys. Chow et al. (1990) used primiparous and multiparous cows. Fat sources were extruded soybeans (Schingoethe et al., 1988), granular (Kincaid and Conrath, 1993; Canale et al., 1990), animal-vegetable blend (Goodling et al., 1992), and yellow grease (Chow et al., 1990).

[b] Original studies may have reported 3.5 or 4% FCM.

Table 5. A summary of studies (Hoffman et al., 1991; Chan et al., 1992; Grant et al., 1993; Cant et al., 1991; Klusmeyer et al., 1991) utilizing factorial arrangement of treatments to examine potential interactions when feeding fat and additional undegradable intake protein (UIP)[a].

Treatment		DMI kg/day	Milk kg/day	FCM[b] kg/day	Fat %	Protein %	Protein g/day
Control	**ave.**	**22.2**	**31.9**	**29.4**	**3.42**	**3.07**	**973**
	range	17-25	24-40	22-34	3.0-3.7	2.9-3.2	735-1180
	SD	3.4	5.8	4.6	.28	.11	169
Control+UIP	**ave.**	**21.2**	**32.2**	**29.4**	**3.35**	**3.06**	**981**
	range	17-23	24-42	22-36	3.1-3.6	3.0-3.2	765-1260
	SD	2.9	6.3	4.9	.24	.09	178
Fat	**ave.**	**22.2**	**33.9**	**31.8**	**3.55**	**2.99**	**1007**
	range	17-25	27-40	26-35	3.3-3.7	2.9-3.1	805-1140
	SD	3.5	4.6	3.6	.19	.09	126
Fat+UIP	**ave.**	**21.3**	**33.2**	**31.2**	**3.61**	**2.95**	**976**
	range	17-25	27-41	25-36	3.3-3.8	2.8-3.1	805-1140
	SD	2.6	4.8	3.6	.23	.13	131

[a] All studies increased dietary UIP by feedstuff substitution except (Cant et al., 1991) which employed ruminal vs abomasal casein infusion. Hoffman et al. (1991) and Cant et al. (1991) used primiparous and multiparous cows. Fat sources were yellow grease (Cant et al., 1991), alginate-treated tallow (Hoffman et al., 1991), tallow (Grant et al., 1993), and granular (Chan et al., 1992; Klusmeyer et al., 1991).

[b] Original studies may have reported 3.5 or 4% FCM.

Table 6. A summary of studies (Casper et al., 1990; Gallegos et al., 1992; Elliot and Drackley, 1993; LaCount et al., 1993; Simas et al., 1992) utilizing factorial arrangement of treatments to examine potential interactions when feeding fat in combination with concentrates varying in fermentable carbohydrate[a].

Treatment[b]		DMI kg/day	Milk kg/day	FCM[c] kg/day	Fat %	Protein %	Protein g/day
Low ferment. conc.	**ave.**	**21.9**	**30.8**	**30.2**	**3.31**	**3.18**	**959**
	range	20-25	24-35	28-33	3.1-3.7	3.0-3.7	881-1030
	SD	2.2	4.5	2.54	.29	.31	54
High ferment. conc.	**ave.**	**21.9**	**31.5**	**31.0**	**3.25**	**3.18**	**985**
	range	19-24	23-39	28-35	2.9-3.7	3.0-3.6	829-1170
	SD	2.2	6.0	2.9	.28	.28	121
Low ferment. conc.+fat	**ave.**	**19.7**	**31.3**	**30.3**	**3.26**	**3.05**	**939**
	range	18-22	24-34	29-32	3.1-3.7	2.8-3.6	865-994
	SD	1.8	4.2	1.5	.27	.33	54
High ferment. conc.+fat	**ave.**	**20.3**	**32.4**	**30.7**	**3.11**	**3.06**	**976**
	range	20-21	24-37	29-33	2.8-3.7	2.7-3.5	830-1070
	SD	.8	4.9	1.4	.37	.27	102

[a] Elliot and Drackley (1993) used Jerseys and Holsteins. Fat sources were extruded soybeans (Casper et al., 1990), granular (Elliot and Drackley, 1993; Simas et al., 1992), and tallow (Gallegos et al., 1992;LaCount et al., 1993).

[b] Ferment.=fermentable; Conc.=concentrate.

[c] Original studies may have reported 3.5 or 4% FCM.

Table 7. A summary of studies (Jerred et al., 1990; Harkness et al., 1993; Canale et al., 1990; Klusmeyer et al, 1991; Grant and Weidner, 1992) utilizing factorial arrangement of treatments to examine potential interactions when feeding fat in combination with diets varying in forage:concentrate ratio[a].

Treatment		DMI kg/day	Milk kg/day	FCM[b] kg/day	Fat %	Protein %	Protein g/day
High forage	**ave.**	**22.4**	**32.9**	**31.9**	**3.61**	**3.19**	**1048**
	range	18-25	27-38	26-37	3.1-3.9	3.0-3.5	820-1130
	SD	2.5	4.2	4.4	.32	.19	130
Low forage	**ave.**	**24.0**	**35.5**	**32.6**	**3.33**	**3.23**	**1138**
	range	22-26	30-41	29-37	2.8-3.6	2.9-3.5	960-1221
	SD	1.9	4.0	4.1	.31	.22	103
High forage+fat	**ave.**	**21.1**	**34.1**	**32.1**	**3.58**	**3.07**	**1047**
	range	18-23	28-38	27-37	3.1-4.0	2.8-3.4	830-1178
	SD	2.0	4.2	3.8	.44	.23	130.7
Low forage+fat	**ave.**	**21.7**	**35.9**	**32.9**	**3.41**	**3.11**	**1112**
	range	18-24	31-42	30-39	3.0-3.7	2.9-3.3	970-1225
	SD	2.5	4.6	4.0	.29	.13	111

[a] High forage treatments were 65 to 70% forage, dry matter basis, in (Jerred et al., 1990; Harkness et al., 1993; Canale et al., 1990; Klusmeyer et al, 1991) and 49% in (Grant and Weidner, 1992). Low forage treatments were 50% forage in (Jerred et al., 1990; Harkness et al., 1993; Canale et al., 1990; Klusmeyer et al, 1991) and 39% in (Grant and Weidner, 1992). Fat sources were granular (Jerred et al., 1990; Harkness et al., 1993; Klusmeyer et al, 1991), tallow (Harkness et al., 1993), and raw soybeans (Grant and Weidner, 1992).

[b] Original studies may have reported 3.5 or 4% FCM.

Table 8. A summary of studies (Horner et al., 1986; Skaar et al., 1989; Driver et al., 1990; Lanham et al., 1992; Erickson et al., 1992; Martinez et al., 1991) utilizing factorial arrangement of treatments to examine potential interactions when feeding fat and/or niacin[a].

Treatment		DMI kg/day	Milk kg/day	FCM[b] kg/day	Fat %	Protein %	Protein g/day
Control	ave.	21.2	31.8	29.9	3.39	3.05	952
	range	19-24	19-39	21-38	3.0-4.1	2.7-3.6	700-1140
	SD	1.9	7.0	6.4	.39	.31	155
Control+niacin	ave.	20.2	31.5	29.7	3.42	3.06	955
	range	16-23	19-38	20-34	3.2-3.9	2.8-3.3	670-1070
	SD	2.8	6.6	6.0	.24	.29	152
Fat	ave.	20.5	33.2	31.0	3.45	2.92	957
	range	17-24	20-39	21-39	3.2-4.0	2.6-3.5	670-1180
	SD	2.5	7.7	6.6	.29	.33	165
Fat+niacin	ave.	20.6	32.4	29.8	3.39	3.01	952
	range	17-23	18-41	19-38	3.1-3.8	2.7-3.6	630-1180
	SD	2.2	8.1	7.0	.23	.31	182

[a] Dose of niacin was either 6 g/day (Horner et al., 1986; Driver et al., 1990; Lanham et al., 1992) or 12 g/d (Skaar et al., 1989; Erickson et al., 1992; Martinez et al., 1991). Fat sources were granular (Skaar et al., 1989; Erickson et al., 1992), heated soybeans (Driver et al., 1990), whole cottonseed (Horner et al., 1986; Lanham et al., 1992;) or yellow grease (Martinez et al., 1991).

[b] Original studies may have reported 3.5 or 4% FCM.

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