

# 3 Fat

Fat is typically fed to increase the energy density of the diet, but fat supplementation has other potential benefits, such as increased absorption of fat-soluble nutrients and reduced dustiness of feed. Fat is usually used as a generic term to describe compounds that have a high content of long-chain fatty acids (FAs) including triglycerides, phospholipids, nonesterified FAs, and salts of long-chain FAs. Long-chain FAs are the energy-rich moiety of fats. Various forms of fat are fed to dairy cattle, including oilseeds, animal and animal-vegetable blends, dry-granular fats, and “protected” fats. Oilseeds contain mostly triglycerides that are rich in unsaturated FAs. Animal and animal-vegetable blends can be made up of triglycerides, free FAs, or both and have an unsaturated to saturated fatty acid ratio greater than or equal to 1:1. Dry-granular fats are often referred to as ruminally inert fats, because they have been manufactured to have minimal effects on ruminal fermentation. Protected fats have been encapsulated in some manner, so ruminal microorganisms are not affected by them; the types of fat and encapsulation process vary.

## DIGESTION AND ABSORPTION

For an excellent review of lipid digestion and absorption in ruminants see Noble (1981) and Jenkins (1993). Esterified FAs, mainly triglyceride, are rapidly hydrolyzed to the free form by lipolytic microorganisms within the rumen. Following hydrolysis, unsaturated FAs are hydrogenated by ruminal microorganisms, but the extent of hydrogenation is dependent on the degree of unsaturation of FAs and the level and frequency of feeding. Estimates for ruminal hydrogenation of polyunsaturated fatty acids (PUFAs) range from 60 to 90 percent (Bickerstaffe et al., 1972; Mattos and Palmquist, 1977). Biohydrogenation of supplemental unsaturated FAs may be as low as 30 to 40 percent if the FAs are fed as calcium salts (Klusmeyer and Clark, 1991). Because of hydrogenation in the rumen, C18:0 and various isomers of C18:1 are the major FAs leaving the

rumen. The generation time for bacteria that are able to degrade long-chain FAs is relatively long precluding substantial inhabitation of the rumen. Consequently, little degradation of long-chain FAs occurs in the rumen. Regression of dietary lipid (measured as fatty acid or ether extract) flow to the duodenum (total lipid flow minus estimate of microbial lipid flow) vs. lipid intake revealed a slope of 0.92 indicating an 8 percent loss of lipid in the rumen (Jenkins, 1993). Digestion coefficients for total FAs within the rumen are negative, which reflects microbial synthesis of FAs. The majority of FAs synthesized by rumen microbes are incorporated into phospholipids. Jenkins (1993) estimated microbial lipid synthesis to be 15 g/kg of lipid-free organic matter digested in the rumen. Approximately 85 to 90 percent of the FAs leaving the rumen are free FAs, and approximately 10 to 15 percent are microbial phospholipids. Since FAs are hydrophobic, they associate with particulate matter and pass to the lower gut.

Although little triglyceride reaches the small intestine of ruminants, bile and pancreatic lipase are required for lipid absorption. If triglycerides are fed at moderate levels in a form that protects them from hydrolysis (e.g., formaldehyde protected casein-fat emulsion), there appears to be sufficient 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 believed to be dependant on lysolecithin and the monounsaturate, oleic acid, for fatty acid emulsification. Lysolecithin is formed by pancreatic phospholipase activity on lecithin that may be of microbial or hepatic origin. Monounsaturated fatty acid is predominantly from digesta leaving the rumen. Therefore, it is critical that a portion of dietary unsaturated fatty acids avoid complete hydrogenation by ruminal organisms. Fatty acid emulsification and micelle formation in the small intestine is essential for the efficient absorption of fat.

DIGESTIBILITY AND ENERGY VALUE OF FATS

Energy values of the fat supplements listed in Table 2-3 were determined as described in Chapter 2. The variability in NE<sub>L</sub> content among fat supplements is a function primarily of the long-chain FA content and the digestibility of the long-chain FAs. Digestibility of FAs can be influenced by dry matter (DM) intake, amount of fat consumed, characteristics of fat in the basal diet, and characteristics of the supplemental fat. Degree of unsaturation is probably the most important characteristic that influences digestion (Grummer, 1995). Fatty acid composition and IV values of selected fat sources are listed in Table 3-1.

Iodine value is an indicator of the degree of unsaturation: the higher the IV, the greater the content of unsaturated fatty acids in the fat. Digestibility may decrease if the iodine value (IV) is below 45 (Firkins and Eastridge, 1994). Maximal digestibility of fats with an IV greater than 40 was 89 percent, compared with 74 percent for fats with an IV less than 40 (Jenkins, 1994). Saturated FAs are less digestible than unsaturated FAs, and the difference is greatest when predominantly saturated fats are supplemented (Borsting et al., 1992). That indicates that unsaturated FAs may have a synergistic effect on the digestibility of saturated FAs.

Increasing FA chain length may also increase digestibility, but, the effects appear to be more subtle than the effects of degree of unsaturation (Grummer, 1995). There are probably interactions between degree of unsaturation and chain length. Firkins and Eastridge (1994) reported that increasing the C16:C18 ratio has a greater effect on digestion as IV increases. Digestibility in the intestine is inversely related to the melting point of the FA, which probably influences micelle formation and movement of fatty acids through the unstirred water layer adjacent to the microvilli of the small intestine.

Decreasing particle size of dry granular fats may increase digestibility, but responses have tended to be small and not statistically significant. A summary of trials (Firkins and Eastridge, 1994) indicated that mean FA digestibility of prilled (n = 8) and flaked (n = 5) hydrogenated tallow was 77 and 69 percent, respectively.

Fat structure—the form in which FAs are fed—may have modest effects on digestibility. A review of the literature (Firkins and Eastridge, 1994) indicated that FA digestibility of diets containing triglyceride prills or FA prills was 77 or 73 percent of control diets without added fat. However, effects of fat structure might have been confounded: mean IV and C16:18 ratio were 20.7 and 0.41 for triglyceride prills and 11.2 and 0.45 for FA prills. If FAs are fed as a salt, digestibility will be determined by

TABLE 3-1 Fatty Acid Composition and Iodine Values of Fats and Oils<sup>a</sup>

Type of Fat	Reference <sup>b</sup>	C14:0	C16:0	C16:1	C18:0	C18:1	C18:2	C18:3	Other Fatty Acids	Iodine Value
<i>Granular fats:</i>										
Calcium salt palm oil FAs	1	1.3	48.6	1.1	4.1	36.5	7.8	0.3	0.2	49
Hydrolyzed tallow FAs	1	2.4	39.7	0.7	42.7	10.9	1.0	—	2.6	12
Partially hydrogenated tallow <sup>c</sup>	1	1.4–2.4	25.4–25.8	0.2–0.7	37.2–52.6	13.8–31.9	0–0.9	0.1–0.2	3.2–4.3	14–31
<i>Animal and animal-vegetable blends:</i>										
Tallow	1, 2, 3	3.0	24.5	3.7	19.3	40.9	3.2	0.7	4.9	48
Choice white grease	1, 2	1.9	23.4	4.3	13.3	43.4	10.9	1.3	1.5	62
Yellow grease	1, 2	1.8	22.1	3.5	11.5	43.7	14.6	0.9	1.9	72
Poultry fat	1, 2	1.0	22.1	7.2	6.5	43.0	18.5	0.9	0.7	82
Fish oil, menhaden <sup>d</sup>	3	8.0	15.1	10.5	3.8	14.5	2.2	1.5	44.5	31
Fish oil, herring <sup>d</sup>	3	7.2	11.7	9.6	0.8	12.0	1.1	0.8	56.8	25
<i>Vegetable oils:</i>										
Canola (rapeseed)	3	—	4.8	0.5	1.6	53.8	22.1	11.1	6.1	119
Corn	3	0.0	10.9	—	1.8	24.2	58.0	0.7	4.4	126
Cottonseed	3	0.8	22.7	0.8	2.3	17.0	51.5	0.2	4.7	107
Linseed	3	—	5.3	—	4.1	20.2	12.7	53.3	4.4	185
Palm	3	1.0	43.5	0.3	4.3	36.6	9.1	0.2	5.0	50
Peanut	3	0.1	9.5	0.1	2.2	44.8	32.0	—	11.3	95
Safflower	3	0.1	6.2	0.4	2.2	11.7	74.1	0.4	4.9	145
Sesame	3	—	8.9	0.2	4.8	39.3	41.3	0.3	5.2	111
Soybean	3	0.1	10.3	0.2	3.8	22.8	51.0	6.8	5.0	131
Sunflower	3	—	5.4	0.2	3.5	45.3	39.8	0.2	5.6	113

<sup>a</sup> Selected FAs are expressed as a percent of total FAs (g/100 g × 100).

<sup>b</sup> 1, scientific literature; 2, rendering industry, including Pearl (1995); 3, US Department of Agriculture *Food Composition Standard Release 12* (1998).

<sup>c</sup> Composition of partially hydrogenated tallow is reported as a range because degree of hydrogenation varies considerably among products.

<sup>d</sup> Other fatty acids consist predominantly of polyunsaturated fatty acids greater than 18 carbons in length.

fatty acid profile, because the salts are dissociated in the acidic abomasum and duodenum (Sukhija and Palmquist, 1990).

Concentration of fat in the diet also can affect postruminal fat digestion. FA digestibility decreased by 2.2 percent for each 100 g of FA intake as intake of supplemental fat increased from 200 to 1400 g/d (Palmquist, 1991). True FA digestibility of tallow was curvilinear with diminishing digestibility as FA intake increased from 200 to 900 g/d (Weisbjerg et al., 1992). Apparent digestibility increased when supplemental fat was increased from 0 to 3 percent of (DM) but decreased when fat was increased from 3 to 6 percent of DM (Wu et al., 1991). The increase in digestibility of fat at low intakes might indicate that supplemental fat was more digestible than fat in the basal diet or that endogenous fat was being diluted. A summary of 20 studies indicated that the rate of decline in digestibility of fat as fat intake increases is greater for fats with an IV greater than 40 than for fats with an IV less than 40 (Jenkins, 1994).

#### EFFECTS OF FAT ON RUMINAL FERMENTATION

Although increasing the degree of unsaturation increases digestibility of FAs, it also increases the likelihood that ruminal fermentation will be adversely affected (Jenkins, 1993). Fat sources with high amounts of polyunsaturated fatty acids include fish oils and some vegetable oils (Table 3-1). Reductions in DM intake, milk fat percentage, and ruminal fiber digestion are indicators that fermentation has been altered. The rate at which unsaturated FAs are released from feeds and exposed to ruminal microorganisms determines whether rumen fermentation is affected. Ruminal microorganisms hydrogenate unsaturated FAs. If the microbial capacity to saturate FAs is exceeded, unsaturated FAs can accumulate and interfere with fermentation. Feeding polyunsaturated oils as part of a whole-oilseed diet has minimal effects on fermentation (Knapp et al., 1991; DePeters et al., 1987), probably because the oil is released slowly from the seed to ruminal fluid. Extrusion of oilseeds releases some of the oil, so the rate of exposure of microorganisms to oil might be sufficient to influence their metabolism. Polyunsaturated fats can be encapsulated to minimize interaction of fat with microorganism. Mineral salts of long-chain FAs and hydrogenated fatty acids are examples of dry granular fats that inhibit fermentation less than unsaturated FAs, probably because they have lower solubility in an aqueous medium. Tallow and yellow grease might be more likely than oilseeds or dry granular fats to inhibit rumen fermentation. However, up to 3 percent of DM as tallow or yellow grease in totally mixed diets has been fed without altering feed intake, milk fat percentage,

or fermentation (DePeters et al., 1987; Knapp et al., 1991). Effects of oilseeds, tallow or yellow grease on fermentation can vary depending on the basal diet. Adverse effects might be more likely when diets based on corn silage (Smith et al., 1993) or low forage (Grant and Weidner, 1992) are fed.

#### UTILIZATION OF FAT IN CALF DIETS

See Chapters 10 and 11 on calf and heifer replacement nutrition for discussions of fat in calf and heifer diets.

#### FAT IN LACTATION DIETS

Milk-yield response to supplemental fat can be influenced by several factors, including basal diet, stage of lactation, energy balance, fat composition, and amount of supplemental fat. If fat supplementation is begun during the early postpartum period, there can be a lag before a milk response (Jerred et al., 1990; Schingoethe and Casper, 1991). An extensive summary by Chilliard (1993) indicated that the average fat-corrected milk response to fat supplementation (average increase 4.5 percent ether extract) during early lactation (beginning before 4 weeks and ending before 11 weeks postpartum) was 0.31 kg/d and not significantly different from controls. Average fat-corrected milk response to fat supplementation during peak lactation (beginning before 8 weeks and ending at 11–24 weeks postpartum; average increase, 3.6 percent ether extract) or middle to late lactation (beginning after 7 weeks postpartum and lasting longer than 5 weeks; average increase, 3.4 percent ether extract) was 0.72 or 0.65 kg/d; the former was significantly different from controls. Another summary (Grummer, 1994) indicated that average fat-corrected milk response to supplementation with dry granular fats (average supplementation 2.3 percent of DM) vs. tallow or vegetable oils (average supplementation 2.65 percent of DM) when diets already contained whole oilseeds was 1.1 vs. 0.1 kg/d, respectively. Average milk production of cows in both summaries was less than 35 kg/d. Milk-yield responses to supplemental fat in cows that produce more than 40 kg/d are not well defined.

Milk-yield response to supplemental fat is curvilinear; the response diminishes as supplemental fat in the diet increases (Palmquist, 1983; Jenkins, 1994). Kronfeld (1976) indicated that milk production reaches its maximal efficiency when FAs constitute 16 percent of metabolizable energy. That equates to about 600–700 g of supplemental fat per day (Jenkins, 1997). A review of the literature indicated that maximal milk-yield responses to dietary fat rarely exceed 3.5 kg of FCM per day. About 700 g of supplemental fat is required to support production of 3.5 kg of FCM, assuming that fat is 80 percent digestible and uptake of

absorbed FAs by the mammary gland is 75 percent (Jenkins, 1997). Assuming 23 kg of DM intake, 700 g of supplemental fat equates to about 3 percent of DM.

Supplemental fat has increased milk yield in many studies; however, responses have been variable. Some of the variation may be due to depression of feed intake when feeding supplemental fat. If feed intake is depressed sufficiently, total energy intake by the cow may not be increased. Mechanisms by which fat reduces feed intake are not known. Potential factors were recently reviewed (Allen, 2000) and include effects on feed intake and gut motility, acceptability of diets supplemented with fat, release of gut hormones, and oxidation of fat by the liver. Sanchez et al. (1998) speculated that insufficient metabolizable protein may account for feed intake depression when feeding fat. However, an extensive summary of the literature indicated that crude protein content of the diet does not appear to have any appreciable effect on intake responses to supplemental fat (Allen, 2000). The same review yielded a comparison among oilseeds, unprocessed fat (tallow and grease), hydrogenated FAs and triglycerides, and calcium salts of FAs on their effects on dry matter intake (Allen, 2000). Calcium salts of FAs decreased dry matter intake by 2.5 percent for each percentage unit in the diet above control. Unprocessed fat also decreased intake, but the decrease was approximately 50 percent of that observed with calcium salts of FAs. Added hydrogenated FAs and triglyceride did not decrease dry matter intake. Feeding oilseeds resulted in a quadratic effect with minimum dry matter intake occurring at 2 percent added fatty acid. The magnitude of depression when feeding oilseeds was less than that when feeding calcium salts of FAs. Differences among fat sources could be due to acceptability, fatty acid chain length or degree of saturation, or form (free fatty acid, triglyceride, or salt). Several studies have suggested that unsaturated FAs are more likely to depress feed intake than saturated FAs (Drackley et al., 1992; Christensen et al., 1994; Firkins and Eastridge, 1994; Bremmer et al., 1998). Dietary unsaturated FAs may be hydrogenated in the rumen. Extent of hydrogenation varies among fat sources; therefore, the profile of FAs reaching the duodenum should be better than the profile of FAs consumed for predicting effects on feed intake. Top-dressed calcium salts of palm oil FAs were less acceptable than tallow, sodium alginate encapsulated tallow, or prilled long-chain FAs (Grummer et al., 1990). Differences were no longer significant when fats were mixed with grain or when cows were allowed an adaptation period.

The influence of supplemental fat on milk fat percentage is variable and depends on fat composition and the amount fed. In general, encapsulated fats, FAs fed as calcium salts, and saturated fats either have no effect on or increase milk fat percentage (Sutton, 1989; DePeters, 1993). As the amount of unsaturated FAs fed in free or esterified form

increases, the likelihood of milk-fat depression increases. Greater formation of trans-FAs during microbial hydrogenation of polyunsaturated FAs might negatively affect mammary lipid synthesis (See Chapter 9; Davis and Brown, 1970; Gaynor et al., 1994).

Feeding supplemental fat decreases milk protein percentage and the effect diminishes slightly as the amount of supplemental fat increases (for example,  $y = 101.1 - 0.6381x + 0.0141x^2$ , where  $y$  = milk protein concentration [(treated/control, %)  $\times$  100] and  $x$  = total dietary fat, %); Wu and Huber, 1994). Casein is the milk nitrogen fraction that is most depressed (DePeters and Cant, 1992). Although milk protein percentage is usually depressed, total protein production usually remains constant or is increased. Of 83 treatment comparisons (fat supplementation vs. control) summarized by Wu and Huber (1994), milk protein production was unchanged or increased in 65 comparisons and decreased in 26. However, in 15 of the 26 comparisons in which protein production was decreased, milk production also was decreased. Why milk protein production does not increase at a similar rate as milk volume during fat supplementation has not been determined.

Fat supplementation can positively influence reproductive performance of dairy cows. A summary of 20 studies indicated that first-service conception rate or overall conception rate was increased in 11 of the studies (Staples et al., 1998). The mean increase was 17 percentage units for all studies. Three studies indicated a negative influence of supplemental fat on reproduction, but the effects were confounded by substantial increases in milk production. Feeding fat increases follicle numbers and the size of the dominant follicle. It has not been determined whether those changes in follicular dynamics have a positive effect on reproductive performance. Potential mechanisms by which fat influences reproduction include amelioration of negative energy balance, enhancement of follicular development via changes in insulin status, stimulation of progesterone synthesis, and modification of the production and release of prostaglandin  $F_{2\alpha}$ , which influences the persistence of the corpus luteum (Staples et al., 1998). In the 20 studies reviewed by Staples et al. (1998), there was little evidence of a relationship between change in energy status and change in conception rate. Likewise, the effects of fat on insulin have not been consistent, although, the trend is toward a reduction. How a reduction in plasma insulin could benefit reproduction has not been determined. Fat supplementation consistently increases plasma progesterone concentration, but the change might be because of depressed clearance rather than increased production (Hawkins et al., 1995). Staples et al. (1998) proposed that feeding fats that are rich in linoleic acid suppresses prostaglandin  $F_{2\alpha}$  and prevents regression of the corpus luteum.

In most situations, total dietary fat should not exceed 6–7 percent of dietary DM. Feeding higher concentrations of fat can result in reduced DM intake, even if the fat has minimal effects on ruminal fermentation (Schauff and Clark, 1992). A reduction in DM intake will negate part or all of the advantage of using fat to increase dietary energy density and can limit milk-production responses. Optimal amounts of fat to include in dairy cattle diets will depend on numerous factors, including type of fat, feeds making up the basal diet, stage of lactation, environment, level of milk production, and feeding management. Feeding less than 6 percent total dietary fat might be prudent during early lactation, when feed-intake depression due to fat supplementation has been observed (Jerred et al., 1990; Chilliard, 1993). Mixtures of cereal grains and forages usually contain about 3 percent fat. Therefore, up to 3 or 4 percent of dietary DM can come from supplemental fat. Oilseeds and animal or animal-vegetable blends are acceptable fat supplements; however, partial substitution with ruminally inert fats might be warranted if the previously mentioned fat supplements are adversely affecting ruminal fermentation, milk fat percentage, or DM intake.

Feeding supplemental fat to ruminants has reduced digestibility of calcium, magnesium, or both in some studies (Tillman and Brethour, 1958; Steele, 1983; Palmquist and Conrad, 1978; Rahnama et al., 1994; Zinn and Shen, 1996). FAs can form insoluble soaps with cations in the rumen, distal small intestine, and large intestine. Soap formation is favored as pH increases (Sukhija and Palmquist, 1990). Soap formation can reduce magnesium absorption from the rumen and calcium absorption from the intestine. Consequently, concentrations of dietary calcium and magnesium higher than those listed in tables in Chapter 14 might be warranted when supplemental fat is fed. However, interactions between diet and cation absorption when fat is fed have not been adequately described, and research to identify optimal amounts of dietary calcium and magnesium to feed when supplementing fat to the diet has not been conducted.

## REFERENCES

- Allen, M. S. 2000. Effects of diet on short-term regulation of feed intake by lactating dairy cattle. *J. Dairy Sci.* 83:1958–1624.
- Bickerstaffe, R., D. E. Noakes, and E. F. Anison. 1972. Quantitative aspects of fatty acid bihydrogenation, 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.* 120:607–609.
- Borsting, C. F., M. R. Weisbjerg, and T. Hvelplund. 1992. Fatty acid digestibility in lactating cows fed increasing amounts of protected vegetable oil, fish oil, or saturated fat. *Acta Agric. Scand., Sect. A, Animal Sci.* 42:148–156.
- Bremmer, D. R., L. D. Ruppert, J. H. Clark, and J. K. Drackley. 1998. Effects of chain length and unsaturation of fatty acid mixtures infused into the abomasum of lactating dairy cows. *J. Dairy Sci.* 81:176–188.
- Chilliard, Y. 1993. Dietary fat and adipose tissue metabolism in ruminants, pigs, and rodents: a review. *J. Dairy Sci.* 76:3897–3931.
- Christensen, R. A., J. K. Drackley, D. W. LaCount, and J. H. Clark. 1994. Infusion of four long-chain fatty acid mixtures into the abomasum of lactating dairy cows. *J. Dairy Sci.* 77:1052–1069.
- Davis, C. L., and R. E. Brown. 1970. Low-fat milk syndrome. Pp. 545–565 in *Physiology of Digestion and Metabolism in the Ruminant*. A. T. Phillipson, ed. Newcastle upon Tyne: Oriel Press Limited.
- DePeters, E. J. 1993. Influence of feeding fat to dairy cows on milk composition. Pp. 199–215 in *Proc. Cornell Nutr. Conf. for Feed Manufacturers*. Cornell University, Ithaca, NY.
- DePeters, E. J., and J. P. Cant. 1992. Nutritional factors influencing the nitrogen composition of bovine milk: a review. *J. Dairy Sci.* 75:2043–2070.
- 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.* 70:1192–1201.
- Drackley, J. K., T. H. Klusemeyer, A. M. Trusk, and J. H. Clark. 1992. Infusion of long-chain fatty acids varying in saturation and chain length into the abomasum of lactating dairy cows. *J. Dairy Sci.* 75:1517–1526.
- Firkins, J. L., and M. L. Eastridge. 1994. Assessment of the effects of iodine value on fatty acid digestibility, feed intake, and milk production. *J. Dairy Sci.* 77:2357–2366.
- Gaynor, P. J., R. A. Erdman, B. B. Teter, J. Sampugna, A. V. Capuco, D. R. Waldo, and M. Hamosh. 1994. Milk fat yield and composition during abomasal infusion of cis or trans octadecenoates in Holstein cows. *J. Dairy Sci.* 77:157–165.
- Grant, R. J., and S. J. Weidner. 1992. Effect of fat from whole soybeans on performance of dairy cows fed rations differing in fiber level and particle size. *J. Dairy Sci.* 75:2742–2751.
- Grummer, R. R. 1994. Fat sources and levels for high milk production. Pp. 130–139 in *Proc. Southwest Nutrition and Management Conference*. University of Arizona, Tucson, AZ.
- Grummer, R. R. 1995. Ruminant inertness vs. intestinal digestibility of fat supplements: can there be harmony. Pp. 13–24 in *Proc. Cornell Nutr. Conf. for Feed Manufacturers*. Cornell University, Ithaca, NY.
- Grummer, R. R., M. L. Hatfield, and M. R. Dentin. 1990. Acceptability of fat supplements in four dairy herds. *J. Dairy Sci.* 73:852–857.
- Hawkins, D. E., K. D. Niswender, G. M. Oss, C. L. Moeller, K. G. Odde, H. R. Sawyer, and G. D. Niswender. 1995. Increase in serum lipids increases luteal lipid content and alters the disappearance rate of progesterone in cows. *J. Anim. Sci.* 73:541–545.
- Jenkins, T. C. 1993. Lipid metabolism in the rumen. *J. Dairy Sci.* 76:3851–3863.
- Jenkins, T. C. 1994. Feeding fat to dairy cattle. Pp. 100–109 in *Proc. Dairy Herd Management Conf.* University of Georgia, Athens, GA.
- Jenkins, T. C. 1997. Success of fat in dairy rations depends on the amount. *Feedstuffs* 69(2):11–12.
- 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.* 73:2842–2854.
- Johnson, T. O., G. E. Mitchell, R. E. Tucker, and O. T. Schelling. 1974. Pancreatic lipase secretion by sheep. *J. Anim. Sci.* 39:947–951.
- Klusemeyer, T. H., and J. H. Clark. 1991. Effects of dietary fat and protein on fatty acid flow to the duodenum and in milk produced by dairy cows. *J. Dairy Sci.* 74:3055–3067.
- Knapp, D. M., R. R. Grummer, and M. R. Dentin. 1991. The response of lactating dairy cows to increasing levels of whole roasted soybeans. *J. Dairy Sci.* 74:2563–2579.
- Kronfeld, D. S. 1976. The potential of the proportions of glucogenic, lipogenic, and aminogenic nutrients in regard to the health and productivity of dairy cows. *Adv. Anim. Phys. Anim. Nutr.* 7:5–26.

- Mattos, W., and D. L. Palmquist. 1977. Biohydrogenation and availability of linoleic acid in lactating cows. *J. Nutr.* 107:1755–1761.
- Noble, R. C. (1981). Digestion, absorption, and transport of lipids in ruminant animals. In *Lipid metabolism in ruminants*, p. 57. (W. W. Christie, Ed.), Pergamon Press, Oxford.
- Palmquist, D. L. 1983. Use of fats in diets for lactating dairy cows. Pp. 357–381 in *Proc. 37th Easter School in Agriculture*, J. Wiseman, ed. London: Butterworth.
- Palmquist, D. L. 1991. Influence of source and amount of dietary fat on digestibility in lactating cows. *J. Dairy Sci.* 74:1354–1360.
- Palmquist, D. L., and H. R. Conrad. 1978. High fat rations for dairy cows. Effects on feed intake, milk and fat production, and plasma metabolites. *J. Dairy Sci.* 61:890–901.
- Pearl, G. C. 1995. Feeding fats. Fats and Proteins Research Foundation Publication No. 269. Bloomington IL: Fats and Proteins Research Foundation. 23 pp.
- Rahnema, S., Z. Wu, O. A. Ohajuruka, W. P. Weiss, and D. L. Palmquist. 1994. Site of mineral absorption in lactation cows fed high-fat diets. *J. Anim. Sci.* 72:229–235.
- Sanchez, W. K., I. P. Moloi, and M. A. McGuire. 1998. Relationship between UIP and inert fat examined. Pages 12–13 in *Feedstuffs*, July 13, 1998.
- Schauff, D. J., and J. H. Clark. 1992. Effects of feeding diets containing calcium salts of long-chain fatty acids to lactating dairy cows. *J. Dairy Sci.* 75:2990–3002.
- Schingoethe, D. J., and D. P. Casper. 1991. Total lactational response to added fat during early lactation. *J. Dairy Sci.* 74:2617–2622.
- Smith, W. A., B. Harris, Jr., H. H. Van Horn, and C. J. Wilcox. 1993. Effects of forage type on production of dairy cows supplemented with whole cottonseed, tallow, and yeast. *J. Dairy Sci.* 76:205–215.
- Staples, C. R., J. M. Burke, and W. W. Thatcher. 1998. Influence of supplemental fats on reproductive tissues and performance of lactating cows. *J. Dairy Sci.* 81:856–871.
- Steele, W. 1983. Intestinal absorption of fatty acids, and blood lipid composition in sheep. *J. Dairy Sci.* 66:520–527.
- Sukhija, P. S., and D. L. Palmquist. 1990. Dissociation of calcium soaps of long-chain fatty acids in rumen fluid. *J. Dairy Sci.* 73:784–787.
- Sutton, J. D. 1989. Altering milk composition by feeding. *J. Dairy Sci.* 72:2801–2814.
- Tillman, A. D., and J. R. Brethour. 1958. The effect of corn oil upon the metabolism of calcium and phosphorous by sheep. *J. Anim. Sci.* 17:782–786.
- U.S. Department of Agriculture, Agricultural Research Service. 1998. USDA Nutrient Database for Standard Reference, Release 12-1. Nutrient Data Laboratory Homepage, <http://www.nal.usda.gov/fnic/foodcomp>.
- Weisbjerg, M. R., C. Borsting, and T. Hvelplund. 1992. Fatty acid metabolism in the digestive tract of lactating cows fed tallow in increasing amounts at two feed levels. *Acta Agric. Scand., Sect. A, Animal Sci.* 42:106–114.
- Wu, Z., and J. T. Huber. 1994. Relationship between dietary fat supplementation and milk protein concentration in lactating cows: A review. *Livest. Prod. Sci.* 39:141–155.
- Wu, Z., O. A. Ohajuruka, and D. L. Palmquist. 1991. Ruminant synthesis, biohydrogenation, and digestibility of fatty acids by dairy cows. *J. Dairy Sci.* 74:3025–3034.
- Zinn, R. A., and Y. Shen. 1996. Interaction of dietary calcium and supplemental fat on digestive function and growth performance of feedlot steers. *J. Anim. Sci.* 74:2303–2309.