EFFECT OF INCREASING DIETARY FAT CONTENT ON PRODUCTION AND FERTILITY OF LACTATING DAIRY COWS

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INTRODUCTION

Because fat is an energy dense nutrient and milk fat content influences unit milk price, interest in feeding supplemental fat has existed for years. Reviews of experiments using supplemental fat for lactating cows began very early, the first appearing in 1907 (Kellner as cited by Sundstol, 1974). No benefit to production of milk or milk fat was found in those studies. Other reviews naturally have followed (Warner, 1960; Palmquist and Jenkins, 1980; Shaver, 1990). These reviewers have concentrated on the influence of dietary fat on milk production and composition. The effect of dietary lipid on the reproduction of the cow has received much less attention. This paper will briefly summarize both, deferring the reader to aforementioned reviews for a more thorough discussion of production responses. We acknowledge the particular help of Shaver (1990) and R.R. Grummer (personal communication) in preparation of this paper.

ROLE OF FAT IN EARLY LACTATION

As milk production per cow continues to increase year after year, efforts to increase energy intake intensify. A common strategy used is to include supplemental fat in the lactating cow diet. This may be of particular importance during the early weeks of lactation when dry matter intake (DMI) is at its lowest point during lactation. Two weeks after calving, DMI was about 2.5% of body weight (Staples et al., 1990). For a 650 kg cow, this amounts to only 16 kg/day. A diet of 50% corn silage, 30% ground corn, and 18% soybean meal (1.71 Mcal/kg DM) can only support about 25 kg of 3.5% fat-corrected milk (FCM; NRC, 1989). Yet at this same time, cows commonly will be producing 33 to 34 kg/day by using body energy reserves to supplement their energy output. With DMI and adipose tissue mobilization maximized during this time, dietary addition of fat may further enhance milk yield. By 6 to 8 weeks after calving, DMI has risen to 3.5% of body weight or 23 kg/day which will support about 41 kg of milk. Thus it appears that supplemental dietary fat can supply needed energy during the first 6 to 8 weeks of lactation while DMI climbs, and beyond this point when milk production exceeds 40 kg/day if dietary energy is limiting production. Although this scenario appears sound, the review of literature below indicates that midlactation cows producing milk as low as 23 to 24 kg/day have increased their production when fed supplemental fat. Therefore the fat may be playing a role other than simply supplying additional energy. Indeed, cows fed a fat-deficient diet increased yield of FCM 47% (from 11.0 to 16.2 kg) when provided with .55 kg of tallow per day (Banks et al., 1976).

Another reason why fat supplementation may be more effective in early lactation is the greater transfer of fatty acids from the blood to the mammary gland in early versus late lactation (30 vs. 5%; Storry, 1988).

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Lipids not only supply energy for milk synthesis but also influence milk fat content.

MILK FAT

Fatty acids in milk having a chain length between 4 and 10 carbons (10% by weight) are synthesized by the mammary gland from ruminal acetate and B-hydroxybutyrate. Fatty acids of carbon-lengths of 18 (40% by weight) are taken up directly from plasma triglycerides primarily of dietary origin. Intermediate length fatty acids (12 to 16 carbons; 50% by weight) are produced by both systems (Storry, 1988). Increasing the dietary lipid content (usually consisting mainly of 16 to 18 carbon fatty acids) can influence the milk fat and protein concentration (demonstrated in the review of literature below). In Table 1, the fatty acid composition of the milk moved toward that of the fatty acid composition of tallow (Table 2) and especially so when the tallow reached the small intestine unchanged.

Table 1. Changing milk composition with dietary unprotected and protected tallow (Storry et al., 1973, 1980).

Fatty Acid of Milk	Control Diet	Tallow Diet	Protected Tallow Diet
C4:0 - C12:0	18.1	15.9	6.9
C14:0 - C14:1	18.0	14.5	7.2
C16:0 - C16:1	39.8	33.4	31.4
C18:0	4.4	7.8	13.3
C18:1	14.9	20.4	33.9

DIETARY FAT

The lipid content of the lactating cow diet containing processed grains and stored forages will range typically from 2 to 4%. It appears that the ruminant is able to transport and utilize more fat than this without a metabolic hazard. Absorption of total fatty acids was linear up to 1200 gm/day of fatty acid intake and curvilinear beyond this amount (Storry, 1988). Palmquist and Conrad (1978) state that diets can contain up to 7 to 8% fat without negative effects upon digestibility.

The type of fat has a lot to do with how much can be fed from a production standpoint. Degree of fatty acid saturation influences fat dynamics both in the rumen and in the intestines. Dietary unsaturated fatty acids that are not biohydrogenated by ruminal bacteria may interfere with ruminal digestion of fiber by physically coating the fiber or by exerting some antimicrobial effect. The latter hypothesis appears more feasible at this time (Jenkins, 1988). Actual production of volatile fatty acids by ruminal bacteria can be reduced by unsaturated dietary lipid (Sutton, 1980) thus reducing the amount of precursor for synthesis of short-chain fatty acids by the mammary gland. This is thought to be the main mechanism by which, on occasion, dietary fat reduces milk fat content. Saturated fatty acids will pass through the rumen relatively intact. Their digestion in the small intestine though is often much less than that of unsaturated fats. Digestibility of yellow grease decreased from 68% to 47% when saturation changed from 43% to 99% (Jenkins and Jenny, 1989). Therefore attempts to protect unsaturated acids from digestion in the rumen will result in higher digestibility for those fats in the lower gut. However too many unsaturated fatty acids in the lower gut can increase the proportion of unsaturated fatty acids in the milk, thus affecting the suitability of milk for manufacturing purposes. The right balance of unsaturated to saturated fats delivered to the lower gut is one objective but what that right balance is being examined. Five specialty fats had similar digestibility coefficients as determined by Palmquist et al. (1989). Fat products which attempt to match the fatty acid content of milk may come closest to impacting milk fat concentration (Table 2).

POPULAR FAT SOURCES

The effect of supplemental dietary fat on DMI, milk yield and milk fat and protein content will vary depending upon the type of basal diet and the amount and type of fat used. Shaver (1990) divided fat sources into two categories: 1) commodity fats such as oilseeds and animal fat and 2) specialty fats which are marketed as ruminally "inert" fats. These include Alifet (Alifet USA Inc., Cincinnati, OH), Booster Fat 95 (Balanced Energy Co., Clinton, IA), Carolac (Carolina Byproducts), Energy Booster 100 (Milk Specialties Co., Dundee, IL), and Megalac (Church and Dwight Co. Inc., Princeton, NJ).

The vast majority if not all the fatty acids in these two groups are a minimum of 14 carbons in length. Differences among fat sources include the proportions of the various long chain fatty acids (Table 2) and whether the fatty acids are free or attached to a glycerol molecule (triglycerides). Unsaturated fats make up the majority of the fatty acids in commodity fats while inert fats contain mostly saturated fats. The long chain fatty acid analysis of milk (Table 2) reveals about equal proportions of palmitic and oleic fatty acids with about 61% of long chain acids being saturated.

Table 2. Fatty acid profile of various commodity and specialty fat sources (Shaver, 1990.)[1]

	Weight %								
Fat Source	Myristic C14:0	Palmitic C16:0	Palmitoleic C16:1	Stearic C18:0	Oleic C18:1	Linoleic C18:2	Linolenic C18:3	Saturated[2] %	Unsaturated[3] %
Cow Milk[4]	13	33	3	15	31	3	2	61	39
Whole cottonseed	1	25	--	3	17	54	--	29	71
Whole Soybeans	--	11	--	4	24	54	7	15	85
Tallow	3	26	6	19	40	5	1	48	52
Yellow Grease	3	18	4	12	47	13	3	33	67
Animal-Vegetable Blend	1	22	5	5	36	29	2	28	72
Alifet	3	27	1	37	31	1	--	67	33
Booster Fat	3	25	3	22	45	2	--	50	50
Carolac	2	24	3	35	33	2	1	61	39
Energy Booster	2	49	--	35	13	1	--	86	14
Megalac	2	51	--	4	35	8	--	57	43

[1]Source: Palmquist, 1988; Palmquist et al., 1989; De Peters et al., 1987; Grummer personal comm. (University of Wisconsin-Madison).
[2]Saturated fatty acids (C14:0, C16:0, C18:0).
[3]Unsaturated fatty acids (C16:1, C18:1, C18:2, C18:3).
[4]Proportion of each fatty acid as a percent of fatty acids > 12 carbons (National Dairy Council, 1978).

DIETARY LIPIDS AND ANIMAL PRODUCTION

Fatty acids are used by the cow for energy for milk synthesis and for direct incorporation into milk fat. Examination of the literature for the impact of various fat products on milk yield and composition reveal that high fat feedstuffs usually have some positive influence.

<u>WHOLE COTTONSEEDS.</u> The impact of feeding whole cottonseed (WCS) on animal performance appears to be influenced by the type of forage in the diet. When corn silage makes up the primary dietary forage, an increase in milk yield with a decrease in milk fat percent is observed usually. In five experiments from Alabama (Umphrey, 1989), Florida (Chik, 1987; Van Horn et al., 1984), and Mississippi (Baker et al., 1989), average milk yield was improved from 24.5 to 26.1 kg/day when WCS was fed at an average of 11.3% of diet DM (Table 3). However milk fat content decreased from 3.73 to 3.31% resulting in a small decrease in milk fat yield. Milk protein content responded variably in that two studies showed decreases while two others showed no effect. Researchers in Texas (Horner et al. 1986) and Wisconsin (Mohamed et al., 1988) fed WCS at about 16% of diet DM and saw no effect of WCS on milk yield or milk fat yield. The fact that bermudagrass hay or alfalfa silage made up 10 and 15% of diet DM respectively for these studies may have prevented the drop in milk fat % seen in the other five studies.

Table 3. Influence of Supplementing Corn Silage-based Diets with Whole Cottonseeds (WCS) on Dry Matter (DM) Intake and Milk Yield and Composition.

Reference	WCS in diet, % DM	DM Intake, kg/day	Milk Yield, kg/day	Fat %	Milk Protein, %
Van Horn et al., 1984	0	18.8	24.0	3.30	2.84
	15	20.7	26.3	3.22	2.89
Van Horn et al., 1984	0	22.7	25.4	3.93	3.31
	14	22.8	27.2	3.07	3.41
Chik, 1987	0	21.1	21.7	3.55	
	15	21.5	22.0	3.20	
Umphrey, 1989	0	16.1	24.7	3.37	3.09
	10.4	17.7	27.2	3.12	3.01
Baker et al., 1989	0	22.3	26.9	4.50	3.92
	11.5	20.2	28.0	3.92	3.49
Horner et al., 1986	0	23.2	31.2	2.97	3.13
	15	23.4	31.6	3.38	3.02
Mohamed et al., 1988	0	23.0	26.9	3.54	3.03
	16.5	21.4	25.8	3.70	3.11

Whole cottonseeds appears to have a different effect when the primary dietary forage is alfalfa. Five studies show remarkable consistency in their results. Milk yield was changed little but milk fat content increased dramatically .33 percentage units from a base of 3.50% while milk protein content decreased .08 percentage units from a base of 3.30% with increasing amount of WCS in the diet (Table 4).

Table 4. Influence of Supplementing Alfalfa-based Diets with Whole Cottonseeds (WCS) on Dry Matter (DM) Intake and Milk Yield and Composition.

Reference	WCS in Diet, % DM	DM Intake, kg/day	Milk Yield, kg/day	Milk Fat, %	Milk Protein, %
Smith et al., 1981	0	19.7	20.8	3.95	3.31
	5	19.0	19.4	3.90	3.24
	15	19.1	21.6	4.29	3.20
	25	20.4	21.2	4.52	3.22
DePeters et al., 1985	0	19.0	24.4	3.14	3.22
	10	19.3	25.0	3.49	3.14
	15	19.1	25.5	3.49	3.14
	20	19.0	25.4	3.61	3.16
Palmquist, 1987	0	17.4	21.8	3.66	3.47
	9.4	18.0	22.5	3.97	3.40
	20.2	16.8	21.5	4.02	3.42
	32.1	15.9	20.9	4.32	3.34
Chik, 1987	0	25.4	22.0	3.25	
	15	22.5	22.3	3.55	
	30	21.4	21.2	3.40	
Hein et al., 1990	0	21.7	29.6	3.46	3.19
	13.8	21.1	28.4	3.65	3.12

Whole cottonseeds have had little effect on animal performance when fed with cottonseed hulls although a limited amount of research prevents any firm conclusions from being made (Chik, 1987; Van Horn et al., 1984).

WHOLE RAW SOYBEANS. Raw soybeans have been fed to lactating dairy cows in order to increase their energy intake. As shown in Table 5, the main consistent effect of feeding raw soybeans was to depress feed intake from an average of 22.9 to 21.4 kg/day. This resulted in an improved production efficiency from 1.24 to 1.32 kg of milk/kg of feed. As in the case of WCS, milk fat content was depressed when corn silage was the sole forage source (Baker et al., 1989; Van Horn et al., 1984).

Table 5. Effect of Including Raw Whole Soybeans (WSB) in the Diet on Dry Matter (DM) intake and Milk Yield and Composition.					
Reference	WSB in diet (% DM)	DM Intake (kg/day)	Mild Yield (kg/day)	Milk Fat (%)	Milk Protein (%)
Faldet, 1989	0	23.4	34.5	3.40	3.00
	14	22.3	34.2	3.50	2.90
Mohamed et al., 1988	0	23.1	26.2	3.53	3.45
	20	20.9	25.7	3.59	3.28
Baker et al., 1989	0	22.3	26.9	4.50	3.93
	10.5	21.5	29.2	3.89	3.59
Van Horn et al., 1984	0	22.7	25.4	3.93	3.31
	14.0	20.8	24.2	3.64	3.39
Bernard, 1990	0	20.6	30.7	3.61	3.23
	9.4	20.5	31.9	3.74	3.21

EXTRUDED SOYBEANS. The processing of whole soybeans changes the nutritional properties of the beans. One such method which has improved milk yield dramatically is extrusion. In four experiments (three of which were done in South Dakota), milk yield jumped an average of 3.1 kg/day (from 31.6 to 34.7 kg) with no real change in feed intake (Table 6). So once again, production efficiency is improved by feeding whole soybeans, only this time with an improvement in milk yield rather than a reduction in feed intake. Milk fat content was depressed from 3.19 to 2.86%, most likely due to a more complete release of the soy oil into the rumen. As seen before, milk protein content was depressed slightly. This effect on milk yield and fat content is similar to that seen with WCS in corn silage-based diets.

Table 6. The Effect of Including Extruded Soybeans (EBS) in the Diet on Dry Matter (DM) Intake and Milk Yield and Composition.					
Reference	ESB in Diet (% DM)	DM Intake (kg/day)	Milk Yield (kg/day)	Milk Fat (%)	Milk Protein (%)
Scott et al., 1990	0	25.9	33.5	3.31	3.06
	16	25.4	35.9	3.20	2.97
Schingoethe et al., 1988	0	19.3	32.2	2.98	2.99
	19	20.5	36.2	2.63	2.85
Kim et al., 1990	0	17.7	29.2	3.20	2.99
	17	18.4	32.4	2.69	2.93
Casper et al., 1990	0	21.0	31.7	3.26	3.03
	17.5	21.1	34.5	2.98	2.95

ROASTING SOYBEANS. Roasting of soybeans has been used to inactivate the trypsin inhibitor and to decrease the proportion of the protein which is ruminally degradable. Cows fed roasted whole soybeans (WSB) receive additional fat and undegradable protein thus making any response in milk yield difficult to interpret. In most of the experiments below, soybeans replaced soybean meal. Including roasted soybeans in the diet from 12 to 24% DM improved milk yield an average of 2.2 kg from a base of 34.1 kg (Table 7). Dry matter intake changed little. Milk fat was improved an average of .09% units from a base of 3.43%. Milk protein content was depressed an average of .11% units from a base of 3.04%.

Table 7. The Effect of Including Roasted Whole Soybeans (RWSB)in the Diet on Dry Matter (DM) Intake and Milk Yield and Composition.

Reference	RWSB in Diet (% DM)	DM Intake (kg/day)	Milk Yield (kg/day)	Milk Fat (%)	Milk Protein (%)
Ruegsegger & Schlutz, 1985	0	22.7	36.2	3.50	2.95
	12.9	22.5	37.0	3.59	2.95
Driver et al., 1990	0	21.4	38.5	3.53	2.84
	13.7	19.3	38.5	3.38	2.66
Voss et al., 1988	0	20.3	37.2	3.52	2.89
	15.0	20.2	38.7	3.73	2.78
Voss et al. 1988	0	19.6	35.2	3.47	2.82
	13.0	20.7	37.4	3.82	2.72
Faldet, 1989	0	23.4	34.5	3.40	3.00
	13.0	23.6	38.9	3.40	2.90
Knapp & Grummer, 1990	0	24.5	34.9	3.23	3.11
	12	24.9	37.4	3.20	3.03
	18	25.0	38.7	3.32	3.00
	24	24.9	38.7	3.37	3.10
Bernard, 1990	0	20.6	30.7	3.61	3.23
	9.4	21.2	32.3	3.53	3.20
Mohamed et al., 1988	0	23.1	26.2	3.53	3.45
	20.0	20.9	26.9	3.59	3.21

TALLOW. In 11 comparisons, feeding tallow at an average of 3.7% of diet DM, milk fat % was increased an average of .22 units (Table 8). Milk protein content was depressed an average of .15 units. In two other studies using alfalfa hay (Wrenn et al., 1978) or CSH (Van Horn et al., 1984), fat content was depressed .50 and .57 units respectively. Feed intake generally was unaffected while milk yield increased an average of 1.2 kg/day (12 comparisons) but decreased 3.0 kg/day in one comparison (Palmquist and Conrad, 1980).

Reference	Tallow in diet (% DM)	DM Intake (kg/d)	Milk Yield (kg/d)	Milk Fat (%)	Milk Protein (%)
Clapperton & Steele, 1983	0	8.0 silage only	11.9	3.94	2.91
	0	10.8 + grain	13.9	3.81	3.15
	4.1	10.0	14.7	4.34	3.02
	10.0	8.4	13.6	4.30	2.98
Clapperton & Steele, 1983	0	10.6 silage only	16.5	3.92	2.75
	0	5.2 + grain	20.7	3.91	3.13
	2.4	15.0	22.3	4.15	2.90
	3.8	14.9	22.0	4.17	2.91
	5.1	14.6	21.7	4.27	3.02
	6.7	14.1	22.7	4.27	2.90
Mattias, 1982	0	19.1	28.3	3.65	
	2.3	19.5	29.3	3.75	
Wrenn et al., 1978	0	17.3	23.5	3.50	3.20
	4.9	19.5	25.8	3.00	3.10
Storry et al., 1973	0		23.8	3.40	
	1		25.0	3.40	
	2		25.3	3.50	
	4		23.5	3.50	
	6		26.5	3.40	
Palmquist & Conrad,1980	0	19.2	32.7	2.85	3.24
	3.3	18.2	29.7	2.98	3.22
Van Horn et al., 1984	0	20.9	22.5	3.58	
	2.5	20.8	22.6	3.01	

Table 8. Influence of Tallow on Dry Matter (DM) Intake and Milk Yield and Composition.

<u>COMMERCIAL FAT SOURCES.</u> Shaver (1990) summarized 15 trials which examined the feeding of Megalac at 2.1 to 3.3% of diet DM. Adding four recent publications to his summary (Schauff and Clark, 1989; Schneider et al., 1990; Sklan et al., 1989; West and Hill, 1990) shows an average decrease in daily DM intake of .6 kg, increase in daily milk yield of 1.3 kg, increase in milk fat percent of .10, and

decrease in milk protein percent of .10 (Table 9). Megalac appears to have an additive effect to BST injections. Cows producing an average of 28.7 kg/day increased fat-corrected milk yield to 30.9 kg/day with BST and to 33.2 kg/day with BST and Megalac (Schneider et al., 1987; Lucy, 1990).

The limited number of experiments using the other fat products restricts the conclusions to be drawn about their efficacy.

Table 9. Response of milking cows to commercial supplements of fat.

Number of studies	Product	% in Diet	DM Intake, kg/day	Milk Yield, kg/day	Milk Fat, %	Milk Protein, %
20	Megalac	2.1-3.3	-.6	+1.3	+.10	-.10
4	Energy Booster	2.3-5.0	-.2	+0.8	-.03	+.04
7*	Prilled Fat	2.4-5.0	-.9	+0.4	+.08	-.01
1	Booster Fat	2.6	0.0	+1.2	+.06	-.07

* Ferguson et al. (1990; 4 data sets) and Schauf and Clark (1989; 2 data sets) added to Shaver's review (1990).

DELAYED RESPONSE TO FAT FEEDING - CONTINUOUS TRIALS

Cows in early lactation that were kept on the same dietary treatment throughout the experiment showed an interesting response. Cows fed prilled fat (Carroll et al., 1990) or roasted WSB (Ruegsegger and Schultz, 1985) starting shortly after calving tended to produce less milk during the first 5 to 6 weeks than controls. At this point, daily milk yield of fat-fed cows surpassed controls (+2 kg/d) the next 8 to 10 weeks of the experiment. Feeding of additional fat immediately after parturition may reduce adipose tissue mobilization as the cow tries to control blood lipid concentration. Once she gets close to neutral energy balance, this "antagonism" is reduced and milk yield responds. Palm7quist (1990) suggests withholding fat from the diet until 5 to 6 weeks into lactation. When Megalac was fed starting at week 2 of lactation, 4% FCM yield was less than controls (26.3 vs. 27.9 kg) over the 15 week study. But when Megalac was withheld until the start of week 6, FCM yield was similar to controls (28.2 vs. 27.9 kg; Eastridge and Palmquist, 1988).

MORE FORAGE CAN BE FED WHEN FEEDING FAT

By replacing the grain portion of the diet with fat and increasing the forage:grain ratio in the diet, the dietary energy concentration can be maintained while potentially decreasing feed costs. DePeters et al. (1989) substituted yellow grease (3.5% of diet DM) for cracked corn and increased the alfalfa hay in the diet from 50 to 65% of DM so that both diets were isocaloric and isonitrogenous. Milk production tended to increase (23.4 and 24.9 kg) as did milk fat content (3.36 and 3.69%) for fat-containing diets. This same strategy has been used with fancy bleached tallow (Palmquist and Conrad, 1980) and Megalac

(Lucy, 1990). Two isocaloric diets were prepared, one containing 50% grain:25% corn silage:25% alfalfa hay (control) and a second, 33% grain:67% forage (corn silage + alfalfa hay) with 3.3% tallow. Milk yield was maintained (32.7 and 32.2 kg/day) and milk fat content increased (2.85 to 3.27%). Using Megalac at 2.2% of diet DM, diets were reformulated from 51% corn silage:49% grain to 65% corn silage:35% grain while maintaining NEL content of diet at 1.67 Mcal/kg (Lucy, 1990). Milk yield and fat content were sustained (28.1 and 28.2 kg/day; 3.25 and 3.29%) when cows received daily injections of bovine somatotropin (BST) but tended to lose some production under control injection treatment (27.0 vs. 24.8 kg; 3.17 vs. 3.32%).

FEEDING THUMB RULES

1. Include as much fat in the diet as is produced in the milk. For example, if milk production is 40 kg at 3.5% fat, then fat production is 1.4 kg and 1.4 kg of fat can be fed. If feed intake is 23 kg, then fat will makeup 6% of diet DM.

2. One third of dietary fat should come equally from normal feedstuffs, oilseeds or fat, and inert fats. For example, if 1.4 kg of fat are to be fed, then about .5 kg of fat (2% of diet) can be supplemented by tallow or by WCS. For WCS, this is 2.5 kg DM (.5 kg ÷ 20% fat in WCS).

3. Dietary concentrations of calcium and magnesium should be increased to 1.0% and .3% (DM) respectively as fat tends to tie up these minerals in the rumen.

4. Increase undegradable intake protein (UIP) an additional 72 g/day for each Mcal of energy coming from dietary fat above 3%. Because fat does not supply any energy to the rumen, bacterial protein synthesis can be reduced. By feeding more UIP, protein delivery to the lower gut can be maintained.

DIETARY LIPIDS AND REPRODUCTION

Although the amount of milk produced per cow has increased since 1952 (2300 to 6500 kg/cow), conception rates to artificial insemination have dropped from 66% to 40-50% (current rate). This has occurred despite constant conception rates in virgin heifers during this period (Butler and Smith, 1989). Evidence is gradually building indicating that the demands of lactation can place limitations on the function and development of the reproductive system.

The early postpartum cow represents a classic scientific example of goal-oriented nutrient partitioning. Milk yield increases dramatically immediately after parturition and usually peaks in 3 to 6 weeks. Dry matter intake climbs slowly during this time period so that energy balance is often negative. Body tissues are orchestrated to supply nutrients for this sudden demand of energy export. During this same time, the uterus, ovary, and hypothalamus/pituitary of the cow undergo a process of recovery and rebuilding for the establishment of subsequent pregnancy.

In general, it is believed that cows in lower energy balance have poorer reproductive performance as reviewed recently by Butler and Smith (1989). Energy balance was correlated positively to size of largest follicle on day 10 postpartum (r^2=.48; Lucy, 1990). Cows that ovulate early in the postpartum period are more fertile because they experience more estrous cycles prior to first insemination. This principle has made number of days to first ovulation one important index of reproductive efficiency. Interval to first ovulation was longer in cows in most negative energy balance (Butler and Smith, 1989).

Lactational performance is extremely dependent on quality, quantity, and balance of feedstuffs consumed. Although not traditionally examined, it seems plausible that dietary ingredients which affect milk production and energy metabolism can influence the function of the hypothalamus, pituitary, and ovary. The best method to manage this interaction between lactation and reproduction may be through unique dietary formulations targeted for the benefit of reproductive performance. This represents a challenging new area of postpartum research.

Currently, one of the most often mentioned nutritional factors thought to be beneficial to reproductive performance is dietary fat supplementation. The specific effect of fat-feeding on reproductive performance is not clear.

A main objective of those feeding dietary fat is to increase energy intake and help reduce the degree of negative energy balance. While this often occurs, an improvement in energy balance does not always result. When dairy cows are fed fat, DM intake is often somewhat reduced and FCM yield is often increased (Shaver, 1990) so energy balance remains unchanged or only slightly improved.

The mobilization of body nutrients which occurs in postpartum cattle results in an array of circulating metabolites which are characteristic of an animal that is undergoing body nutrient depletion. The possibility exists that the concentration of various metabolites in the blood may affect directly the function of the ovary or indirectly by influencing the various reproductive metabolic hormones known to modify reproductive function. The relationship of dietary fat to some of these metabolites, hormones, and growth factors will be reviewed here. In addition, the effect of supplemental dietary fat on commonly used measurements of reproductive efficiency will be examined.

METABOLITES

CHOLESTEROL AND PROGESTERONE. Plasma cholesterol concentration usually is increased by supplemental dietary fat (Carroll et al., 1990; Sklan et al., 1989). Cholesterol is a precursor for luteal cell progesterone (P4) synthesis. Progesterone appears after ovulation, preparing the uterus for the reception of the embryo and for its nutrition. Progesterone has been associated with improved fertility of cattle (Fonesca et al., 1983). Serum cholesterol was related inversely to interval from calving to conception (Kappel et al., 1984).

1. Carroll et al. (1990) fed prilled fat at either 0 or 5% of diet DM to 46 multiparous Holstein cows from day 5 to 100 of lactation. FCM yields were not different until weeks 6 to 14 of lactation. Mean plasma cholesterol content increased from 159 to 204 mg/dl and progesterone concentrations increased during the second and third estrous cycles of fat-fed cows compared to controls. A linear correlation between plasma cholesterol and plasma P4 concentration during the mid to late luteal phase of the second and third estrous cycles of lactating cows was determined (r^2=.11). However, fertility in this study was not improved Energy Booster

during breeding at these two cycles (9/15 conceived for controls and 4/13 conceived for prilled fat).

2. The feeding of whole cottonseed (15% of diet DM) to 350 kg Holstein heifers for 70 days elevated serum concentrations of cholesterol from about 100 to 170 mg/dl throughout the estrous cycle and progesterone from about 7 to 9 ng/ml during the mid-to-late luteal portion of their estrous cycle (Talavera et al., 1985).

3. Williams (1989) fed diets with and without WCS (30% of diet DM) to beef cows. Plasma cholesterol concentrations were elevated by WCS. In addition, more of the lipid-fed cows had a low level P4 release prior to first ovulation (81 vs. 37%). This P4 may prime the uterus or follicle so that the cycles following the first ovulation will be full length cycles rather than a short cycle. This recrudescence to normal ovarian cycles is essential for achieving normal fertility and embryo survival.

4. At the University of Florida (Lucy, 1990), cows were fed diets continuously for 92 days with and without Megalac (2.2% of diet DM). Yield of FCM and DM intake were not different. Megalac tended to increase plasma cholesterol (220 vs. 185 mg/dl, P=.20) and growth hormone (6.7 vs. 5.7 ng/ml; P=.12). Diameter of the preovulatory follicle was greater for Megalac-fed cows (18.8 vs. 16.6 mm; P<.08).

<u>LINOLEIC ACID.</u> Commodity fat sources, especially oilseeds, have significant amounts of linoleic acid (18:2; Table 2), a required fatty acid for ruminants. It should be protected from ruminal bacterial hydrogenation. 85% of dietary linoleic acid from rapeseed was biohydrogenated in the rumen (Murphy et al., 1987). Linoleic acid is a precursor for synthesis of arachidonic acid and the prostaglandins (eg. PGF). PGF is released from the uterus and can increase recruitment of ovarian follicles and stimulate follicle growth. It may therefore by possible to augment postpartum PGF concentrations and enhance ovarian function by feeding ruminally protected linoleic acid to cows.

1. One liter of a 20% soybean oil emulsion (50% linoleic acid, 26% oleic acid, 10% palmitic acid, 9% linolenic, and 3.5% stearic acid) or of physiological saline was infused via jugular vein cannula into synchronized 310 kg Holstein heifers from days 9 to 13 of the estrous cycle (Lucy, 1990). Fat content of infusion increased fat intake by 2.9 percentage units, similar to that used in practical fat-feeding situations. Heifers infused with oil had higher plasma concentrations of PGFM (144 vs. 30 pg/ml). It is not likely that these increases came from direct conversion of linoleic acid to PGF as studies with other species determined that 2 to 5 days were required for this conversion to take place, although cattle may be different in this regard. Soybean oil infusion also resulted in more follicles per ovary (6 vs 2) and a larger diameter of the largest follicle (10.2 vs. 7.0 mm) as determined by ultrasonography on day 16. Linoleic acid specifically or fatty acids in general may simply cause an immediate secretion of PGF. Safflower oil (70% linoleic acid) and olive oil (7% linoleic acid) caused similar increases in PGFM when infused into the abomasums of cattle (400 ml/d) indicating that the PGFM increases were not an artifact of oil emulsion (Lucy, 1990). This effect may have been due to increased energy, fatty acids, or linoleic acid. However, the increased concentrations of PGF, which has been shown by others to increase follicular recruitment (Guilbault et al., 1987), was postulated to be the mechanism for enhanced follicular development.

2. Megalac, containing about 9.5% linoleic acid, was fed (2.2% diet DM) to half of 18 Holstein cows for the first 77 days of lactation (Lucy et al., 1991b). FCM yield was not changed by diet. Plasma concentrations of PGF metabolite (15 days of sampling between days 1 and 40) were not different between control and fat-fed groups (698 vs. 755 pg/ml). Amount of linoleic acid ingested was possibly too low to have an effect or it was not completely protected from biohydration in the rumen or PGF secretion was already at maximum for these cows. Other feeds such as fish oil contain high concentrations of arachidonic acid and may be more effective. The ovarian follicular environment of cows was standardized from days 25 to 40 using an intravaginal P4 releasing device (CIDR). Seven cows out of nine had ovulated prior to day 25 (CIDR insertion) for both treatments. Upon removal of the CIDR (day 40), number of cows having ovulation and CL formation, cystic follicles, and no ovulation was 5, 3, and 1 for controls and 7, 2, and 0 for the Megalac group. Of those cows having ovulation and CL formation, it was determined by ultrasonography that Megalac cows had more small (3 to 5 mm; 2.9 vs. 1.6) and large follicles (>15 mm; .7 vs. .2) than control cows. Not only were there more large follicles when Megalac was fed, but the mean diameter of the largest (18 vs. 12 mm) and second largest follicles (11 vs. 7 mm) were greater. These follicles likely were physiologically active based on the fact that the number of medium size (6 to 9 mm) follicles were reduced within the Megalac group illustrating the phenomena of follicular dominance. Increased incidence of follicles greater than 15 mm may be a result of slower follicular turnover or enhanced follicular growth. Cholesterol-fatty acid esters and/or metabolic hormones, such as insulin, IGF-1, or growth hormone, may be involved with the maturation of dominant follicles.

It is clear that feeding by-pass fatty acids (eg. Meglac) stimulates the number of follicles greater than 3 mm and increases the size of the preovulatory follicle during the postpartum period (days 7-60 postpartum; Lucy, 1991b). Such a stimulation of ovarian activity may be an advantage regarding the development of reproductive management systems that are integrated with nutritional management of the postpartum dairy cow. However, additional research is needed to determine if a dietary stimulation in postpartum follicle development influences the following physiological responses: does enhanced follicle development on the ovary adjacent to the previous pregnant uterine horn result in normal preovulatory follicle development and formation of a competent corpus luteum; does stimulated follicle development result in normal follicle dynamics in which follicles turnover (grow and undergo atresia) and do not undergo cystic follicular degeneration; and whether enhanced follicle development after artificial insemination does or does not antagonize the antiluteolytic mechanisms induced by the conceptus and thus enhanced embryo mortality.

DIETARY FAT AND REPRODUCTIVE EFFICIENCY

Reproductive protocols were rarely given in the following studies thus reducing one's ability to assess actual treatment effects.

PRILLED FATS.

1. Dietary prilled fat was evaluated using 39 cows in Israel and 214 cows on three farms in Pennsylvania (PA) from 0 to 110 to 150 days postpartum (Ferguson et al., 1990). Days to first service were alike (80 days). Cows receiving the fat supplement were 2.2 times more likely to become pregnant than controls. Both first service (59 vs. 43%) and all services (59 vs. 41%)

conception rates were higher for cows consuming prilled fat. Most of the observed differences were due to two herds in PA whose first service conception rates of control cows were low, 38 and 33%. 3.5% FCM yields were improved a significant 1.8 kg/d for Israeli cows and a nonsignificant .7 kg/d for PA cows.

2. Carroll et al. (1990) fed prilled fat at either 0 or 5% of diet DM to 46 multiparous Holstein cows from day 5 to 100 of lactation. FCM yields were not different until weeks 6 to 14 of lactation. Mean plasma cholesterol and progesterone concentrations increased. However increased progesterone concentrations did not result in improved conception rates. Average conception rates over the first three breedings for control and fat-fed cows were 13/22 (59%) and 7/16 (44%). Seven out of the eight cows not bred were from the prilled fat treatment and five of those seven were not detected in estrus the first 100 days of lactation.

SOYBEANS.

1. Holstein cows (n=30) were fed either roasted soybean meal or roasted whole soybeans for 60 days starting on day 13 after calving (Voss et al, 1988). Fat intake was 629 g/d greater by cows fed roasted WSB. Only reproductive data reported was days open and they were not different between groups (122 vs. 106) as standard errors were quite large.

2. 58 Holstein and Brown Swiss dairy cows received diets with and without 415 g of fat from roasted WSB from day 10 to 105 of lactation (Ruegsegger and Schultz, 1985). Milk yield was increased a mean of .8 kg/d by cows fed WSB but no differences in reproductive measures were found although days open (109 vs. 115) and breedings per conception (1.8 vs. 2.1) numerically favored fat-fed cows.

3. 305 day lactation data was summarized from cows fed no additional fat (2.5 to 3.0% fat; n=94) or fat in the form of extruded soybeans or sunflower seeds ($\geq$5% fat in diet; n=96; Schingoethe and Casper, 1990). Although milk yield was improved .9 kg/d by oilseeds, days open (125 vs. 126) and services per conception (2.15 vs. 2.38) were similar (P>.24).

CALCIUM SALTS OF LONG CHAIN FATTY ACIDS.

1. Calcium soaps of long chain fatty acids (500 g/d) were evaluated by 108 Israeli-Fresian dairy cows for the first 170 days of lactation (Sklan et al., 1989). Milk yield favored fat-fed cows, 32.1 vs. 30.7 kg. After three services, 76% of cows fed fat conceived compared to 58% for control cows with the difference due primarily to the first service. Days open were less for fat-fed cows also (74 vs. 86) but in neither case were differences significant. Serum phospholipids and cholesterol concentrations were higher in cows fed fat. These increases were likely due to additional dietary fat and increased mobilization of adipose tissue as body condition scores of fat-fed cows were .4 to .5 lower than controls.

2. A second study in Israel used 108 cows for an approximate 110 day study in which cows fed Megalac (500 g/d) increased FCM yield 2.9 kg/d over controls (Schneider et al., 1988). In addition, a greater proportion of cows fed Megalac conceived at first service (60 vs. 43%) and were pregnant at the end of the study (87 vs. 72%) although statistical differences were not given.

3. Seven dairy farms in Pennsylvania participated in a study evaluating Megalac for the first 150 days of lactation. FCM yield by multiparous cows (n=80/group) was improved an average of 3.8 kg/d although no change was seen by primiparous cows (n=20/group; Ferguson et al., 1988). Conception rates (45 vs. 36%) and days open (90 vs. 97) were not different for the control and Megalac groups (Chalupa and Ferguson, 1988).

4. Forty cows were divided between 0 and 3% Megalac diets from day 15 through 98 of lactation (Erickson, 1989). Dry matter intakes were similar (18.2 kg) but FCM yields favored cows fed fat (32.5 vs. 34.8 kg/d). Energy balances were similar (-2.2 vs. -1.8 Mcal/d) but blood glucose was reduced 55.3 to 52.6 mg/dl by Megalac. Megalac did not influence time to return to first ovulation (31 vs. 30 days). However fat-fed cows had significantly longer intervals to first insemination (66 vs. 91 d), required more inseminations per cow (1.8 vs. 2.6), and had a lower proportion pregnant at the end of the study (50 vs. 20%). Percent conception was not different between groups when the whole lactation was examined (70 vs. 65%) but days open favored controls (90 vs. 147; Lucy, 1990).

5. Number of days to first service (78 vs. 81) were similar for 18 Holstein cows divided between a 0% and 2.2% Megalac diet (Lucy et al., 1991). Pregnancy rates and services per conception by day 77 of lactation were not different although numerically favored Megalac (3/9 vs. 6/9; 2.4 vs. 1.7).

One of the most exciting areas of future research may be the integration of digestive function with ovarian function and specific formulation of diets to enhance efficiency of reproductive management and fertility. Once we have a clearer understanding of those metabolic signals that affect the ovary we can begin to integrate traditional knowledge of nutrition and reproduction.

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