Net Energy for Lactation of Calcium Salts of Long-Chain Fatty Acids for Cows Fed Silage-Based Diets[1,2]

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ABSTRACT

The NE_L of calcium salts of long-chain fatty acids from palm oil was determined in mature Holstein cows. Twelve lactating (fed for ad libitum intake) and six nonlactating (restricted to near maintenance intake) Holstein cows were fed 0 or 2.95% fat supplement in diets formulated to contain 16 or 20% CP in a 2 x 2 factorial arrangement of treatments in a single reversal design within protein level. The fat supplement was substituted for ground corn and minerals. Two 6-d total collection balance trials were conducted during which cows were in open circuit respiration chambers. Intake of OM was lower for lactating cows fed the fat supplement (18.1 vs. 19.1 kg/d), but energy intake did not differ (93.2 Mcal/d). Total long-chain fatty acid intake was increased from 477 to 820 eld with fat feeding. Apparent digestibility of long-chain fatty acids was increased 11.1 percentage units with increased dietary CP for lactating cows with no difference in fatty acid digestibility for the dry cows. Milk yield was higher (34.3 vs. 32.0 kg/d) with fat feeding, but milk energy yield did not differ (22.6 Mcal/d). The NEL of the fat supplement was estimated from the incremental differences in energy values within cows, assuming NEL of corn replaced by fat to be 1.96 Mcal/kg DM, and was determined to be 6.52 Mcal/kg DM (SE = 1.74). The efficiency of the use of metabolizable energy for lactation from dietary fat was 77.2%. The energy in calcium salts of long-chain fatty acids is utilized efficiently for lactation in mature cows.

(Key words: net energy lactation, calcium soaps, dairy cows)

Abbreviation key: Ca-LFA = calcium salts of long-chain fatty acids, IE = intake energy, ME = metabolizable energy, NDS = neutral detergent solubles.

INTRODUCTION

Supplemental fat has been added to diets of lactating cows to provide additional energy during early lactation when high producing cows are in negative tissue energy balance. Dietary fat supplements increase the energy density of the diet, but dietary fats can have a negative impact on rumen fermentation and fiber digestibility (24). Calcium salts of long-chain fatty acids (Ca-LFA) of palm oil are chemically bound dietary fats that do not adversely affect ruminal fermentation (6, 29) or fiber digestibility (28) in lactating cows.

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TABLE 1. Design of experiment, indicating animal assignment to diets in a single reversal of fat supplement within protein level for lactating (L) and nonlactating (N) cows.

Experimental period	Stage	Treatment 16% CP — fat	16% CP + fat	20% CP — fat	20% CP + fat
	L	1, 2, 3[1]	4, 5, 6	7, 8, 9	10, 11, 12
	N	13, 14	15	16, 17	18
2	L	4, 5, 6	1, 2, 3	10, 11, 12	7, 8, 9
	N	15	13, 14	18	16, 17

[1]Individual animal code number.

Increases in milk production have been *reported* in cows fed dietary fat (3, 23), including Ca-LFA (29). Effect of Ca-LFA on milk fat content has been variable (3, 9, 23). Dietary fat supplementation has resulted in decreases in milk protein content (4, 8). DePeters et al. (8) determined that there was a decrease in the casein fraction of milk protein with fat feeding. The mechanism by which fat supplementation affects milk protein content has not been elucidated. Possibly, dietary protein requirements increase with fat supplementation.

There is a dearth of information available on the efficiency of use of dietary fat for milk production. Theoretically, the direct transfer of dietary fat to milk fat should be more efficient than de novo synthesis (18). Estimates of transfer efficiencies of dietary C18 fatty acids to milk fat ranged from 30 to 50% in diets that were supplemented with fat (22). Van der Honing (34) reported that the efficiency of the use of metabolizable energy (ME) for milk production tended to be greater for cows fed diets supplemented with 5% tallow. Knowledge of the energy value of the fat supplement Ca-LFA can be used to improve ration formulation in order to optimize the energy status of the lactating dairy cow.

The objective of this experiment was to evaluate the NEL value of a commercial fat supplement for dairy cattle fed silage-based diets at two levels of CP.

MATERIALS AND METHODS

Animals and Diets

Eighteen mature Holstein cows (12 early lactation and 6 nonlactating cows) were fed TMR containing either 16 or 20% CP each with either 0 or 2.95% Ca-LFA [Megalac[9] calcium salts of fatty acids (85% fatty acids); Church and Dwight Co., Inc., Princeton, NJ] in a 2 x 2 factorial arrangement of treatments. Three lactating and one or two nonlactating cows were assigned randomly to one of the four dietary treatments in a single-reversal design within protein level (Table 1). Lactating cows were assigned to treatments immediately postpartum. Nonlactating cows were assigned to treatments 5 wk prior to measurements. If one dry cow was assigned to a CP level, then following diet reversal, two dry cows would be fed that diet to achieve three dry cows per CP level. Nonlactating cows were included in the experiment to characterize digestibility and energy partition at maintenance intake. Cows were housed in an environmentally controlled tie-stall barn and bedded with sawdust when not in respiration chambers.

The components of the four TMR are in Table 2. The fat supplement was added at 2.95% of the diet DM by substitution of 236% ground corn and .63% limestone in the low protein diet and 2.51% ground corn plus .50% limestone in the high protein diet. The Ca-LFA was added at a level to supply approximately 454 g/d of Ca-LFA per cow. The CP level of the diet was increased by increasing the amounts of soybean meal, distillers grains, blood meal, and fish meal at the expense of ground corn. Diets were balanced to meet the requirements for rumen undegradable intake protein, ADF, Ca, and P for lactating cows (21). Due to an error in mixing, Mg was added to the 20% CP diets at twice the level compared with the 16% CP diets. This resulted in diet Mg levels of .22 and .50% at the 16 and

TABLE 2. Ingredients (% of DM) of diets containing either 16 or 20% CP with either 0 or 2.95% Ca salts of long-chain fatty acids (Ca-LFA).

Item	Treatment			
	16% CP - Ca-LFA	16% CP + Ca-LFA	20% CP - Ca-LFA	20% CP + Ca-LFA
Forages				
Corn silage	40.00	40.00	40.00	40.00
Alfalfa silage	10.00	10.00	10.00	10.00
Concentrates				
Ground corn	24.91	22.55	12.66	10.15
Distillers grains	9.00	9.02	14.82	14,84
Soybean meal (48% CP)	7.91	7.92	13.27	13.29
Barley	3.95	3.97	3.96	3.96
Fish meal	.84	.84	1.25	1.26
Blood meal	.82	.82	1.23	1.23
Ca-LFA[1]	. . .	2.95	. . .	2.95
Vitamins and minerals				
Limestone	.91	.28	.92	.42
Dicalcium phosphate	.90	.90	.69	.69
Selenized TM salt[2]	.50	.50	.50	.50
Sulfur	.09	.09	.09	.09
Magnesium oxide	.05	.05	.50	.50
Vitamin E[3]	.05	.05	.05	.05
Vitamin A[4]	.04	.04	.04	.04
Vitamin D[5]	.02	.02	.02	.02
Zinc oxide	.002	.002	.002	.002

[1]Megalace, Church and Dwight Co., Inc., Princeton, NJ.

[2]Trace-mineralized salt contains NaC1 not >99.0% and not <94.0% and also contains not less than .2% Mn, .1% Fe, .1% Mg, .05% Se, .025% Cu, .01% Co, .008% Zn, and .007% I.

[3]Contains 44,000 III vitamin E/kg.

[4]Contajos 10,000,000 USP units vitamin A/kg.

[5]Contains 3,013,735 11.1 vitamin D3/kg.

20% CP levels, respectively. Magnesium requirement for lactating cows is .25% (21). Although maximum levels of Mg have been established at .50% (21), there were no detrimental effects when Mg was added at .61% of the diet as magnesium oxide (10). The diets were fed twice daily at 0830 and 2030 h. Lactating cows were fed to achieve 10% refusals, and the nonlactating cows were fed to maintain **BW.**

Experimental and Laboratory Procedures

Lactating cows were fed their respective diets for the first 14 wk of lactation. Energy balance was measured at wk 8 as part of another objective of the experiment, to examine the effects of protein level and energy density on tissue mobilization in early lactation. Energy balance measurements were repeated at wk 14 of lactation, and this represented period 1 of the reversal design for lactating cows. Each energy balance trial consisted of three cows fed the same CP level, one lactating cow fed 0% Ca-LFA, one lactating cow fed 2.95% Ca-LFA, and one nonlactating cow alternating between 0 and 2.95% Ca-LFA. Each consecutive balance trial consisted of animals fed a different CP level so that balance trials alternated between the two CP levels. Energy balance was measured with a 6-d total collection of feces and urine while animals were housed in the Beltsville open circuit respiration chambers for measurement of CH4 and CO2 production and 02 consumption (12). Respiratory exchange was measured for two or three consecutive 24-h periods beginning on d 2 of the excreta collection. Diets then were switched within protein level and following a 5-wk diet adaptation; energy balance measure-

ments were repeated, and this constituted period 2 of the switchback design.

Body weights were recorded biweekly throughout the experiment except when cows were in the chambers. Heart rate and rectal temperature were taken daily 1 wk prior to and during energy balance measurements. Cows were milked, and milk weights were recorded twice daily at 0730 and 1930 h. Milk weights were recorded during balance trials and sampled over two consecutive !lacings for determination of fat, protein, and SNF by infrared analysis (Environmental Systems Services, College Park, MD). During respiratory exchange measurements, daily milk was sampled and composited to be analyzed for energy and N. Rations offered and orts were weighed daily throughout the experiment. Rations offered were adjusted weekly to compensate for changes in the DM of the silages. During balance trials, representative samples of rations and orts were frozen daily and processed for chemical analyses at the end of each balance trial. Feces and urine were weighed and sampled daily during the balance trial (feces were refrigerated, and urine was frozen) and composited at the end of each trial.

The determination of energy (adiabatic oxygen bomb calorimetry) (1) and N (2) were performed on milk, rations, orts, feces, and urine using wet-processed composite samples. Total long-chain fatty acid content (determined by a one-step extraction, direct methylation, and quantification of fatty acids by GLC) (30), ash by combustion at 600°C for 16 h (2), and NDF components (13) were determined in rations, orts, and fecal composite samples that were dried at 65°C to a constant weight. Heat production was calculated from respiratory exchange plus CH4 and urine N output using the Brouwer equation (5). Energy balance was calculated as described by Flatt and Tab*ler* (11).

The energy density of the fat supplement was computed as the difference in energy concentration of the diets with and without Ca-LFA at each protein level for each cow, adjusting for the estimated energy values of the corn replaced by fat. These calculations were made for each cow using measured intake energy (IE), digestible energy, ME, and NEL of the diets. An example for calculating IE for the fat supplement (low protein diet) is provided: JIFF = (lEA — (IEB — (.0236 x 4.4)))/.0295 where lEF = IE value of fat supplement, lE_A = 1E value of 16% CP diet containing fat, and IEE = IE value of 16% CP diet without fat. In the substitution of corn for fat, 2.36% of the corn was removed with an assumed energy value of the corn being 4.4 Mcal/kg DM (derived from bomb calorimetry). Because fat was added at 2.95% of the diet DM, the difference was divided by .0295 to express the energy value of the fat supplement as megacalories per kilogram of DM.

Statistical Analysis

Data were analyzed as a single-reversal of fat within protein percentage in a split-plot design using the general linear models procedure of SAS (27). Lactating and nonlactating cows were analyzed separately. The statistical model for both groups of cows included protein, cow within protein (error term for protein effects), period, fat, and fat by protein interaction. The fat effect and fat by protein interaction were tested using the residual error term. All data are presented as least squares means, and significance was declared at $P < .05$ unless otherwise noted.

RESULTS

All animals completed the balance trials. Organic matter intake and chemical composition of ration OM consumed are summarized in Table 3. Intake and composition of diets are expressed on an OM basis due to differences in ash intake between the lactating and nonlactating cows. Nonlactating cows consumed a higher proportion of dietary ash due to an increased consumption of salt from a salt block. Lactating cows fed Ca-LFA consumed less OM than controls. There was no effect of fat or protein level on OM intake for the nonlactating cows because intake was restricted for this group. The CP content of the OM consumed averaged 17.0 and 20.8% for the diets formulated to contain 16 and 20% CP on a DM basis. Long-chain fatty acid concentration was higher ($P < .01$) for diets that contained fat, as designed. Long-chain fatty acid content of the consumed diet was lower for cows fed the 20% CP diets compared with those fed the 16% CP diets. However, intake of fatty acids was not affected ($P > .10$) by diet

TABLE 3. Organic matter intake and chemical composition of consumed diets containing either 16 or 20% CP with either 0 or 2.95% Ca salts of fatty acids (Ca-LFA) fed to lactating (L) and nonlactating cows (N).

Item	Stage	Treatment				SEM
		16% CP - Ca-LFA	16% CP + Ca-LFA	20% CP Ca-LFA	20% CP + Ca-LFA	
n	L	6	6	6	6	
	N	3	3	3	3	
OM Intake, kg/d	L	19.2	18.1	19.0	18.1	.4b
	N	5.2	4.8	4.6	4.9	.1
Ash intake, kg/d	L	1.28	123	1.48	1.50	.00
	N	.51	.43	.52	.51	.05
				(% of OM)		
NDS[1]		56.4	56.6	48.3	51.3	**1.5c**
CP		16.9	17.1	20.8	20.9	**.3c**
LTIP,[2] (% of CP)		36.5	36.3	35.6	35.3	. . .
Long-chain fatty acids		2.51	4.76	2.48	4.30	**.12"**
Soluble residue'		36.9	34.7	25.1	26.3	**1.6[e]**
NDF		43.6	43.4	51.7	48.5	1.5'
Hemicellulose		20.4	20.2	27.1	24.4	1.6'
Cellulose		18.0	18.0	18.9	18.2	.4
Lignin (KMn04)		5.16	5.03	5.58	5.58	.3e

[a]Fat effect ($P < .01$).

[b]Fat effect ($P < .05$).

'Protein effect ($P < .01$).

[d]Protein effect ($P < .05$).

`Protein effect ($P < .10$).

'Neutral detergent solubles.

[2]Undegradable intake protein, calculated from NRC (21) tables.

[3]Soluble residue = NDS - (CP + fatty acids).

CP level and averaged 477 and 820 g/d for lactating cows fed 0 and 2.95% Ca-LFA, respectively. Diets formulated to be 20% CP contained higher levels of NDF but less soluble residue compared with those containing 16% CP due to changes in ingredient composition, primarily the substitution of distillers grains for ground corn (Table 2). There was no *effect* ($P > .10$) of protein or fat concentrations on cellulose content of the diets, as expected because diets were *balanced* for ADF content.

Body weight tended to be lower ($P < .10$) for lactating cows fed fat (Table 4) with no effect of treatment on BW for nonlactating cows. Numerically, the nonlactating cows tended to be heavier than the lactating cows. Age, heart rate, and rectal temperature did not differ ($P > .10$) across the treatment groups for both dry and lactating cows with the exception that heart rate was reduced for the nonlactating cows fed fat. The cows fed the 16% CP diet averaged 130 d in lactation over the experimental period, whereas the cows fed the 20% CP diet averaged 141 d in lactation and were pregnant approximately 10 d longer than those fed the lower protein diet.

Milk production was increased 2.3 kg/d for cows fed the supplemental fat diets ($P < .01$) and was not affected ($P > .10$) by protein level (Table 4). Differences in milk fat content were not statistically significant. There were no treatment effects on yields of 4% FCM and milk fat yield. Milk protein and SNF contents were reduced for cows fed fat (Table 4). However, due to increased milk yield with Ca-LFA addition, yield of protein was not affected ($P > .10$) by dietary treatment, but yield of SNF increased with Ca-LFA.

Apparent digestibility of DM (67.2%) and OM digestibility (68.7%) for the lactating cows were not affected ($P > .10$) by fat treatment (Table 5). There was a trend toward an

TABLE 4. Physiological characteristics of lactating cows (L) and nonlactating (N) cows and milk yield and composition during balance trials for lactating cows fed diets containing either 16 or 20% CP with either 0 or 2.95% Ca salts of fatty acids (Ca-LFA).

		Treatment				
Item	*Stage*	16% CP - Ca-LFA	16% CP + Ca-LFA	20% CP - Ca-LFA	20% CP + Ca-LFA	SEM
n	L	6	6	6	6	
	N	3	3	3	3	
Animal characteristics						
BW, kg	L	620	611	591	589	3
	N	690	671	641	650	8
Age, mo	L	59.2	59.2	55.7	55.5	.1
	N	67.7	67.9	65.6	65.1	.2
Heart rate, beats/min	L	86.7	86.1	80.7	82.4	1.7
	N	57.5	50.1	66.9	57.5	2.6[b]
Rectal temperature, 'C	L	38.5	38.7	38.5	38.5	.04
	N	38.3	38.2	38.2	38.2	.04
		Lactating cows				
Days lactating		130.0	130.0	141.0	141.0	1.2[d]
Days pregnant		20.0	24.0	33.0	31.0	7.8
Milk yield, kg/d		31.8	34.2	32.2	34.3	.6[a]
4% FCM, lcg/d		30.2	30.9	30.1	32.1	.8
Milk fat, %		3.70	3.30	3.56	3.57	.18
Milk protein, %		3.23	2.97	3.13	2.96	.07 13
Milk *SNF, %*		8.74	8.45	8.89	8.64	.08[a]
Milk fat, g/d		1166	1144	1144	1226	48
Milk protein, g/d		1016	1009	1006	1019	22
Milk *SNF, g/d*		2758	2871	2859	2968	44 b

[a]Fat *effect (P* < .01). [b]Fat effect *(P* < .05). `Fat *effect (P* < .10). [d]Protein effect *(P* < *.10).*

interaction ***(P*** < .10) of dietary CP level and fat level for DM digestibility in the nonlactating cows in which DM digestibility was reduced with fat supplementation only at the low protein level. Digestibility of the neutral detergent soluble (NDS) fraction was increased with the higher ration protein content for lactating cows. This was reflected in improved ***(P*** < .01) digestibilities of CP, fatty acid, and soluble residue for the 20% CP treatment in lactating cows. There was an interaction of diet CP and supplemental fat concentrations for NDS digestibility for the nonlactating cows; fat addition resulted in a higher digestibility of ***NDS*** in diets containing 20% CP level but no change in diets containing 16% CP. Also, digestibility of soluble residue was reduced for nonlactating cows fed Ca-LFA with the 16% CP diets and an improvement in its digestibility with Ca-LFA addition to the 20% CP treatment. The digestibility of NDF and components of NDF were not affected by dietary treatments for the lactating cows (Table 5). In nonlactating cows, digestibility of the fibrous fractions of the diets was not affected ***(P*** > .10) by treatment except for improvements in cellulose digestibility ***(P*** < .10) with Ca-LFA supplementation and in lignin digestibility ***(P*** < .05) with increased dietary protein level.

The partition of intake N and N balance are summarized in Table 6. Fecal and urine N outputs were reduced for both groups of cows fed Ca-LFA. Milk N was not affected by treatment. The resulting N balances were unexplainably highly negative except for one treatment for the dry cows. Possibly the distillers grains in the diets were less available for absorption.

Although diets containing fat had higher fatty acid concentrations (Table 3), OM intake

TABLE 5. Apparent digestibilities of dietary components for lactating (L) and nonlactating (N) cows fed diets containing either 16 or 20% CP with either 0 or 2.95% Ca salts of fatty acids (Ca-LFA).

Item	Stage	Treatment				SEM
		16% CP - Ca-LFA	16% CP + Ca-LFA	20% CP - Ca-LFA	20% CP + Ca-LFA	
n	L	6	6	6	6	
	N	3	3	3	3	
DM	L	66.2	67.4	67.2	67.8	.8
	N	75.9	74.5	75.3	75.7	.3e
OM	L	67.7	68.9	68.7	69.3	.8
	N	77.4	76.6	77.0	77.6	.3
NDS[1]	L	80.6	80.1	82.3	82.4	.9[c]
	N	88.0	86.3	82.8	86.1	.6[a]
CP	L	59.7	61.6	65.6	67.1	1.2[b]
	N	71.6	71.5	73.1	75.5	1.1
Fatty acids	L	77.5	78.4	88.1	90.0	2.0[b]
	N	93.8	93.0	87.8	88.2	1.5
Soluble residue[2]	L	90.3	89.6	94.2	92.9	1.0[b]
	N	94.8	92.9	92.2	94.4	.9[e]
NDF	L	51.0	54.4	53.9	53.8	1.5
	N	63.4	63.6	715	69.1	2.1
Hemicellulose	L	53.4	57.1	60.0	59.3	3.3
	N	73.1	70.0	79.6	77.6	2.9
Cellulose	L	53.1	562	50.9	51.3	1.0
	N	62.4	64.1	64.7	67.0	.8'
Lignin	L	37.0	40.3	40.9	41.1	3.3
	N	37.0	41.8	52.9	44.9	6.3[c]

'Fat effect ($P < .10$).

[b]Protein effect ($P < .01$).

'Protein effect ($P < .05$).

[d]Fat x protein interaction ($P < .05$).

[e]Fat x protein ($P < .10$).

[f]Neutral detergent solubles.

[2]Soluble residue = NDS - (CP + fatty acids).

was reduced, and this resulted in similar energy intakes across the dietary treatment groups within each group of cows (Table 7). The resulting IE averaged 93.2 and 24.4 Mcal/ d for lactating and nonlactating cows, respectively (Table 7). Fecal energy as a percentage of 1E was not affected ($P > .10$) by treatment, and this resulted in similar energy digestibili-ties within groups of cows. Digestible energy expressed as a percentage of 1E was 68.8 for lactating cows and 76.3 for nonlactating cows. Numerically, energy digestibility was higher for dry cows than for lactating cows, indicating an effect of level of intake as reported previously (31). Methane energy was reduced for diets containing supplemental fat for both the lactating ($P < .05$) and dry ($P < .10$) cows. Energy in urine of lactating cows was increased ($P < .01$) with higher dietary protein. The metabolizability of the diets tended to be improved ($P < .10$) when fat was supplemented to lactating cows, averaging 60.8 and 59.2% ME per unit IE for lactating cows fed 2.95 and 0% Ca-LFA, respectively. Also heat energy as a percentage of IE was similar (32.6%) across diets for lactating cows, which resulted in a trend toward improved ($P < .10$) energy retention for cows fed fat (28.3 vs. 26.6% of IE for the diets supplemented with 2.95 or 0% Ca-LFA). There was a trend ($P < .10$) toward increased milk energy expressed as a percentage of IE with Ca-LFA feeding and no significant change in tissue energy retention (Table 7). There was an interaction ($P < .10$) of protein and fat concentrations for dry cows in that ME was reduced at 20% CP with no

TABLE 6. Partition of intake N (grams per day) and N balance in lactating (L) and nonlactating (N) cows fed diets containing either 16 or 20% CP with either 0 or 2.95% Ca salts of fatty acids (Ca-LFA).

Item	*Stage*	Treatment				
		16%CP— Ca-LFA	16% CP + Ca-LFA	20% CP — Ca-LFA	20% CP + Ca-LFA	SEM
n	L	6	6	6	6	
	N	3	3	3	3	
Intake N	L	517	495	631	614	19[f]
	N	140	132	155	163	7[e]
Fecal N	L	207	191	216	201	5b
	N	40	37	41	40	2[a]
Urine N	L	170	152	290	264	7 6,c1
	N	109	104	138	122	4c,d
Milk N	L	166	161	161	160	4
N balance	L	—28.3	—12.0	—37.7	—13.8	13.4
	N	—8.8	—9.8	—25.2	.2	6.5

"Fat effect ($P < .01$).

[b]Fat effect ($P < .05$).

`Pat effect ($P < .10$).

[d]Pmtein effect ($P < .01$).

'Protein effect ($P < .05$).

[f]Protein effect ($P < .10$).

added fat but not at 16% CP. Heat energy was reduced when nonlactating cows were fed supplemental fat. This resulted in greater ($P < .01$) retained energy for dry cows fed Ca-LFA, which is an estimate of their tissue energy retention.

The energy concentrations of the diets are in Table 8. The IE, digestible energy, and ME were higher in diets with Ca-LFA supplementation for both groups of cows. Also, the NE_L of the diets containing fat were greater for the lactating cows. These measurements were the basis for the computations of energy density of fat summarized in Table 9. The energy concentrations of the fat supplement for each dietary protein level, computed and averaged over protein levels, are summarized in Table 9. The values were not significantly different ($P > .10$) across dietary protein level. However, there was great variation associated with these numbers because the fat supplement was a small proportion of the total DM of the diets (2.95%).

Averaging values over protein level for lactating cows and for nonlactating cows provided estimates of the energy value of the fat supplement (Table 9). The ME of the fat supplement for lactating cows was calculated to be 8.44 Mcal/kg DM, and the NEL was calculated to be 6.52 Mcal/kg DM with an efficiency of 72.6% for the use of IE from Ca-LFA for milk production.

DISCUSSION

In this study, Ca-LFA addition to the diets of lactating cows resulted in a decrease in OM intake (Table 3). Reported effects of dietary addition of various fats on feed intake have been variable (14, 16, 23). Grummer (14) observed no decrease in intake when Ca-LFA of palm oil or prilled fatty acids were included in the diets of lactating cows. Dietary supplementation with yellow grease decreased DMI, whereas hydrogenated yellow grease did not affect intake in lactating cows (16). Palmquist and coworkers (25) determined that abrupt introduction of Ca-LFA into the diets of lactating cows resulted in initial decreases in DMI with recovery of intake after 3 to 5 d. In another study, Grummer et al. (15) reported that adaptation improved acceptability to diets containing various fats with the exception of Ca-LFA. Decreases in DMI in the present study may have been due to abrupt changes in diets for the switchback design. Also, DMI

TABLE 7. Intake energy and partition of intake energy for lactating (L) and nonlactating (N) cows fed diets containing either 16 or 20% CP with either 0 or 2.95% Ca salts of fatty acids (Ca-LFA).

Item	Stage	Treatment				SEM
		16% CP - Ca-LFA	16% CP + Ca-LFA	20% CP - Ca-LFA	20% CP + Ca-LFA	
n	L	6	6	6	6	
	N	3	3	3	3	
Intake energy, Mcal/d	L	93.9	91.7	94.2	93.2	2.1
	N	25.4	24.3	23.1	24.9	.5
		(% of intake energy)				
Fecal energy	L	32.6	31.0	312	30.2	.8
	N	23.8	23.9	24.2	23.0	.4
Digestible energy	L	67.4	69.0	68.8	69.8	.8
	N	76.2	76.1	75.8	77.0	.4
Gaseous energy	L	5.45	5.17	5.41	5.05	.10[b]
	N	8.34	8.09	8.15	7.44	.18[c]
Urinary energy	L	3.02	2.88	3.88	4.10	21[d]
	N	5.07	5.39	8.41	5.40	.62[e]
Metabolizable energy	L	58.9	60.9	59.5	60.6	.7[c]
	N	62.8	62.6	592	64.1	3e
Heat energy	L	32.5	32.1	32.8	32.9	.5
	N	61.6	60.2	65.1	60.0	.9b
Retained energy	L	26.4	28.9	26.7	27.7	.8a[c]
	N	1.23	2.43	-5.94	4.05	.74[e]
Milk energy	L	23.5	24.4	23.5	25.4	.6[e]
Tissue energy	L	2.82	4.45	2.91	2.28	1.23

[a]Fat effect *(P* < .01).

[b]Fat effect *(P* < .05).

[c]Fat effect *(P* < .10).

[d]Protein effect *(P* < .01).

[e]Fat x protein interaction *(P* < *.10)* .

initially was increased 1 to 2 kg for cows switched from the diets containing fat to those without fat. Animals fed the 16% CP diet reduced DMI when diets were switched to fat supplemented rations, and this was maintained throughout the second period. This suggests that diet CP level may influence the acceptability of diets containing fats. However, because of the low numbers of animals represented, these results may reflect animal variation.

Supplemental Ca-LFA addition to lactating cow diets resulted in increased milk yields at both levels of dietary protein (Table 4), as has been reported in other studies (4, 22). Our study was not designed to test production parameters; the response in milk production was observed even though energy intakes and tissue energy balance did not differ across treatment groups. This suggests that the use of energy from the dietary fat supplement for lactation was more efficient than the use of energy from the other components of the diet. Efficiency of the use of ME from Ca-LFA was 77.2% in the present study compared with average efficiency of the use of ME from common diets of 64% as reported by Moe et al. (19). Kronfeld (18) suggested that efficiency of milk production is optimized when 16% of the ME is derived from long-chain fatty acids. In our study, energy in dietary fatty acids accounted for approximately 13.1% of ME, which may have approached the optimal ratio. However, the effect of fat on milk production may have been due to a reduced rumi-nal production of VFA while increasing ME intake (22). Additionally, CH4 production was reduced with dietary fat supplementation (Table 7). Because we noted no decrease in fiber

TABLE 8. Diet energy concentrations for lactating (L) and nonlactating (N) cows fed diets containing either 16 or 20% CP with either 0 or 2.95% Ca salts of fatty acids (Ca-LFA).

Item	Stage	Treatment				SEM
		16% CP - Ca-LFA	16% CP + Ca-LFA	20% CP - Ca-LFA	20% CP + Ca-LFA	
n	L	6	6	6	6	
	N	3	3	3	3	
		(Mcal/kg DM)				
Intake energy	L	4.58	4.74	4.60	4.75	02[a]
	N	4.47	4.65	4.48	4.56	02[a]
Digestible energy	L	3.09	3.27	3.17	3.31	.03[a]
	N	3.42	3.51	3.40	3.51	03[a]
Metabolizable energy	L	2.70	2.89	2.74	2.88	.03"
	N	2.83	2.91	2.65	2.92	.01'
NEL	L	1.73	1.92	1.73	1.85	03[a]

[a]Fat effect ($P < .05$).

digestion of diets with Ca-LFA, this suggests that CA-LFA caused some other minor change in rumen fermentation due to incomplete inertness in the rumen of the supplemental fat. In other studies, Ca-LFA did not affect rumen digestibility of fiber or rumen pH (6, 28). Another explanation of the decrease in CH4 output may be due to the substitution of a nonfermentable substrate (Ca-LFA) for a fermentable substrate (ground corn), thus reducing the overall fermentability of the diet. In the present study, there was a reduction ($P < .10$) in NDF intake with fat feeding (8.1 vs. 8.8 kg/ d) associated with equal energy intakes, which could account for the reduced methane output per unit intake energy. Applying the equation of Moe and Tyrrell (20) to calculate methane output from intake of digestible hemicellulose, cellulose, and soluble residue to our data set suggests that CH4 output would be reduced for diets containing the fat supplement.

Dietary CP level did not affect milk production or milk composition. Although apparent digestibility of diet CP was improved with increased CP level (Table 5), there was an increase in loss of N in urine at 20% CP (44.5% of intake N) compared with 16% CP (31.8% of intake N) (Table 6). Tyrrell and Moe (32) reported that the optimum ME of diets for lactating cows was achieved at 17% CP when they examined CP levels ranging from 11 to 20%. The energy cost for the synthesis and elimination of urea at the high protein level may limit the available energy for milk synthesis (33). Also, the hypothesis that fat addition may increase the requirement for dietary protein was not confirmed in the present study in that milk protein content was depressed with Ca-LFA supplementation at both the 16 and 20% CP levels.

Milk fat content was not affected by dietary fat supplementation in this experiment (Table 4). Milk fat content was increased (3, 23) in some studies and unchanged (9) in others with supplemental fat feeding. Milk protein content was depressed with dietary fat supplementation (Table 4). Addition of dietary fat generally results in a decrease in milk protein content (4, 22), particularly the casein fraction (8, 9). However, a decrease is not always observed (23). The mechanisms responsible have not been elucidated. Palmquist and Moser (26) reported that feeding fat increased insulin resistance as measured by intravenous glucose tolerance tests, suggesting a decrease in insulin-dependent uptake of amino acids by the mammary gland. However, arteriovenous differences of glucose and amino acids across the mammary gland (not adjusted for blood flow) were not affected by dietary fat (7).

Supplemental fat did not affect apparent digestibility of diet components, except for nonlactating cows in which cellulose digestibility was improved with Ca-LFA (Table 5). Supplemental fat fed at this level generally has no effect on digestibility or can improve di-

TABLE 9. Calculated energy values of the fat supplement (Ca-LFA) by protein level and averaged over protein levels for lactating (L) and nonlactating (N) cows.

			Ca-LFA				
			CP level			Overall	
Item	Stage	Corn	16%	20%	SEM	X	SEM
n	L		6	6		12	
	N		3	3		6	
			(Mcal/kg DM)				
Intake energy	L	4.40[1]	9.11	8.85	.88	8.98	.62
	N	. . .	10.45	7.40	2.31	8.93	1.63
Digestible energy	L	3.75[2]	9.38	8.25	2.28	8.82	1.62
	N	. . .	7.79	8.04	2.41	7.92	1.71
Metabolizable energy	L	3.342	9.25	7.64	2.58	8.44	1.82
	N	. . .	7.31	12.08	1.49	9.70	1.06
NEL	L	1.962	7.53	5.52	2.46	6.52	1.74

[1]Derived from laboratory analyses.

[2]Derived from NRC tables (21).

gestibility of ether extract, CP, and energy, although feeding rumen-unprotected fats can reduce digestibility of fiber (22). Increasing the dietary CP level resulted in an improvement in apparent digestibility of the NDS fractions of the rations (Table 5). In other studies, OM digestion was increased with an increase in diet CP level over a wide range (17). The increase in digestibility may be due to an effect on rumen fermentation. But in our study, CP level did not affect the digestibility of the fibrous fractions of the diet. Another possibility is that apparent digestibility was altered due to the change in the dietary ingredients when CP level was increased (Table 2).

Retained energy (tissue energy + milk energy) as a percentage of energy intake (Table 7) tended to be improved in dairy cows fed supplemental fat. In lactating cows, this was reflected in a small increase in milk energy output with no change in tissue energy retention. This agrees with the study by Palmquist and Conrad (23), in which fat feeding increased milk yield with no effect on BW change. In the present study, there was a trend toward a decrease in BW with Ca-LFA, but this may reflect the reduced gastrointestinal fill with fat supplementation. Heat production as a percentage of IE was not affected by fat supplementation for lactating cows in our study. However, there was a decrease in heat production for nonlactating cows that resulted in an increase in tissue energy. This provides conflicting evidence that fat feeding results in lower heat production and suggests that fat feeding may affect utilization of ME differently, depending on level of feed intake or physiological state.

There was considerable variation associated with the calculated energy values because the fat supplement was only 2.95% of the total dietary DM (Table 9). These values were derived from measured estimates of the energy values of the total mixed diets (Table 8). The Ca-LFA used in this study was sampled, and the gross energy (adiabatic bomb calorimeter) was determined to be 8.03 Mcal/kg Ca-LFA DM SE = .014 or 7.71 Mcal/kg Ca-LFA on an as-fed basis. This value is lower than the IE value derived from the difference method (Table 9). The gross energy value for Ca-LFA is similar to the theoretical energy value derived from the heat of combustion of the fatty acids of Ca-LFA (7.71 Mcal/kg) (C. L. Davis, personal communication). A possible explanation of the high IE value from the difference method is that the diets may not have been mixed or sampled correctly. The increase in the fatty acid content of the diets and orts that contained Ca-LFA suggested that Ca-LFA was added at the appropriate levels. However, because IE is the foundation for the remaining calculations, this high value may inflate the NEL estimate. If the gross energy value for Ca-

LFA is used in place of the IE value and it is assumed that the proportionality among 1E, digestible energy, ME, and NEL remains the same, then the calculated NEL value is reduced to 5.85 Mcal/kg DM, which is similar to the NRC (21) value of 5.84 Mcal/kg DM for a dietary fat. However, a 95% confidence interval around the IE values derived by the difference method includes the gross energy value. Consequently, the IE values derived by the difference method are within the limits of the error associated with the measurements. If the digestibility and fatty acid composition are taken into account, then extrapolation of this value to other dietary fats may be appropriate.

In conclusion, Ca-LFA fed at 2.95% of the diet DM was digested and metabolized efficiently by dairy cattle fed silage-based diets formulated to be 16 or 20% CP. The NEL value of 6.52 Mcal/kg DM for Ca-LFA was derived from substitution of Ca-LFA for corn and minerals and reflects a high efficiency (77.2%) of utilization of ME from Ca-LFA for milk energy.

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