Yield Response of Lactating Holstein Dairy Cows to Dietary Fish Meal or Meat and Bone Meal[1]

J. M. AKAYEZU,* W. P. HANSEN,* D. E. OTTERBY,*
B. A. CROOKER,* and G. D. MARX[†]
*Department of Animal Science,
University of Minnesota, St. Paul 55108
[†]Northwest Experiment Station,
University of Minnesota, Crookston 56716

ABSTRACT

Experiments were conducted to examine the effects of the source and amount of dietary protein on yield and composition of milk from Holstein dairy cows. Study 1 used 36 multiparous cows at 125 ± 59 d in milk in a replicated 2 × 2 Latin square design. Treatments were diets formulated to contain 16% crude protein (CP) in which 11% was fish meal or meat and bone meal supplied 11% of dietary CP. Intakes of dry matter, CP, and net energy for lactation; yields of milk; and percentage of milk fat were not affected by treatment. Fish meal increased contents of milk total N, casein N, and noncasein N but did not increase contents of NPN; fish meal also tended to increase milk CP yields. Study 2 used 78 cows (31 primiparous) at 31 ± 2 d in milk in a randomized block design. Two treatment diets were formulated to contain 16 or 18.5% CP, and soybean meal was the sole source of supplemental protein in those diets. The two other treatment diets were formulated to contain 16% CP; in these diets, fish meal or meat and bone meal partially replaced soybean meal. Treatments did not influence yield or composition of milk from multiparous cows. Compared with a soybean meal diet containing 16% CP, a soybean meal diet containing 18.5% CP or diets containing 16% CP and containing meat and bone meal or fish meal increased the milk yield of primiparous cows similarly. Fish meal or meat and bone meal increased the efficiency of protein utilization for milk yield.

(**Key words**: protein source, meat and bone meal, fish meal, milk yield and composition)

Abbreviation key: **BCS** = body condition score, **FM** = fish meal, **FMD** = diet containing FM, **FM16** = FMD formulated to contain 16% CP, **MBM** = meat and bone meal, **MBMD** = diet containing MBM, **MBM16** = MBMD formulated to contain 16% CP, **NWES** = Northwest Experiment Station, **SBM** = soybean meal, **SBM16** = SBM control diet containing 16% CP, **SBM18** = SBM control diet containing 18.5% CP, **SPC** = St. Paul campus.

INTRODUCTION

The purpose of including protein supplements with low ruminal degradability in the diet is not only to reduce protein losses during microbial fermentation in the rumen but also to increase the quantity of protein supplied to the small intestine for absorption and to improve the AA balance of absorbed protein. These effects may improve the milk yield of animals that have increased protein requirements because the efficiency with which protein is utilized is determined by the amount and pattern of absorbed AA (17). However, yield responses to dietary RUP have been variable. Increased dietary RUP has increased milk yield, milk protein content, or milk protein yield in some studies (9, 13) but not others (7, 21).

The lack of yield response to RUP has been attributed to the inability of the protein supplement to increase the total quantity or improve the quality of protein flowing to the small intestine. Often, in these situations, the supplement was fed in small quantities, failed to supply needed amounts of limiting AA, or provided excess amounts of RUP, which might have decreased microbial protein synthesis in the rumen (8, 9, 18). In addition, when milk yield is low, or when DMI is high, protein does not likely limit yield, and increased dietary RUP may not be needed (7, 8). Overestimation of RUP content or intestinal availability of protein supplements can also result in a lack of yield response (8, 18). The choice of protein supplements should not be based solely on their RUP contents but also on their AA profile and intestinal availability.

Meeting protein requirements of high yielding cows is difficult partly because AA requirements are not

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well defined. Lysine and Met are considered to be the most limiting AA for milk yield and milk protein synthesis (30). Because the protein in ensiled forages and in soybean meal (**SBM**) is rapidly and extensively degradable (17) and because corn protein contains little Lys (30), supplementation of diets of ensiled forages, corn, and SBM with protein sources that are resistant to ruminal microbial degradation and that are rich in Lys and Met might be beneficial.

Fish meal (**FM**) is a good source of RUP (60% of CP) (17), although the amount of RUP can vary depending on the source and processing conditions (14). Fish meal is also an excellent source of AA, especially Lys and Met (29). The AA profile of the protein in FM closely resembles that of milk protein and ruminal bacterial protein (29), and >85% of the RUP is estimated to be digestible in the small intestine (5, 23). Meat and bone meal (**MBM**) also has good RUP content (49% of CP) (17), but, compared with FM, MBM has lower contents of total essential AA, Lys, and Met (29) and lower estimates of intestinal RUP digestibility (55 to 60%) (5, 23).

Experiments were conducted to study the effects of the source and amount of supplemental dietary protein on the yield and composition of milk and the efficiency of protein utilization for milk yield by Holstein dairy cows.

MATERIALS AND METHODS

Study 1

Cows and management. Thirty-six multiparous cows, 20 at the Northwest Experiment Station (**NWES**) and 16 at the St. Paul campus (**SPC**) of the University of Minnesota, were used. At the start of the study, cows averaged ($\overline{X}$ ± SD) 125 ± 59 DIM, 621 ± 66 kg of BW, and 3.1 ± 0.6 units of body condition score [**BCS**; five-point scale where 1 = thin to 5 = fat; (37)]. Cows were housed in tie-stall facilities, were fed TMR once (NWES) or twice (SPC) daily, and were milked twice daily. Once weekly at the NWES, ration formulations were adjusted for DM contents of feeds. The amount of feed offered was regularly adjusted to allow 5 to 10% orts. At SPC, all cows received intramuscular injections of 13.8 mg/d of bST (Somavubove®; The Upjohn Company, Kalamazoo, MI).

Experimental design and treatments. Within locations, a replicated 2 × 2 Latin square design was used; 2 cows (columns) and two periods (rows) were within each square (pair of cows). Cows were paired by DIM, milk yield, and genetic line (NWES) or by DIM and milk yield (SPC) and were randomly assigned to treatments. Treatments consisted of two diets, a diet containing MBM (**MBMD**) and a diet containing FM (**FMD**) (Tables 1 and 2), that were formulated to contain 16% CP (DM basis). The MBM or menhaden FM (ruminant grade FM, Sea Lac™; Zapata Protein Inc., Hammond, LA), provided a portion of the dietary CP. Diets were formulated so that an average cow consuming 22 kg of DM would not consume >0.75 kg/d of MBM or FM to minimize feed refusal and milk fat depression. As a result, MBM provided about 3.2% of dietary DM, and FM provided

TABLE 1. Ingredient composition of experimental diets (study 1).

	NWES[1]		SPC[1]	
Ingredient	FMD[2]	MBMD[2]	FMD	MBMD
	(% of DM)			
Alfalfa hay	...	...	19.16	19.35
Alfalfa haylage	29.70	30.10	...	...
Alfalfa pellets	...	...	7.15	7.28
Corn silage	14.03	14.38	23.68	24.11
High moisture shelled corn	40.33	39.33	...	...
Corn grain, cracked[3]	...	...	25.00	24.29
Oats[3]	...	...	4.41	4.29
Soybean meal[3]	2.76	2.70	7.66	7.73
Sunflower seeds	3.61	3.63	...	...
Distillers dried grains[3]	1.72	1.72	1.75	1.76
Menhaden fish meal[3,4]	2.50	...	2.62	...
Meat and bone meal[3]	...	3.42	...	3.11
Animal fat[3]	...	...	3.07	3.10
Dried sugar beet molasses[3]	...	...	2.46	2.48
Molasses products[5]	3.07	3.09	...	...
Dicalcium phosphate[3]	0.63	...	1.24	0.64
Trace-mineralized salt[3,6]	0.48	0.48	0.49	0.50
Vitamin premix[3,7]	0.47	0.45	0.46	0.46
Sodium bicarbonate[3]	0.48	0.48	0.47	0.48
Magnesium oxide[3]	0.24	0.24	0.24	0.26
Dynamate®[3,8]	...	...	0.14	0.15

[1] NWES = Northwest Experiment Station (University of Minnesota, Crookston); SPC = St. Paul campus of the University of Minnesota.

[2] FMD = Diet containing fish meal; MBMD = diet containing meat and bone meal.

[3] Ingredients supplied in a grain mix in diets used at SPC.

[4] Ruminant grade fish meal (Sea Lac™; Zapata Protein Inc., Hammond, LA).

[5] Mixture of sugar beet molasses and roughage products (Lots O' Lass™; Grain Terminal Association Feeds Inc., Willmar, MN). Contained ≥38% total invert sugars (guaranteed analysis). Chemical analysis (DM basis): 11.8% CP, 20.6% NDF, and 15.4% ADF.

[6] Guaranteed analysis: ≥38.08% but ≤38.90% Na, ≥58.72% but ≤59.99% Cl, ≥0.200% Mn, ≥0.160% Fe, ≥0.033% Cu, ≥0.010% Co, ≥0.007% I, and ≥0.005% Zn. At SPC, the contents of Fe, Co, and Zn were 0.206, 0.0052, and 0.361%, respectively.

[7] Contained 1,023,201 IU/kg of vitamin A, 314,829 IU/kg of vitamin D, 3935 IU/kg of vitamin E, 41.29 g/kg of Ca, 14.01 g/kg of S, 0.032 g/kg of Co, 3.098 g/kg of Cu, 0.130 g/kg of I, 9.784 g/kg of Fe, 9.875 g/kg of Mn, 0.062 g/kg of Se, and 12.390 g/kg of Zn.

[8] Contained 11.0% Mg, 18.0% K, and 22.0% S (IMC-Agrico, Co., Mundelein, IL).

about 2.5% of dietary DM. At both locations, FM and MBM provided about 11% of dietary CP.

Period 1 was preceded by a 4-wk period during which a blend of FM and MBM (1:1 wt/wt; DM basis) was gradually increased in the diet to about 3% of DM. Treatment periods consisted of 21 d (SPC) or 25 d (NWES). During the first 7 d (SPC) or 11 d (NWES), cows were allowed to adjust to the diets; the last 14 d were for data collection. At the beginning of period 2, treatments were switched for all cows. Periods 1 and 2 were separated by a 3-d transition period at NWES. All cows at SPC received daily injections of bST (13.8 mg) beginning 2 wk before period 1. Injections were discontinued at the end of period 1 and resumed 2 wk later. Period 2 started 2 wk after bST injections were resumed. During the 28-d transition period (2 wk without bST treatment and 2 wk with bST treatment), cows were fed the diet containing a blend of FM and MBM.

Measurements. Milk weights were recorded for each cow at each milking. Milk samples from consecutive p.m and a.m milkings were analyzed weekly for fat, CP, lactose, and SCC by infrared analysis (Minnesota DHI, Sauk Center or Zumbrota, MN). Composite samples of milk from consecutive p.m and a.m milkings were also prepared for each cow based on milk yield at each milking and were used to determine milk N fractions (total, casein, noncasein, and NPN) (24). Once weekly, jugular blood was collected by venipuncture into sterile evacuated tubes. The serum was separated by centrifugation and frozen until analyzed for glucose (kit no. 510-A; Sigma Chemical Co., St. Louis, MO). Amounts of feed offered and orts were recorded daily. Feeds were sampled weekly, and composites were made for each period. Composite samples were analyzed for CP, ADF, NDF, and minerals by the Northeast DHIA Forage Testing Laboratory (Ithaca, NY). Estimates of intestinal digestion of RUP from FM and MBM were determined using the in vitro procedure of Calsamiglia and Stern (5). Body weights were determined once (NWES) or on 2 consecutive d (SPC) each week. Body condition scores were taken once weekly (NWES) or every other week (SPC).

Statistical analysis. Data were analyzed using the GLM procedure of SAS (28). The statistical model was

$$Y_{ijklmn} = \mu + L_i + S_j(L_i) + C_k + (LC)_{ik} + [CS(L_i)]_{kj} + P_l + (LP)_{il} + T_m + (LT)_{im} + \epsilon_{ijklmn}$$

where

Y_{ijklmn} = observed response,
μ = overall mean,
L_i = effect of location i,
S_j = effect of square j,
C_k = effect of cow or column k,
P_l = effect of period l,
T_m = effect of treatment m, and
ϵ_{ijklmn} = error term.

Results are reported as least squares means and pooled standard errors. Observed differences were considered significant at $P \leq 0.05$.

TABLE 2. Chemical composition of experimental diets (study 1).

	NWES[1]		Pooled SD	SPC[1]		Pooled SD
	FMD[2]	MBMD[2]		FMD	MBMD	
DM, %	58.41	58.20	3.76	73.19	72.9	0.16
CP, % of DM	16.62	16.60	0.37	15.46	15.38	0.41
RDP,[3] % of CP	71.60	72.65	...	63.39	65.15	...
RUP,[4] % of CP	28.40	27.35	...	36.61	34.85	...
ADF, % of DM	17.55	17.89	0.58	20.53	21.35	1.73
NDF, % of DM	26.37	27.16	0.65	29.30	29.55	0.24
Ether extract,[5] % of DM	5.03	5.23	...	6.27	6.42	...
NE_L,[6] Mcal/kg of DM	1.64	1.64	0.01	1.60	1.59	0.04

[1] NWES = Northwest Experiment Station (University of Minnesota, Crookston); SPC = St. Paul campus of the University of Minnesota.

[2] FMD = Diet containing fish meal; MBMD = diet containing meat and bone meal.

[3] Calculated using NRC (17) values. For molasses products, RDP was assumed to be 90% of CP.

[4] Calculated as RUP = 100 − RDP.

[5] Calculated using NRC (17) values for feeds other than FM and MBM. Ether extract contents of FM and MBM, determined by chemical analysis (1), were 9.55 and 13.35% of DM, respectively, at NWES and 8.90 and 12.50% of DM, respectively, at SPC.

[6] Calculated using NRC (17) values.

Study 2

Cows and management. Seventy-eight Holstein cows (37 primiparous and 41 multiparous) from the NWES herd were used. Cows averaged ($\overline{X}$ ± SD) 31 ± 2 DIM, 585 ± 67 kg of BW, and 3.4 ± 0.4 units of BCS. Cow management and feeding were as described for study 1 at NWES.

Experimental design and treatments. The study was divided into a pre-treatment period and a 119-d collection period. The pretreatment period consisted of the first 27 to 35 d postpartum. During this period, cows were fed a diet containing (DM basis) 31.82% alfalfa haylage, 16.82% corn silage, 29.46% high moisture shelled corn, 8.37% SBM, 3.82% sunflower seeds, 2.01% distillers dried grain, 1.49% menhaden FM (ruminant grade FM, Sea Lac™), 1.47% MBM, and 2.59% molasses products (a mixture of sugar beet molasses and roughage products, Lots O' Lass™; Grain Terminal Association Feeds Inc., Willmar, MN). Minerals and vitamins were also added to meet requirements. The diet was formulated to contain 18.5% CP. During the last 2 wk of the pretreatment period, measurements of DMI, milk yield, and milk composition were obtained and used as covariates in statistical analyses for the parameters measured.

Within parity groups (primiparous vs. multiparous), cows were blocked by genetic line (cows bred to be small, cows bred to be large, or other) and randomly assigned to one of four treatments in sets of 4 according to calving date (12-wk interval) and mean daily milk yield during the pretreatment period (10-kg interval).

Treatments consisted of four diets. Two control diets, **SBM16** and **SBM18**, were SBM diets formulated to contain 16% or 18.5% CP (DM basis), respectively. The SBM was the sole source of supplemental protein. Two test diets, **MBM16** and **FM16**, were formulated to contain 16% CP (DM basis); in these diets, SBM was partially replaced by MBM or menhaden FM (ruminant grade FM, Sea Lac™), respectively. The same restrictions used to formulate diets in study 1 were applied to the formulation of MBM16 and FM16. Thus, MBM was about 3.1% of dietary DM, and FM was about 2.3% of dietary DM; each provided about 10% of dietary CP. All diets had similar estimated energy contents (Table 5).

Measurements. Milk weights were recorded at each milking for each cow. Weekly milk samples from two consecutive milkings were analyzed for fat, CP, lactose, and SCC by infrared analysis (Minnesota DHI, Sauk Center, MN). Amounts of feed offered and orts were recorded daily for each cow. Body weights and BCS were determined weekly. Feed ingredients were sampled weekly, and monthly composites were analyzed for CP by the Kjeldahl procedure (1), for ADF and NDF (35), and for ether extract (1). Additionally, a composite over the entire experimental period was prepared for each feed ingredient and was used to determine protein fractions using the procedures of Roe et al. (22) and the in situ method. Protein fractions were also determined on samples of mixed rations prepared from composites over the entire experimental period. The mixed rations were formulated to be similar in composition to SBM16, MBM16, FM16, and SBM18. Analyses were done in duplicate except for the in situ procedure.

In situ procedure. A lactating cow at 65 DIM fitted with a ruminal canula and fed a diet containing 50% forage and 50% concentrate (DM basis) was used. Samples of feed ingredients and mixed rations were ground through a 2-mm screen, except sunflower seeds, which were used whole and unprocessed. Dacron polyester bags with a mean pore size of 52 ± 16 μm (Erlanger Blumgart and Co., Inc., New York, NY) and measuring 6 × 10 cm were filled with approximately 0.5 g of sample, heat-sealed, attached near the weighted end of a weighted cord, and incubated in the rumen for 0, 1, 2, 4, 8, 12, 16, 24, 36, and 48 h. Empty bags were included to serve as blank controls. For the 0-h incubation, bags were soaked in warm water (initial temperature = 38 ± 1°C) for 15 min. Duplicate bags of blanks and each test feed were removed from the rumen at the end of each incubation time, thoroughly washed with tap water, and dried at 100°C for 24 h. The procedure was repeated so that there were four replicates of each test feed for each time point.

Bags and their contents were analyzed for residual N by the Kjeldahl procedure (1). Ruminal protein degradability was calculated according to the equation of Mathers and Miller (16) as

$$\text{RDP (percentage of CP)} = S + [(100 - S) \times (k_d/(k_d + k_p))]$$

where S = protein solubility expressed as a percentage of total CP, k_d = degradation rate constant, and k_p = passage rate constant for the protein fraction that was slowly degraded in the rumen. Nitrogen disappearing from the bags after 15 min of incubation in warm water was used as an estimate of protein solubility. Passage rate was assumed to be 6%/h (k_p = 0.06). The rate of N degradation was estimated as the slope of the regression line of natural log transformation of residual N on ruminal exposure time.

Energy and protein balance. For each cow, energy balance was calculated as the difference between energy intake and energy requirements for maintenance, growth, and milk yield (17). Dietary energy content was calculated from feed ingredients using NRC (17) values of 1.94, 1.67, 1.62, and 1.79 Mcal of NE_L/kg of DM for SBM, FM, MBM, and molasses products (assumed to be similar in composition to beet pulp plus molasses), respectively. Energy content of sunflower seeds was estimated to be 1.95 Mcal of NE_L/kg of DM (12). Prediction equations used at the Northeast DHIA Forage Testing Laboratory were used to estimate NE_L content of alfalfa silage, corn silage, and high moisture corn [megacalories of NE_L per kilogram of DM = $(2.297 - 0.027) \times$ percentage of ADF for alfalfa silage and $(2.068 - 0.017) \times$ percentage of ADF for corn silage and high moisture shelled corn]. Protein balance was calculated as the difference between protein intake and NRC (17) estimates of protein requirements for maintenance, growth, and milk yield.

Statistical Analyses. Data were analyzed using the GLM procedure of SAS (28) for a randomized, unbalanced block design. The statistical model was

$$\begin{aligned} Y_{ijklm} = {} & \mu + P_i + L_j + (PL)_{ij} + B_k(LP)_{ji} + T_l \\ & + (PT)_{il} + (LT)_{jl} + (PLT)_{ijl} \\ & + \beta(X_{ijklm} - \overline{X}\ldots.) + \epsilon_{ijklm} \end{aligned}$$

where

Y_{ijklm} = observed response,
μ = overall mean,
P_i = effect of parity i,
L_j = effect of genetic line j,
$B_k(LP)_{ji}$ = effect of block k (based on calving date and milk yield) within genetic line i and parity j,
T_l = effect of treatment l,
$\beta(X_{ijklm} - \overline{X}\ldots.)$ = covariate adjustment for pretreatment performance, and
ϵ_{ijklm} = error term.

Data from primiparous and multiparous cows were also analyzed separately without parity effects in the statistical models. Results are reported as least squares means and pooled standard errors. Observed differences were considered to be significant at $P \le 0.05$. The least significance difference procedure was used to separate means when treatment effects were significant. In situ and in vitro protein fractions are reported as means and standard deviations.

RESULTS AND DISCUSSION

In both studies, interactions of treatment with other model components that were tested were not significant. Therefore, only main effects of treatment are reported.

Study 1

Within locations, diets were fairly similar in composition (Tables 1 and 2). At NWES, high moisture corn and corn silage had greater CP and less ADF and NDF than anticipated. This result contributed to slightly greater than expected dietary protein contents and lower than recommended ADF and NDF contents (17). At SPC, CP contents of hay and of the diets were lower than anticipated. The calculated RDP estimates in diets (Table 2) met or exceed recommended concentrations of RDP (17). Dietary RUP content of the FMD and the MBMD was 80 and 78% of NRC (17) recommendations, respectively.

Dry matter intake was not affected by treatment and averaged 22.8 kg/d. Daily CP and NE_L intakes were similar across treatments (Table 4). On average, because of the relatively high DMI, the intakes of CP and NE_L by cows exceeded requirements for the milk yields observed in this study.

Treatment had no effect on milk yield (Table 3). Milk yield and 3.5% FCM yield averaged 35.7 and 34.8 kg/d, respectively. Milk fat contents were similar across treatments and averaged 3.38%. Milk fat yields were not affected by treatment. Milk protein content increased (3.20% vs. 3.11%), and protein yield tended to increase ($P = 0.10$), when FM was fed (Table 3). The increase in milk protein content corresponded to an increase in true protein content as the casein N and noncasein N contents in milk increased, but NPN content was not affected (Table 4). As a consequence, the proportion of NPN in total milk N tended to be greater when MBM was fed. The tendency toward increased NPN as a proportion of total milk N appeared to reflect dietary differences in RDP contents, although these differences were small. Meat and bone meal tended to increase ($P = 0.10$) lactose concentration in milk (4.86% vs. 4.83%) but did not alter lactose yield. Blood glucose concentrations were not affected by treatment (Table 3).

The intestinal supply of AA that usually limit milk protein synthesis might have increased when FM was fed, which might explain the increased protein content in milk from cows fed the FMD. The protein in FM usually contains greater amounts of total essential AA, especially Lys and Met (29), than does the protein in MBM. Protein in FM is also less degradable in the rumen (17), and its RUP is more digestible in the intestine (5, 23) than are the protein and RUP in MBM. Using the procedure of Calsamiglia and

TABLE 3. Effects of dietary fish meal (FM) or meat and bone meal (MBM) on intakes, milk yield and composition, and blood glucose concentrations (study 1).

	Diet			
Item	FM	MBM	SE	*P*
Cows, no.	18	18		
DMI, kg/d	22.6	22.9	0.23	0.51
CP Intake, kg/d	3.63	3.65	0.04	0.67
NE_L Intake, Mcal/d	36.6	36.9	0.38	0.66
Milk, kg/d	35.7	35.7	0.41	0.99
3.5% FCM, kg/d	34.5	35.1	0.48	0.43
Fat, %	3.36	3.40	0.05	0.55
Protein, %	3.20^{a}	3.11^{b}	0.02	0.01
Lactose, %	4.83	4.86	0.01	0.10
Fat, kg/d	1.18	1.21	0.02	0.28
Protein, kg/d	1.12	1.10	0.01	0.10
Lactose, kg/d	1.73	1.74	0.02	0.74
Blood glucose, mg/dl	69.8	69.3	1.64	0.83

^{a,b}Means within the same row without a common superscript differ ($P \le 0.05$).

Stern (5), in vitro estimates of intestinal RUP digestion were 48.5 and 80.9% for the MBM and FM, respectively, used in this study.

Lysine and Met are thought to be the most limiting AA for milk yield and milk protein synthesis (29, 30). Milk protein content was increased when the supply of these AA to the intestine was increased by the inclusion of ruminally protected forms of Lys and Met in the diet, by the postruminal infusion of synthetic forms of Lys and Met (26, 30), or by the inclusion of protein feeds such as FM, which are rich in these AA (25). The amino acids that were supplied to the small intestine were not measured in this study. Based on published values of AA and RUP contents of protein in FM and MBM (30) and intakes in the present study, FM supplement supplied 18 g/d of Lys and 7 g/d of Met postruminally. Similar estimates for MBM are 10 g/d of Lys and 3 g/d of Met. Based on these estimates, FM supplied 8 g/d more Lys and 4 g/d more Met than did MBM. Socha et al. (32) infused early lactation cows with 10 g of Lys plus incremental amounts (0 to 16 g) of DL-Met postruminally. Milk protein content increased when as little as 3.5 g of DL-Met were infused, and the response increased when the quantity of the DL-Met infusion increased. The quantity of AA infused in the treatment containing 10 g of Lys and 3.5 g of Met was comparable with the estimated amount of Lys and Met supplied by FM over that supplied by MBM in our study. Thus, a greater milk protein content would be expected for cows fed the FMD. On a DM basis, the diets used by Socha et al. (32) contained 17.3% CP and consisted of 21.1% corn silage, 10.5% haycrop silage, 10.6 chopped alfalfa hay, 36.9% corn meal, 8.9% SBM, 6% cracked raw soybeans, 1% blood meal, and 1% tallow (32).

Study 2

Crude protein contents of the diets were very close to the target values used for formulation of those diets (Table 5). The contents of ADF in the diets (Table 5), although similar across treatments, were slightly less than the NRC (17) recommendations. Dietary RDP as a percentage of dietary CP slightly decreased when SBM was partially replaced by MBM or FM (71.9, 69.5, and 68%, respectively). The RDP content was not altered (71.9 vs. 72.3% of CP) when the amount of SBM was nearly doubled from SBM16 to SBM18, which allowed evaluation of the effects of protein content without changing RDP content.

With the exception of SBM and sunflower seeds, estimates of protein solubility (Table 6) in water were generally numerically equal to or greater than estimates of protein solubility in borate phosphate buffer. However, differences were not large and could have reflected differences in pore sizes between the nylon bag used to determine solubility in water and the filter paper (number 541; Whatman, Clifton, NJ) used to determine solubility in borate phosphate buffer. With either technique, CP that is filterable is considered to be soluble protein.

Ruminally degradable protein contents of alfalfa silage, corn silage, FM, and MBM were similar to NRC (17) values. Conversely, RDP contents of high moisture shelled corn and SBM were markedly greater than NRC (17) values. Others (34) have also reported greater RDP values for SBM than those values reported by the NRC (17). Protein degradabil-

TABLE 4. Effects of dietary fish meal (FM) or meat and bone meal (MBM) on the concentration and yield of milk N fractions (study 1).

	Diet			
Item	FM	MBM	SE	*P*
Cows, no.	18	18		
Total N, mg/ml	5.06^{a}	4.92^{b}	0.03	<0.01
Casein N, mg/ml	3.97^{a}	3.86^{b}	0.03	<0.01
Noncasein N, mg/ml	1.09	1.06	0.01	0.07
NPN, mg/ml	0.27	0.27	0.003	0.86
Total N, g/d	172.0	168.1	1.67	0.10
Casein N, g/d	135.0	131.8	1.36	0.11
Noncasein N, g/d	37.0	36.2	0.36	0.14
NPN, g/d	9.38	9.44	0.16	0.81
Casein N:total N	0.78	0.78	0.001	0.68
Noncasein N:total N	0.22	0.22	0.001	0.68
NPN:Total N	0.05	0.06	0.001	0.11

^{a,b}Means within the same row without common superscripts differ ($P \le 0.05$).

ity of whole, unprocessed sunflower seeds was low (12% of CP). However, unpublished data (W. Waldorf, J. M. Akayezu, and D. E. Otterby, 1993) obtained in our laboratory indicate that protein degradability is extensive (82% of CP) when sunflower seeds are ground.

Estimates of dietary RDP calculated from RDP contents of individual feed ingredients (Table 5) were generally similar to in situ measurements of samples of prepared mixed rations (Table 6). Stallings et al. (34) also found that RDP contents of individual ingredients can be used to predict dietary RDP. However, the RDP value (67.9%) determined in situ for a sample of the mixed ration that was prepared to be similar in composition to SBM18 (Table 6) was markedly less than that calculated from RDP of individual dietary ingredients (72.3%) (Table 5). Calsamiglia et al. (6) have also reported inconsistencies between in situ measurements of dietary RDP and estimates derived from RDP contents of individual ingredients.

Overall, DM and NE_L intakes were increased when cows were fed SBM18 (Table 7). However, differences were only significant among primiparous cows, even though the DMI of multiparous cows fed SBM18 were at least 1.8 kg/d more than the DMI of multiparous cows fed the other diets (Figure 1, A and B). When diets with reduced CP or RDP are fed, ruminal

TABLE 5. Composition of experimental diets (study 2).

Composition	Diet[1] SBM16	MBM16	FM16	SBM18	SD[2]
	(% of DM)				
Ingredient					
Alfalfa haylage	33.65	34.47	34.45	31.98	1.64
Corn silage	14.05	14.54	14.51	13.50	0.84
High moisture shelled	36.09	37.02	37.01	31.85	1.80
Soybean meal	6.94	3.10	3.12	13.36	0.21
Sunflower seeds	3.43	3.43	3.43	3.44	0.12
Menhaden fish meal[3]	...	...	2.27	...	0.08
Meat and bone meal	...	3.06	...	...	0.10
Molasses products[4]	2.58	2.59	2.59	2.58	0.09
Dicalcium phosphate	1.60	0.17	0.97	1.61	0.04
Trace-mineralized salt[5]	0.49	0.49	0.48	0.49	0.02
Vitamin premix[6]	0.45	0.45	0.45	0.45	0.02
Sodium bicarbonate	0.49	0.49	0.48	0.49	0.02
Magnesium oxide	0.24	0.24	0.25	0.24	0.01
Chemical					
CP	15.93	15.97	15.93	18.34	0.39
RDP,[7] % of CP	71.96	69.52	68.04	72.31	0.25
NDF	28.38	28.57	28.57	27.63	0.77
ADF	17.10	17.19	17.20	16.75	0.72
Ether extract	3.19	3.52	3.24	3.13	0.19
NE_L,[8] Mcal/kg DM	1.70	1.71	1.70	1.71	0.02
Forage:concentrate	48:52	49:51	49:51	45:55	...

[1] SBM16 = Soybean meal (SBM) control diet containing 16% CP, MBM16 = diet containing meat and bone meal and formulated to contain 16% CP, FM16 = diet containing fish meal and formulated to contain 16% CP, and SBM18 = SBM control diet containing 18% CP.

[2] Computed based on weekly ration mixing records and chemical composition determined on monthly composites of feed ingredients (n = 44 to 47).

[3] Ruminant grade fish meal (Sea Lac™; Zapata Protein Inc., Hammond, LA).

[4] Mixture of sugar beet molasses and roughage products (Lots O' Lass™; Grain Terminal Association Feeds Inc., Willmar, MN). Contained ≥38% total invert sugars (guaranteed analysis). Chemical analysis (DM basis): 32.5% NDF, 23.6% ADF, 9.8% CP, and 2.4% ether extract.

[5] Guaranteed analysis: ≥38.08% but ≤38.90% Na, ≥58.72% but ≤59.99% Cl, ≥0.200% Mn, ≥0.160% Fe, ≥0.033% Cu, ≥0.010% Co, ≥0.007% I, and ≥0.005% Zn.

[6] Contained 1,023,201 IU/kg of vitamin A, 314,829 IU/kg of vitamin D, 3935 IU/kg of vitamin E, 41.29 g/kg of Ca, 14.01 g/kg of S, 0.032 g/kg of Co, 3.098 g/kg of Cu, 0.130 g/kg of I, 9.784 g/kg of Fe, 9.875 g/kg of Mn, 0.062 g/kg of Se, and 12.390 g/kg of Zn.

[7] Calculated using RDP contents of feed ingredients (Table 6).

[8] Calculated using NRC (17) values. For molasses products, NRC (17) values for beet pulp plus molasses were used; 1.95 Mcal of NE_L/kg of DM were used for sunflower seeds (12).

TABLE 6. Protein fractions in feeds and diets used in study 2.

Feed[2]	CP		Protein fraction[1]											
			WSOL		$A + B_1$		B_2		B_3		C		RDP[3]	
	(% of DM)		(% of CP)											
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
AH	18.62	0.28	68.55	0.14	66.26	0.01	22.48	0.15	4.09	0.08	7.17	0.08	77.73	0.51
CS	7.95	0.26	62.39	4.51	54.46	0.23	31.75	0.01	9.12	0.32	4.67	0.10	69.26	5.86
HMSC	10.78	0.01	29.84	0.27	15.68	0.47	70.18	0.66	13.33	0.30	0.81	0.12	69.55	0.35
SBM	49.15	0.05	17.25	0.20	22.82	0.67	74.49	0.59	0.98	0.04	1.71	0.01	74.20	1.30
SFS	18.17	0.02	3.70	1.38	10.00	3.41	...	...	...	...	4.41	0.13	12.01	2.46
FM	70.74	0.46	21.10	0.10	9.44	0.81	62.71	1.48	25.98	0.66	1.87	0.01	36.21	0.07
MBM	53.71	0.84	37.79	1.41	29.04	0.44	29.15	0.29	39.23	0.03	2.58	0.18	50.78	0.45
MP	9.65	0.01	88.47	0.24	85.74	0.56	4.99	0.52	2.68	0.08	6.59	0.14	90.00	0.30
SBM16-P[4]	16.15	0.03	47.00	1.27	41.04	1.34	48.72	1.49	6.18	0.11	4.06	0.25	70.42	0.91
MBM16-P[4]	16.30	0.26	49.00	2.81	43.23	1.73	43.25	1.85	9.49	0.18	4.03	0.08	68.76	2.02
FM16-P[4]	16.07	0.10	49.33	0.52	41.12	0.66	45.74	0.63	9.30	0.21	3.84	0.18	67.56	0.74
SBM18-P[4]	18.39	0.03	38.19	1.31	37.91	0.16	53.37	0.06	5.30	0.16	3.42	0.07	67.93	0.97

[1] WSOL = CP soluble in water (dacron bag method); A, B_1, B_2, B_3, and C = protein fractions as defined by and determined according to Roe et al. (22); $A + B_1$ = CP that was soluble in borate phosphate buffer; and C = acid detergent insoluble protein (ADIN × 6.25).

[2] AH = Alfalfa haylage, CS = corn silage, HMSC = high moisture shelled corn, SBM = soybean meal, SFS = whole sunflower seeds, FM = menhaden fish meal (ruminant grade FM; Sea Lac™; Zapata Protein Inc., Hammond, LA), MBM = meat and bone meal, and MP = molasses products [made of a mixture of sugar beet molasses and roughage products (Lots O' Lass™; Grain Terminal Association Feeds Inc., Willmar, MN)].

[3] Estimated by the in situ nylon bag procedure.

[4] Mixed rations SBM16-P, MBM16-P, FM16-P, and SBM18-P were prepared from composite samples of feed ingredients used in experimental diets and were formulated to be similar in composition to the SBM control diet containing 16% CP, the diet containing MBM and formulated to contain 16% CP, the diet containing FM and formulated to contain 16% CP, and the SBM control diet containing 18.5% CP, respectively.

TABLE 7. Effects of dietary treatment on nutrient intake (study 2).

Item	Diet[1]				SE	P
	SBM16	MBM16	FM16	SBM18		
	All cows					
Cows, no.	19	18	20	20		
DM, kg/d	21.1^{b}	20.6^{b}	21.3^{b}	23.6^{a}	0.77	0.04
NE_L, Mcal/d	36.1^{b}	35.3^{b}	36.4^{b}	40.3^{a}	1.30	0.04
CP, kg/d	3.35^{b}	3.27^{b}	3.40^{b}	4.32^{a}	0.13	<0.01
RDP, kg/d	2.41^{b}	2.27^{b}	2.32^{b}	3.13^{a}	0.09	<0.01
RUP, kg/d	0.94^{c}	1.00^{bc}	1.09^{b}	1.19^{a}	0.04	<0.01
	Primiparous cows					
Cows, no.	9	9	9	10		
DM, kg/d	18.4^{b}	18.4^{b}	18.4^{b}	21.3^{a}	0.70	0.01
NE_L, Mcal/d	31.4^{b}	31.6^{b}	31.5^{b}	36.5^{a}	1.18	0.01
CP, kg/d	2.91^{b}	2.92^{b}	2.92^{b}	3.91^{a}	0.12	<0.01
RDP, kg/d	2.09^{b}	2.03^{b}	1.99^{b}	2.83^{a}	0.09	<0.01
RUP, kg/d	0.82^{c}	0.89^{bc}	0.94^{b}	1.08^{a}	0.04	<0.01
	Multiparous cows					
Cows, no.	10	9	11	10		
DM, kg/d	23.7	22.7	24.0	25.8	1.19	0.37
NE_L, Mcal/d	40.5	38.9	41.2	43.9	2.00	0.41
CP, kg/d	3.77^{b}	3.60^{b}	3.87^{b}	4.72^{a}	0.19	<0.01
RDP, kg/d	2.72^{b}	2.50^{b}	2.64^{b}	3.41^{a}	0.14	<0.01
RUP, kg/d	1.06^{c}	1.10^{bc}	1.23^{ab}	1.30^{a}	0.06	0.02

[a,b,c] Means within the same row without common superscripts differ ($P \leq 0.05$).

[1] SBM16 = Soybean meal (SBM) control diet containing 16% CP, MBM16 = diet containing meat and bone meal and formulated to contain 16% CP, FM16 = diet containing fish meal and formulated to contain 16% CP, and SBM18 = SBM control diet containing 18.5% CP.

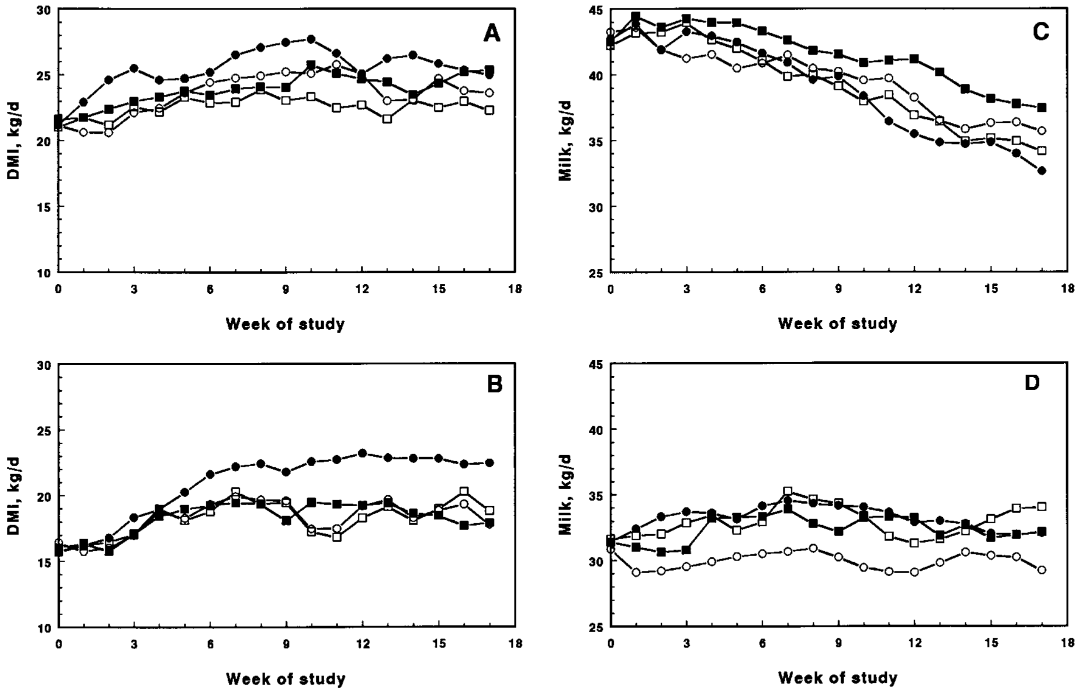

Figure 1. The DMI and actual milk yield of early lactation cows fed diets containing 16 (○) or 18.5% (●) CP with soybean meal as the sole source of supplemental protein or diets containing 16% CP in which soybean meal was partially replaced with meat and bone meal (□) or fish meal (■). A) DMI of multiparous cows, B) DMI of primiparous cows, C) milk yield of multiparous cows, and D) milk yield of primiparous cows.

NH_3 may be inadequate for microbial growth, and decreased DM digestibility may result (18, 19). However, Léonard and Block (15) found no effect on DMI when dietary CP was increased from 15.4 to 20.8% of DM. In the present study, diets met or exceeded recommendations (17) for RDP. The greater proportion of concentrate in SBM18 (Table 5) might have contributed to the increased DMI when this diet was fed. However, in studies in which increased DMI was attributed to the increased proportion of concentrate in diets (11, 36), changes in the proportion of concentrates were much larger (10 to 20 percentage units) than in the present study (3 to 4 percentage units).

Meat and bone meal (3.1% of DM) or FM (2.3% of DM) did not adversely affect DMI in this study (Table 7; Figure 1, A and B). Decreased DMI when FM was fed has been reported by some researchers (33, 38) but not by others (39). Spain et al. (33) determined that DMI decreased linearly when FM was increased from 2.6 to 7.8% of dietary DM. Compared with a control diet containing no FM, the decrease in DMI was only significant when FM supplied 7.8% of dietary DM. Windschitl (38) observed decreased DMI when FM provided 9.4% of the DM, but Zerbini et al. (39) did not detect a decrease in DMI when FM provided 12.9% of dietary DM.

Changes in BW and BCS during the study overall were similar among treatment groups of primiparous cows. Body weight gains ranged from 26 to 31 kg, and BCS at the conclusion of the study were similar among treatment groups and were less than a quarter of a unit below the BCS at the start of the study (Table 8). Among multiparous cows, although treatment effects on BW and BCS changes were statistically significant, actual changes were small. During the study, BW gains tended to be greater, and BCS changes were greater, for cows fed MBM16 or SBM18 than for cows fed SBM16 or FM16 (Table 8). Multiparous cows fed MBM16 or SBM18 gained less than a quarter of a unit of BCS, and those fed SBM16 or FM16 had less than a quarter of a unit of BCS to recover relative to their BCS at the initiation of the study.

Within parity, CP and RDP intakes were similar for cows fed SBM16, MBM16, or FM16 and were significantly less than CP and RDP intakes for cows fed SBM18 (Table 7). As a percentage of NRC (17) requirements, CP intakes were 101, 97, 98, and 128% for multiparous cows and 102, 97, 101, and 122% for primiparous cows fed SBM16, MBM16, FM16, and SBM18, respectively.

Intakes of RUP were greatest for cows fed SBM18, intermediate for those fed MBM16 or FM16, and least for cows fed SBM16 (Table 7). The inclusion of MBM at 3% of dietary DM or of FM at 2.3% of dietary DM resulted in a small increase in the RUP content of the diet. As a percentage of NRC (17) recommendations, RUP intakes were 82, 86, 90, and 102% for multiparous cows and 85, 88, 96, and 101% for primiparous cows fed SBM16, MBM16, FM16, and SBM18, respectively.

Although cows fed FM produced at least 2 kg/d more milk (Table 9) and appeared to be more persistent (Figure 1C) than multiparous cows fed the other diets, treatments did not affect yields of milk, FCM, and SCM or composition of milk from multiparous cows or from all cows (multiparous and primiparous cows combined) (Table 9). In contrast, an increase in CP from 16 to 18.3% in SBM diets or the replacement of a portion of the SBM with MBM or FM in diets containing 16% CP increased milk yield of primiparous cows (Table 9; Figure 1D). However, because milk fat and protein contents tended to be lower when primiparous cows were fed MBM or FM, yields of FCM and SCM from cows fed SBM16, MBM, or FM diets were not significantly different and tended to be lower than those from cows fed SBM18 (Table 9).

The inability of source or amount of CP to alter milk yield of multiparous cows suggests either that protein was probably not limiting or that energy was equally limiting milk yield for all treatments. Multiparous cows fed SBM16, MBM16, or FM16 achieved energy balance after wk 6 of the study (wk 10 to 11 of lactation; Figure 2A) and achieved protein balance around wk 7 of the study (wk 11 to 12 of lactation; Figure 2C). These cows remained at or slightly above

TABLE 8. Effects of dietary treatment on feed efficiency, protein and energy balance, and BW and body condition score (BCS) changes (study 2).

	Diet[1]					
Item	SBM16	MBM16	FM16	SBM18	SE	*P*
	All cows					
Cows, no.	19	18	20	20		
Yield efficiency[2]						
Milk:DMI	1.67^{ab}	1.78^{a}	1.79^{a}	1.58^{b}	0.05	0.03
Milk:CP intake	10.5^{a}	11.2^{a}	11.2^{a}	8.7^{b}	0.35	<0.01
NE_L Balance, Mcal/d	2.0^{b}	1.2^{b}	1.0^{b}	5.8^{a}	1.1	0.01
Protein balance, kg/d	0.06^{b}	-0.05^{b}	-0.07^{b}	0.96^{a}	0.11	<0.01
BW Change,[3] kg	21.8	33.3	22.8	35.1	7.65	0.45
BCS Change,[3] units	–0.2	0.0	–0.3	0.03	0.1	0.09
	Primiparous cows					
Cows, no.	9	9	9	10		
Yield efficiency						
Milk:DMI	1.65^{bc}	1.79^{ab}	1.80^{a}	1.62^{c}	0.06	0.05
Milk:CP intake	10.4^{b}	11.3^{a}	11.3^{a}	8.8^{c}	0.04	<0.01
NE_L Balance, Mcal/d	0.4^{b}	-0.4^{b}	-0.9^{b}	3.0^{a}	0.9	0.03
Protein balance, kg/d	0.01^{b}	-0.12^{b}	-0.16^{b}	0.69^{a}	0.09	<0.01
BW Change, kg	30.9	25.8	23.6	25.2	11.8	0.97
BCS Change, units	–0.1	–0.1	–0.3	–0.1	0.2	0.75
	Multiparous cows					
Cows, no.	10	9	11	10		
Yield efficiency						
Milk:DMI	1.71	1.75	1.79	1.54	0.08	0.17
Milk:CP intake	10.8^{a}	11.0^{a}	11.2^{a}	8.5^{b}	0.50	<0.01
NE_L Balance, Mcal/d	3.3	2.6	2.5	9.1	1.7	0.06
Protein balance, kg/d	0.06^{b}	0.01^{b}	-0.05^{b}	1.28^{a}	0.16	<0.01
BW Change, kg	12.8	40.7	22.0	45.0	9.42	0.08
BCS Change, units	-0.2^{b}	0.1^{a}	-0.2^{b}	0.2^{a}	0.1	0.02

[a,b,c]Means within the same row without common superscripts differ ($P \le 0.05$).

[1] SBM16 = Soybean meal (SBM) control diet containing 16% CP, MBM16 = diet containing meat and bone meal and formulated to contain 16% CP, FM16 = diet containing fish meal and formulated to contain 16% CP, and SBM18 = SBM control diet containing 18.5% CP.

[2] Milk:DMI = Kilograms of milk per kilogram of DMI; milk:CP intake = kilograms of milk per kilogram of CP intake.

[3] Change over the 119-d treatment period.

energy and protein balance throughout the remainder of the study. Multiparous cows fed SBM18 achieved positive energy balance after wk 2 of the study (wk 6 to 7 of lactation; Figure 2A) and achieved protein balance at the end of the covariate period (Figure 2C). These cows remained in a positive energy and protein balance thereafter. The high DMI of multiparous cows used in this study allowed cows to meet or exceed their CP requirements. The RUP value of protein supplements, even those considered to be highly degradable, such as SBM, may be underestimated when the DMI is high (7, 8). These factors likely contributed to the lack of detectable treatment effects.

The greater milk yield by primiparous cows fed SBM18 than by cows fed SBM16 was the result of increased energy and protein intakes because of greater DMI and protein concentration in the diet. These results are in agreement with those of others (15). In contrast, primiparous cows fed SBM16, MBM16, or FM16 consumed similar amounts of DM, NE_L, and CP, but those fed MBM16 or FM16 yielded more milk than did cows receiving SBM16. These results and the failure of SBM18 to increase milk yield more than did MBM16 or FM16 suggest that the quantity and quality of AA supplied to the small intestine when MBM16, FM16, or SBM18 was fed were similar and greater than that supplied when SBM16 was fed. Alternatively, MBM16 and FM16 might have provided less total AA and an improved AA quality, resulting in better efficiency of utilization of absorbed protein.

Clark et al. (8) indicated that protein supplements with low ruminal degradability must contribute ≥35% of CP intake to increase protein flow to the small intestine. In the present study, MBM and FM supplied only 10% of dietary CP. Based on CP and RUP intakes (Table 7), protein flow to the small intestine

TABLE 9. Effects of dietary treatments on milk yield and composition (study 2).

	Diet[1]					
Item	SBM16	MBM16	FM16	SBM18	SE	*P*
	All cows					
Cows, no.	19	18	20	20		
Milk, kg/d	34.9	36.2	37.1	36.2	0.98	0.41
3.5% FCM, kg/d	33.5	33.7	35.5	34.6	0.96	0.38
SCM, kg/d	31.6	32.0	33.3	32.5	0.88	0.49
Fat, %	3.27	3.12	3.21	3.21	0.09	0.67
Protein, %	3.13	3.05	3.02	3.14	0.04	0.09
Lactose, %	4.98	5.04	5.00	4.97	0.03	0.35
	Primiparous cows					
Cows, no.	9	9	9	10		
Milk, kg/d	30.0^{b}	33.0^{a}	32.5^{a}	33.3^{a}	0.87	0.05
3.5% FCM, kg/d	28.8	30.1	30.9	32.8	1.04	0.10
SCM, kg/d	27.6	28.8	29.4	31.1	0.92	0.08
Fat, %	3.34	2.95	3.09	3.37	0.15	0.18
Protein, %	3.20	3.05	3.07	3.18	0.06	0.16
Lactose, %	5.09	5.12	5.09	5.11	0.04	0.93
Fat, kg/d	0.98	0.96	1.02	1.14	0.05	0.11
Protein, kg/d	0.95	0.99	1.01	1.06	0.03	0.11
Lactose, kg/d	1.52^{b}	1.69^{a}	1.66^{a}	1.71^{a}	0.04	0.03
	Multiparous cows					
Cows, no.	10	9	11	10		
Milk, kg/d	39.5	39.1	41.5	38.7	1.51	0.53
3.5% FCM, kg/d	37.7	36.8	39.9	36.5	1.43	0.28
SCM, kg/d	35.2	34.6	37.0	34.0	1.34	0.40
Fat, %	3.19	3.15	3.27	3.17	0.10	0.80
Protein, %	3.05	3.07	2.98	3.09	0.05	0.37
Lactose, %	4.89	4.96	4.91	4.83	0.04	0.16
Fat, kg/d	1.27	1.23	1.35	1.21	0.06	0.24
Protein, kg/d	1.20	1.19	1.22	1.18	0.04	0.91
Lactose, kg/d	1.94	1.94	2.05	1.89	0.08	0.53

[a,b] Means within the same row without common superscripts differ ($P \leq 0.05$).

[1] SBM16 = Soybean meal (SBM) control diet containing 16% CP, MBM16 = diet containing meat and bone meal and formulated to contain 16% CP, FM16 = diet containing fish meal and formulated to contain 16% CP, and SBM18 = SBM control diet containing 18.5% CP.

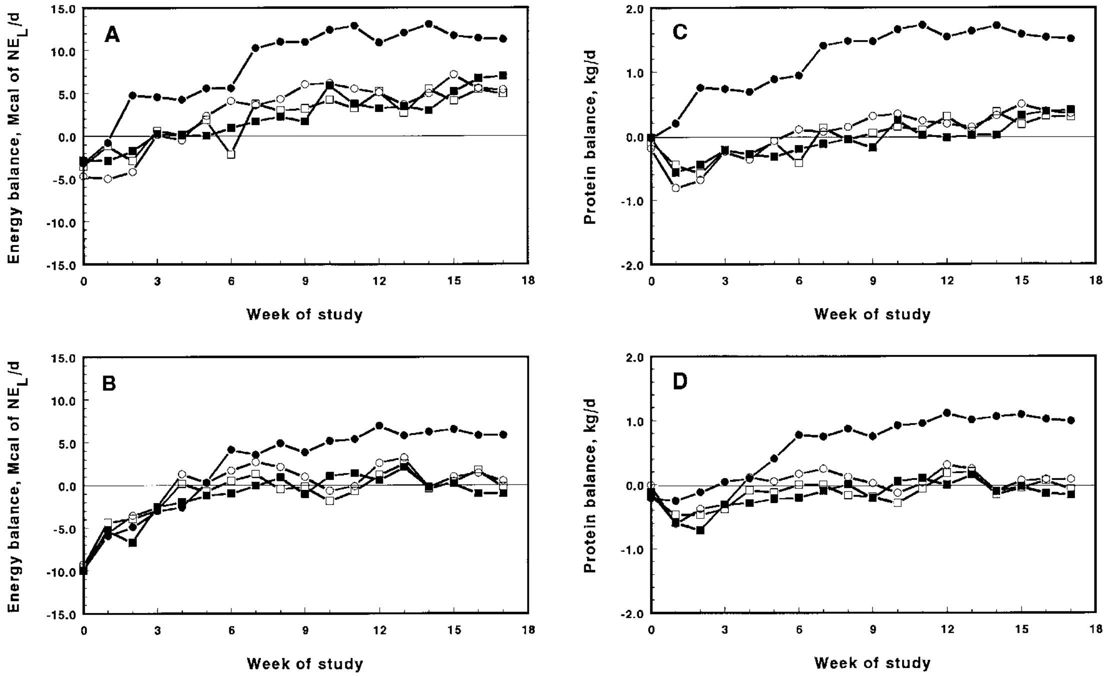

Figure 2. Energy and protein balance of early lactation cows fed diets containing 16 (○) or 18.5% (●) CP with soybean meal as the sole source of supplemental protein or diets containing 16% CP in which soybean meal was partially replaced with meat and bone meal (□) or fish meal (■). A) Energy balance of multiparous cows, B) energy balance of primiparous cows, C) protein balance of multiparous cows, and D) protein balance of primiparous cows.

was probably greater for cows consuming SBM18 than for cows consuming MBM16 or FM16, unless microbial protein synthesis was increased when MBM16 or FM16 was fed.

Primiparous cows fed SBM18 achieved protein balance at wk 3 of the study (wk 7 to 8 of lactation) and were in a positive protein balance from about wk 5 of the study (Figure 2D). Primiparous cows fed SBM16 reached and maintained protein balance from wk 4 of study (Figure 2D), but primiparous cows fed MBM16 or FM16 remained in a negative protein balance until wk 7 of the study (11 to 12 wk into lactation) and barely achieved protein balance thereafter (Figure 2D).

The efficiency of protein utilization for milk yield (calculated as kilograms of milk yielded per kilogram of CP intake) increased when MBM or FM was fed (Table 8). Santos et al. (27) also reported greater efficiency of DM conversion to milk and numerically greater milk yield for cows fed FM than for cows fed urea or SBM as sources of supplemental CP in diets containing 18.5% CP. Increased efficiency of protein utilization for milk yield when MBM or FM was fed might have been the result of improved AA balance of absorbed protein. Experimental diets in this study were evaluated using the Cornell Net Carbohydrate and Protein System (31). At observed intakes, predicted total essential AA flows to the small intestine were 1397, 1354, 1515, and 1557 g/d for multiparous cows and 1087, 1104, 1165, and 1280 g/d for primiparous cows fed SBM16, MBM16, FM16, and SBM18, respectively. The milk yield that was allowable by the AA in the diet and as predicted by the model (31) was 37.0, 35.9, 42.9, and 41.8 kg/d for multiparous cows and 27.0, 27.5, 31.2, and 32.8 kg/d for primiparous cows fed SBM16, MBM16, FM16, or SBM18, respectively. According to the model, cows fed FM16 or SBM18 met or exceeded requirements for all essential AA, but cows fed SBM16 or MBM16 did not meet Met, Lys, His, and Ile requirements. The reason for the less than expected milk yield for multiparous cows fed SBM18 is unclear. Conversely, actual milk yields of cows fed the MBM16 diet were greater than predicted yields, suggesting that the quality of MBM used in this study was perhaps higher than that usually reported (5, 23) or that the model is inadequate. In vitro estimates of intestinal protein digestion using the procedure of Calsamiglia and Stern (5) were 48.3 and 78.8% of RUP for MBM and FM, respectively.

Fat content tended to decrease ($P = 0.18$) in milk from primiparous cows but not in milk from multiparous cows when MBM or FM was fed. Milk fat depression from diets containing FM has been reported (38, 39) and has been associated with the highly unsaturated fatty acids in fish lipids (4, 33, 38). Fish oil in the diet may decrease ruminal acetate production (20, 38) and may also have a more significant postruminal effect on milk fat synthesis (4, 33). Opstvedt (20) reported that milk fat content was consistently decreased when fish oil intake exceeded 100 g/d and suggested that milk fat could be depressed by <100 g/d of fish oil when dietary fiber content was low. In our study, primiparous and multiparous cows fed FM16 consumed 35 and 50 g/d of fish oil, respectively.

Information regarding the effects of dietary MBM on milk composition is limited. When MBM or cottonseed meal partially replaced SBM in diets of lactating cows, milk yield increased, and milk fat content decreased (2). Milk and 3.5% FCM yields by early lactation cows fed diets containing 55% of DM as forage were not altered (3) when the source of supplemental protein was urea, SBM, MBM, or SBM plus MBM (50:50, CP basis). However, CP and total true protein content of milk was decreased when MBM was fed (3). In contrast, in the study by Grummer et al. (13), yields of milk, 3.5% FCM, fat, and protein were increased, but fat and protein contents were not altered, when cows were fed diets in which SBM was partially replaced by raw soybeans or roasted soybeans or totally replaced by raw soybeans plus animal by-products (82% MBM).

CONCLUSIONS

Increased amounts of dietary protein or partial substitution of dietary SBM with MBM or FM increased the milk yield of primiparous cows but not of multiparous cows. Milk yields of dairy cows fed MBM or FM were similar in studies 1 and 2. In study 1, dietary FM increased milk protein content and tended to increase milk protein yield compared with dietary MBM, but this effect was not observed in study 2. Reasons for the discrepancy are unclear, but these variable results are consistent with those of other reports (10). Dietary FM or MBM tended to increase efficiency of DM and to increase efficiency of protein utilization for milk yield by cows in early lactation. The results support the view that certain types of RUP in the diet may improve animal performance, but animal response is difficult to predict.

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