Milk Production During the Complete Lactation of Dairy Cows Fed Diets Containing Different Amounts of Protein[1]

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ABSTRACT

Milk production response to four different amounts of protein supplementation was measured in a complete lactation study utilizing 58 multiparous Holstein cows treated with bovine somatotropin. The four treatments were as follows (the first number is the dietary crude protein content (% of dry matter) during the first 16 wk of lactation and the second number is the protein content for wk 17 to 44 of lactation): 15.4-16.0, 17.4-16.0, 17.4-17.9, and 19.3-17.9. Diets were formulated to maximize the supply of amino acids to the intestine. High moisture ear corn was finely ground to promote ruminal fermentation and microbial protein synthesis, and roasted soybeans and expeller processed soybean meal were used as the protein supplements to provide relatively high amounts of rumen-undegradable protein. Alfalfa silage and corn silage (3:2) provided the forage. Milk production for the 308-d lactation for each of the treatment groups was 10,056, 10,831, 11,095, and 11,132 kg. Cows of this production level fed diets similar to those used in this experiment benefit from dietary protein of approximately 17.5% during the first 30 wk of lactation. A reduction in dietary protein to 16% can be made around wk 30 of lactation. This amount of dietary protein should, with prevailing feed prices, be compatible with maximum profit and a moderate amount of nitrogen excretion to the environment.
(**Key words:** dairy cows, lactation, milk, protein requirement)

INTRODUCTION

The increase in milk production following incremental additions of protein to the dairy cow diet is a diminishing response, and the point of maximum profitability is likely to be at a dietary protein concentration below that needed for maximum milk production (12). Close management of dietary protein is needed to maximize profits and to minimize risk of environmental damage caused by excessive nitrogen excretion in urine and feces. The National Research Council recommendations on the nutrient requirements of dairy cattle (10) were developed in the belief that cows in the first weeks of lactation need more dietary protein to compensate for low feed intake during this period. Many of the studies used to develop the current standards utilized cows with relatively low levels of milk production and did not use protein supplements of low rumen degradability or cows treated with bST. Some recent studies (2, 3, 9) examining the relationship between dietary protein and milk production have used high producing cows and diets supplemented with protein of low rumen degradability, but the studies covered only the first part of lactation. Information is needed from complete lactation studies with high producing cows and diets that enhance the supply of AA to the small intestine to determine optimum amounts of dietary protein to maximize profitability and minimize environmental impact.

The objective of this study was to determine milk production response in high producing dairy cows to dietary supplementation of different amounts of dietary protein having low rumen degradability. Treatments were designed to identify the minimum amount of protein needed for the entire lactation.

MATERIALS AND METHODS

Fifty-eight multiparous Holstein cows were used in a 308-d lactation trial approved by the Animal Care Committee of the College of Agricultural and Life Sciences, University of Wisconsin, Madison. Diets (Table 1) containing 15.4, 17.4, or 19.3% CP were fed during wk 1 through 16 of lactation to groups of 15, 29, or 14 cows, respectively. Cows were randomly assigned to the groups at calving. Beginning with wk 17 of lactation, cows were changed to diets that were fed for the remainder of lactation, which was projected to be wk 44. Cows that were on the diet with 15.4% CP during the first 16 wk were kept on a low protein diet (16.0% CP).

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[1]Trade names and the names of commercial companies are used in this report to provide specific information. Mention of a trade name or manufacturer does not constitute a guarantee or warranty of the product by the USDA or an endorsement over products not mentioned.

Table 1. Ingredients and chemical analysis of diets varying in CP content during lactation wk 1 to 16 and 17 to 44.

	Wk 1 to 16			Wk 17 to 44	
Item	15.4% CP	17.4% CP	19.3% CP	16.0% CP	17.9% CP
	(% of DM)				
Alfalfa silage	33.0	33.0	33.0	33.0	33.0
Corn silage	22.0	22.0	22.0	22.0	22.0
HMEC[1], finely ground	32.0	27.0	22.0	32.6	27.6
Soybeans, roasted	10.0	10.0	10.0	10.0	10.0
Soybean meal, expeller processed[2]	. . .	5.0	10.0	. . .	5.0
Calcium carbonate	1.0	1.0	1.0	1.1	1.1
Dicalcium phosphate	0.7	0.7	0.7	. . .	. . .
Sodium bicarbonate	0.6	0.6	0.6	0.6	0.6
Magnesium oxide	0.2	0.2	0.2	0.2	0.2
Salt	0.4	0.4	0.4	0.4	0.4
Mineral and vitamin mix[3]	0.1	0.1	0.1	0.1	0.1
Chemical analyses					
CP	15.4	17.4	19.3	16.0	17.9
RUP, % of CP[4]	33.5	35.8	37.6	33.5	35.8
RUP, % of DM[4]	5.2	6.2	7.3	5.4	6.4
RDP, % of DM[4]	10.2	11.2	12.0	10.6	11.5
NDF	29.3	29.6	30.0	29.0	29.4
ADF	20.1	20.3	20.5	20.0	20.2
NE_L, Mcal/kg[4]	1.64	1.64	1.65	1.61	1.61

[1]High moisture ear corn.

[2]Soyplus (West Central Cooperative, Ralston, IA).

[3]Contained 0.32 mg of Se/g, 0.43 mg of Co/g, 1.03 mg of I/g, 13.35 mg of Cu/g, 23.99 mg of Fe/g, 51.00 mg of Mn/g, 62.01 mg of Zn/g, 7,000,000 IU of vitamin A/kg, 2,222,000 IU of vitamin D/kg, and 17,630 IU of vitamin E/kg.

[4]Estimates based on feedstuff values (10).

Fourteen of the 29 cows fed the 17.4% CP diet in early lactation were kept at a similar level of protein (17.9% CP), while the remaining 15 cows in that group were fed the 16.0% CP diet. Cows receiving the 19.3% CP diet in early lactation were switched to the 17.9% CP diet at wk 17. Thus, the following four treatments were formed over the entire lactation with these dietary CP percentages: 15.4→16.0, 17.4→16.0, 17.4→17.9, and 19.3→17.9%; the change in dietary protein occurred at the beginning of wk 17. We decided at the beginning of the experiment that the diet formulations would not be altered during the trial to accommodate small changes in protein content of diet ingredients. Higher than anticipated protein content of alfalfa silage fed in the last 28 wk of lactation resulted in small increases in total dietary protein for this phase of lactation.

Diets (Table 1) were formulated to enhance protein supply to the intestine. The two protein supplements used, roasted full-fat soybeans with a protein dispersibility index of 9 to 11 (8) and expeller processed soybean meal (Soyplus; West Central Cooperative, Ralston, IA), contained approximately 50% of the protein as RUP. Dietary protein content was increased by replacing high moisture ear corn with expeller soybean meal. This substitution would increase about equally the RDP and RUP content of the diet, but would slightly alter the AA content of the protein reaching the intestine. The RDP content of the lowest protein treatment was more than adequate to meet rumen microbial needs, based on NRC recommendations (10). The other protein treatments would provide RDP in further excess of need. High moisture ear corn was ground through a roller mill upon removal from the silo, reducing the geometric mean diameter (6) from 4.5 to 2.3 mm. Fine grinding of corn increases the amount of starch degraded in the rumen and increases the amount of microbial protein synthesized (4, 7).

Cows were housed in a tie stall barn and fed a TMR once daily ad libitum (5 to 10% refusal). Actual amounts of feed offered and refused by individual cows were recorded daily to obtain net intake. Milking was at 0500 and 1700 h, and milk yields were recorded each time. Milk samples were collected biweekly from two consecutive milkings and analyzed at the AgSource Milk Analysis Laboratory, Menomonie, Wisconsin, for fat, protein, lactose, total solids, and SCC, using an infrared spectrophotometer with a B filter (Fossomatic 605; Foss Technology, Eden Prairie, MN); SNF was calculated as total solids minus fat. Cows were weighed after milking early in lactation (averaging 15 DIM) and every 4 wk thereafter. A final weight was obtained at the end of lactation. All cows were administered bST (Posilac; Monsanto Co., St. Louis, MO) every 2 wk starting at wk 9 of lactation.

Alfalfa silage, corn silage, and orts were sampled daily and kept frozen to generate weekly composites. High moisture ear corn, roasted soybeans, and soybean meal were sampled weekly. All weekly feed samples were analyzed for DM by oven-drying at 60°C for 48 h. Diet formulations (as-fed basis) were adjusted weekly for changes in DM content of the ingredients. Orts were used only for DMI calculations. The weekly samples of diet ingredients, following drying, were ground through a Wiley mill with a 1-mm screen (Arthur H. Thomas, Philadelphia, PA). Ground samples were analyzed for DM (105°C), CP (Carlo Erba, NA 1500 N analyzer; Fisons Instruments, Inc., Beverly, MA), and NDF (heat stable α-amylase and Na_2SO_3 were used) and ADF (11). The NDF and ADF content of soybeans and soybean meal was measured on only one composite sample from wk 1 to 16 and again from wk 17 to 44. All chemical analyses were expressed on a DM basis (105°C DM). Dietary nutrient content was computed from average analyses of the ingredients over the experimental periods; however, NE_L and RUP were calculated with values for ingredients from NRC (10).

Cows were dried off or removed from the experiment following completion of 44 wk of lactation. As a normal herd management practice, cows were also dried off when their milk yield dropped below 9 kg/d, or were culled when they developed health problems. As a result, 14 cows were removed from the experiment during wk 31 to 44 of lactation (Table 2). To obtain 308-d lactation information for cows terminated early, milk yields from the five preceding weekly measures were used to extrapolate by linear regression to obtain estimates for the missing weeks. Treatment averages for milk fat and milk protein content, along with the extrapolated milk yield, were used to obtain estimates for 3.5% FCM and milk protein yield for the missing weeks. We acknowledge that some error is introduced by doing this, but it is small in comparison to the full lactation value. The error would be larger for the production values for wk 17 to 44. Data were analyzed separately for lactation wk 1 to 16, 17 to 44, and 1 to 44 using a completely randomized design with the general linear models procedure of SAS (14) according to the following model:

$$Y = \mu + T + E$$

where Y = observation, μ = overall mean, T = dietary treatment, and E = residual error. A pooled SEM, using harmonic mean cell size, is presented for simplicity, despite differences in numbers of observations between treatments. This action was justified because of the large number of observations, and the SEM differed only slightly among treatments. Nonorthogonal mean comparisons were generated in the statistical analysis by requesting PDIFF (probability for difference) along with least squares means.

RESULTS AND DISCUSSIONS

Alfalfa silage and corn silage batches changed two to three times during the experiment, resulting in some variation in nutrient analyses as the experiment progressed (Table 3). Overall, the CP content of the diets increased slightly as the experiment proceeded due to small increases in CP content of alfalfa silage, corn silage, and high moisture ear corn; alfalfa silage had the greatest impact. The CP content of alfalfa silage averaged 21.5% (SD 2.1) for wk 1 to 16, and 22.6% (SD 1.6) for wk 17 to 44 of lactation. The increase in protein content of alfalfa silage as the experiment progressed caused total dietary CP for wk 17 to 44 to be about 0.5 percentage units higher than for wk 1 to 16. Because the protein in alfalfa silage is highly degradable in the rumen (approximately 80%), the actual deviation in intestinally absorbed protein from the targeted amount was small. Content of NDF and ADF in diet ingredients remained relatively constant throughout the experiment.

Table 2. Number of cows that left the trial before completing 44 wk of lactation.

	Week of lactation											
Treatment[1]	30	31	34	36	37	39	40	41	42	43	44	Total
15.4-16.0	1(h)[2]	1(m)		1(h)				1(d)				4
17.4-16.0							1(h)			1(d)	1(d)	3
17.4-17.9	1(h)		1(m)			1(h)			1(d)		1(d)	5
19.3-17.9					1(h)					1(d)		2

[1]Treatments varying in dietary CP content: 15.4% during lactation wk 1 to 16 and 16.0% during wk 17 to 44, 17.4% during wk 1 to 16 and 16.0% during wk 17 to 44, 17.4% during wk 1 to 16 and 17.9% during wk 17 to 44, and 19.3% during wk 1 to 16 and 17.9% during wk 17 to 44.

[2]Reasons for termination: h = health problems; m = milk yield < 9 kg/d; d = dried off to allow for a 55-d dry period.

Table 3. Analyses of dietary ingredients fed during wk 1 to 16 and wk 17 to 44 of lactation.

	Wk 1 to 16				Wk 17 to 44			
Ingredient	DM	CP	NDF	ADF	DM	CP	NDF	ADF
	(%)							
Alfalfa silage								
$\overline{X}$	34.3	21.5	42.7	37.8	35.7	22.6	42.3	37.3
SD	6.0	2.1	4.0	3.9	6.8	1.6	3.6	3.4
Corn silage								
$\overline{X}$	37.7	7.2	40.6	24.5	37.3	7.6	40.7	25.6
SD	2.3	0.4	2.2	1.8	8.7	0.6	3.1	2.2
HMEC[1], finely ground								
$\overline{X}$	70.2	8.2	12.7	4.7	70.2	8.6	10.3	3.6
SD	1.3	0.2	2.4	1.1	1.7	0.6	2.7	1.4
Soybeans, roasted								
$\overline{X}$	97.6	40.9	24.9	8.2	96.7	41.7	25.0	8.3
SD	0.9	1.0	. . .	. . .	0.8	1.2	. . .	. . .
Soybean meal[2]								
$\overline{X}$	90.6	47.2	19.3	8.3	90.4	46.8	19.2	8.3
SD	0.5	0.7	. . .	. . .	0.6	1.0	. . .	. . .

[1]High moisture ear corn.

[2]Soyplus (West Central Cooperative, Ralston, IA).

Reproductive measures were associated with large variation, and none of the measures differed ($P > 0.10$) among treatments (Table 4). Overall, reproductive efficiency was low. More cows were identified for culling because of failure to become pregnant by 230 DIM for the 15.4-16.0 and 17.4-17.9% CP treatments than for the 17.4-16.0 and 19.3-17.9% CP treatments. Although the number of cows used in this experiment was too small to support firm conclusions regarding reproductive performance, the results would support those of Barton et al. (1) who concluded that high concentrations of dietary protein need not be detrimental to reproductive performance.

Health problems were within reasonable limits, except for mastitis. The frequency of mastitis infections was high. No treatment effects on the incidence of health problems were evident.

Milk yield for the 308-d lactation for the 17.4-16.0% CP treatment (10,832 kg) was 776 kg higher ($P < 0.12$) than that for the 15.4-16.0% CP treatment (10,056 kg), and similar ($P = 0.55$) to the yields of 11,095 kg and 11,132 kg for the 17.4-17.9 and 19.3-17.9% CP treat-

Table 4. Reproductive measures and health records of lactating cows fed diets varying in protein content.

	Treatment[1]					
Item	15.4-16.0 (n = 15)	17.5-16.0 (n = 15)	17.4-17.9 (n = 14)	19.3-17.9 (n = 14)	SEM	*P*
Days to first estrus	65.5	70.3	85.3	90.4	11.0	0.34
Days to first AI	82.2	84.1	92.4	96.9	9.5	0.66
Days open[2]	126.2	148.4	133.0	157.5	16.7	0.55
Conception rate at first AI, %	26.7	26.7	50.0	21.4	. . .	. . .
Pregnancy rate						
Before 120 DIM, %	40.0	26.7	35.7	21.4	. . .	. . .
Before 230 DIM, %	66.7	93.3	78.6	92.9	. . .	. . .
Services per conception	2.7	3.1	2.4	2.8	0.5	0.77
Abortions	2	2	2	0	. . .	. . .
Cases of foot rot	1	0	3	2	. . .	. . .
Incidence of off feed	1	5	9	6	. . .	. . .
Incidence of mastitis[3]	17	20	17	20	. . .	. . .

[1]Treatments varying in dietary CP content: 15.4% during lactation wk 1 to 16 and 16.0% during wk 17 to 44, 17.4% during wk 1 to 16 and 16.0% during wk 17 to 44, 17.4% during wk 1 to 16 and 17.9% during wk 17 to 44, and 19.3% during wk 1 to 16 and 17.9% during wk 17 to 44.

[2]Includes only cows that became pregnant before 230 DIM.

[3]Each separate infection was counted as a new case.

Table 5. Milk yield, intake N, milk N, and manure N of cows fed diets varying in CP content during 308-d lactation.

Item	Treatment[1] 15.4-16.0 (n = 15)	17.4-16.0 (n = 15)	17.4-17.9 (n = 14)	19.3-17.9 (n = 14)	SEM	P* a > b	b > c	a > c
	(kg)							
Milk yield	10,056[c]	10,832[b]	11,095[a]	11,132[a]	349	. . .	0.12	0.04
3.5% FCM	10,690[b]	11,628[a]	11,804[a]	11,559[a]	368	0.10	. . .	. . .
Intake N	177.8[c]	189.1[b]	213.7[a]	214.2[a]	4.0	0.01	0.05	0.01
Milk N	51.2	48.9[b]	51.5	53.0[a]	1.6	0.08	. . .	. . .
Manure N[2]	126.6[c]	140.2[b]	162.2[a]	161.2[a]	3.8	0.01	0.01	0.01

*a,b,c Values without superscripts do not differ (P > 0.15) from other values within a row.

[1]Treatments varying in dietary CP content: 15.4% during lactation wk 1 to 16 and 16.0% during wk 17 to 44 (15.4-16.0), 17.4% during wk 1 to 16 and 16.0% during wk 17 to 44 (17.4-16.0), 17.4% during wk 1 to 16 and 17.9% during wk 17 to 44 (17.4-17.9), and 19.3% during wk 1 to 16 and 17.9% during wk 17 to 44 (19.3-17.9).

[2]Calculated from intake N – milk N, assuming no net deposition or mobilization of tissue N.

ments (Table 5). Overall, milk yield averaged 11,019 kg for the 308-d lactation for the three highest protein groups. The yield of 3.5% FCM for the 17.4-16.0% CP treatment (11,628 kg) was 938 kg higher (P < 0.10) than the yield for the 15.4-16.0% CP treatment, but similar to the yields for the 17.4-17.9 and 19.3-17.9% CP groups.

Means for N intake over the entire lactation (Table 5) reflected the formulated CP concentrations for the treatments, except that the intake for the 19.3-17.9% CP treatment was not higher than for the 17.4-17.9% CP treatment because cows consumed slightly more feed for the 17.4-17.9% CP group (Figure 1). The amount of excreted N, estimated from intake N minus milk N (assuming no net change in tissue N), largely reflected N intake. The efficiencies for converting feed N to milk N, ranging from the lowest to the highest dietary protein treatments, were 28.8, 25.9, 24.0, and 24.7%. The lowest protein treatment resulted in the highest efficiency for converting dietary N to milk N, but this treatment was clearly deficient in protein. The deficiency was likely in RUP, based on NRC recommendations (10). It will be difficult to convert more than 30% of feed N to milk N over a total lactation by feeding less protein and still maintain acceptable milk production. For example, had another protein treatment (15.4-13.4% CP) been included, and assuming milk production and feed consumption equal to those for the 15.4-16.0% CP treatment reported in Tables 5 and 6, then efficiency of converting feed N to milk N would have been approximately 31%. At most, only modest improvements in converting feed N to milk N can be anticipated when soy proteins are the source of supplemented protein (AA).

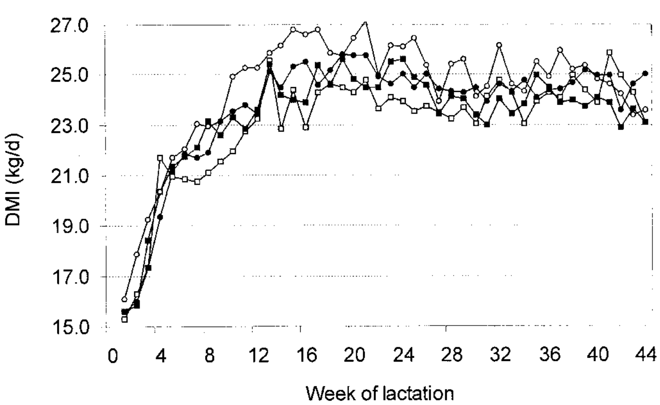

Figure 1. The DMI of cows fed diets containing different concentrations of CP: 15.4% during lactation wk 1 to 16 and 16% during wk 17 to 44 (□), 17.4% during wk 1 to 16 and 16% during wk 17 to 44 (■), 17.4% during wk 1 to 16 and 17.9% during wk 17 to 44 (○), and 19.3% during wk 1 to 16 and 17.9% during wk 17 to 44 (●).

Means for DMI did not differ (P > 0.05) among dietary protein concentrations for wk 1 to 16 of lactation, but tended (P < 0.1) to be higher for the 17.4-17.9 group than for the 15.4-16.0 and 17.4-16.0 groups for wk 17 to 44 of lactation (Table 6). Dry matter intake for the lowest protein group was often less than for the other treatments for the first 30 wk of lactation (Figure 1).

Daily milk yield for the lowest dietary protein group was approximately 3 kg lower than for the other treatments during the first 16 wk of lactation and averaged about 2.5 kg less for the last 28 wk. The next to lowest protein group (17.4-16.0% CP) had the same dietary protein content as the lowest protein group (15.4-16.0% CP) during the latter part of lactation but tended to produce more milk (32.4 vs. 30.1 kg/d). It appears that the difference in milk production established in early lactation between the two treatments was carried through in large part for the last part of lactation.

Mean daily milk yield during wk 1 to 16 was 1.3 kg higher for cows fed 19.3% CP than for cows fed 17.4%

Table 6. Lactation performance of cows fed diets varying in CP content.

Item	Dietary CP for lactation wk 1 to 16					Dietary CP for lactation wk 17 to 44					
	15.4 (n = 15)	17.4 (n = 29)	19.3 (n = 14)	SEM	P* (a > b)	15.4-16.0 (n = 15)	17.4-16.0 (n = 15)	17.4-17.9 (n = 14)	19.3-17.9 (n = 14)	SEM	P* (a > b)
DMI, kg/d	21.2	22.3	21.8	0.6	. . .	24.0[b]	24.2[b]	25.4[a]	24.7	0.5	0.08
Milk, kg/d	36.9[b]	39.5[a]	40.8[a]	1.0	0.05	30.1[b]	32.9	33.8[a]	33.5[a]	1.4	0.09
3.5% FCM, kg/d	39.8[b]	43.2[a]	44.3[a]	1.0	0.02	31.8[b]	34.7	35.5[a]	33.7	1.5	0.09
Milk fat											
%	3.97	4.05	3.94	0.12	. . .	4.06[a]	3.96	3.98	3.72[b]	0.14	0.08
kg/d	1.461[b]	1.601[a]	1.626[a]	0.047	0.03	1.182	1.274	1.297	1.203	0.061	. . .
Milk protein											
%	2.92[a]	2.84[b]	2.86	0.04	0.07	3.36[a]	3.19[b]	3.12[b]	3.23[b]	0.06	0.10
kg/d	1.086[b]	1.128	1.179[a]	0.027	0.03	0.972	1.028	1.024	1.050	0.042	. . .
Milk lactose, %	4.85	4.85	4.87	0.04	. . .	4.73	4.77	4.78	4.74	0.04	. . .
Milk SNF, %	8.51	8.43	8.45	0.06	. . .	8.84	8.69	8.70	8.76	0.07	. . .
Milk SCC, 10^3/ml	689	509	587	172	. . .	720	528	431	587	136	. . .
BW during lactation											
Beginning[1], kg	628	612	638	15	. . .	623	610	632	631	10	. . .
End, kg	623	621	631	11	. . .	696	680	688	703	15	. . .
Change, g/d	–15	95	35	111	. . .	415	370	312	381	68	. . .

*[a,b]Values without superscripts do not differ ($P > 0.15$) from other values within a row and within a lactation period.

[1]Beginning weights were obtained at an average of 15 DIM.

CP, but the difference was not significant ($P > 0.05$) (Table 6). A possible difference in milk production between these two treatments may have occurred between wk 7 to 16 of lactation (Figure 2). It does appear that the high protein group achieved greater peak production. Conceivably, body protein reserves were depleted by wk 7, and at this point cows fed the high protein diet could continue increasing milk production to achieve higher peak production. According to Komaragiri and Erdman (9), tissue protein depletion occurs primarily in the first 5 wk of lactation. In their study, cows fed a diet with 20.9% CP peaked slightly higher, and then sustained milk production at a higher level than cows fed a diet with 17.3% CP. The difference between their groups averaged 2.6 kg/d of milk over the first 16 wk of lactation, with all the increase occurring during wk 7 to 16. In fact, milk yield was lower for the higher protein group during the first 6 wk of lactation. Cunningham et al. (3) showed a beneficial effect on milk yield during early lactation when dietary CP was increased from 16.4 to 18.4% by substituting processed soybean meal with low-degradable protein for high moisture corn. Milk yield was 2.8 kg/d higher for the high protein group during the 12-wk experiment.

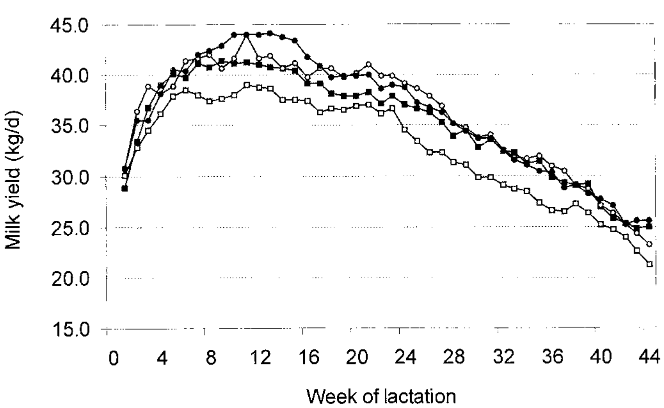

Figure 2. Lactation curves of cows fed diets containing different concentrations of CP: 15.4% during lactation wk 1 to 16 and 16% during wk 17 to 44 (□), 17.4% during wk 1 to 16 and 16% during wk 17 to 44 (■), 17.4% during wk 1 to 16 and 17.9% during wk 17 to 44 (○), and 19.3% during wk 1 to 16 and 17.9% during wk 17 to 44 (●).

Milk yield decreased dramatically between wk 16 and 18 for the 19.3-17.9% CP group (Figure 2). Some of this drop in production occurred before the decrease in dietary protein from 19.3 to 17.9% at wk 17, raising the question of how much, if any, of the reduction in milk yield between wk 16 and 18 was due to the change in dietary protein. Milk yield for the two highest protein groups was nearly identical for the last 28 wk of lactation. This is different from the two lowest protein groups, suggesting that the highest protein (19.3%) did not impact the latter part of lactation despite its possible effect at peak lactation.

When dietary CP was decreased at wk 17 for the 15 cows in the 17.4-16.0% CP group, milk yield decreased relative to the group of 14 cows in the 17.4-17.9% CP treatment, and remained lower until wk 30 of lactation. The two groups of cows had similar production prior to being divided into the 16.0 and 17.9% CP groups for the latter part of lactation. The divergence in milk production at wk 17 for the two groups (Figure 2) suggests that 16.0% CP was not providing sufficient protein for cows producing about 40 kg/d of milk at wk 17 of lactation. It was not until milk yield had decreased to about 34 kg/d at wk 29 that milk yield of these two groups became similar.

Milk fat content did not differ among treatments during wk 1 to 16 of lactation, but was higher ($P = 0.08$) during wk 17 to 44 for the 15.4-16.0% CP treatment than for the 19.3-17.9% CP treatment, possibly reflecting the difference in milk yield (Table 6). Differences in milk fat yield and 3.5% FCM yield basically reflected total milk yield. Milk protein percentage was higher ($P = 0.07$) for the 15.4% CP diet than for the 17.4% CP diet in wk 1 to 16. During wk 17 to 44 the low protein group again had a slightly higher milk protein percentage ($P = 0.10$) than did the other three groups. Lower milk protein percentages for the higher protein diets might have resulted from the substitution of soybean meal for high moisture ear corn, which would result in an increased proportion of intestinal protein as soy protein and a decreased proportion as microbial protein. Because soy protein is lower in methionine than microbial protein, these changes could lead to lower methionine content of intestinal protein and lower milk protein content. Wu et al. (17) concluded that diets with soybean meal as the protein supplement are limiting in methionine. Despite this effect, yield of milk protein was higher ($P < 0.05$) for the 19.3% CP treatment than for the 15.4% treatment during wk 1 to 16. Content of lactose, SNF, and SCC did not differ ($P > 0.10$) among treatments in either period. Overall, milk SCC was high, resulting from a few mastitic cows with high counts. The beginning and ending BW did not differ among treatments in either period, and the large variation in BW change made the treatment means of less value.

Based on the results shown in Table 5, it appears that milk production for the total lactation is essentially similar for the two highest protein treatments (19.3-17.9 and 17.4-17.9% CP), suggesting no benefit from feeding more than 17.4% CP in early lactation. Figure 2, on the other hand, suggests that feeding 19.3% CP was beneficial during wk 7 to 16. The surprising reduction in milk yield during wk 16 to 18 for the high protein group confounds the interpretation, and makes one wonder whether milk yield would have remained elevated had the high CP been continuously fed. How much of the milk production decrease during wk 16 to 18 was related to the decrease in dietary protein from 19.3 to 17.9% is not known. Was the decrease in milk production merely a consequence of the ration change? Is it possible that catabolism of excess protein was sufficiently large and slow to change in the cows fed 19.3% CP that a sudden shift to 17.9% CP could cause a temporary deficiency of protein resulting in reduced milk production? This seems most unlikely, in that metabolic shifts to facilitate homeostasis in the face of dietary changes normally occur quickly. On the other hand, ruminants have been well buffered against dietary protein changes during their evolutionary development and may not be as nimble as other animal species in adapting to a reduction in the amount of protein absorbed from the gut.

Three other studies conducted under circumstances similar to this study, but only during early lactation, have been reported (2, 3, 9). In all cases, relatively high producing Holstein cows were used, and corn silage, alfalfa, or both provided the forage. Corn was the major grain source, and protein supplements high in RUP were used to raise dietary protein from an average of 16.7% to an average of 19.6% CP. Two (3, 9) of the three studies reported nonsignificant increases in milk production, while the third study noted a very small, nonsignificant decline in milk production as dietary protein was increased. Taking all four studies into consideration, we conclude that an increase in peak production from feeding more than 17.5% CP is possible, but the increase from feeding more than 17.5% CP in early lactation to high producing cows fed corn silage, alfalfa, corn grain, and protein supplements having relatively high RUP values will be marginally profitable at best. In the worst-case scenario, feeding diets with more than 17.5% in early lactation (assuming diets are similar to what has been herein described) will simply add cost and unwanted amounts of nitrogen to urine and manure.

Diets similar to the 15.4-16.0 and 17.4-16.0% CP treatments were supplemented with ruminally protected methionine in two separate experiments (16). The relatively high lysine content of heat processed soy protein positioned methionine as the first limiting AA for milk production (15). Supplementing cows on this diet with protected methionine during early to mid lactation had mixed effect, which suggests that fine tuning these diets with protected methionine might have a marginal benefit in increasing secretion of milk protein and could facilitate a slight reduction in dietary protein.

The requirement for protein is especially high in early lactation because feed intake lags behind milk production, resulting in significant tissue mobilization to support milk production. Because the mobilized nutrients consist of a disproportionate amount of calories relative to protein, the diet should contain proportionally more protein to balance the mobilized tissue. Increasing dietary CP from 17.4 to 19.3% failed to enhance milk yield during wk 1 to approximately wk 7 postpartum in this study, but appeared to increase milk production from wk 7 to wk 16. The use of bST has had the effect

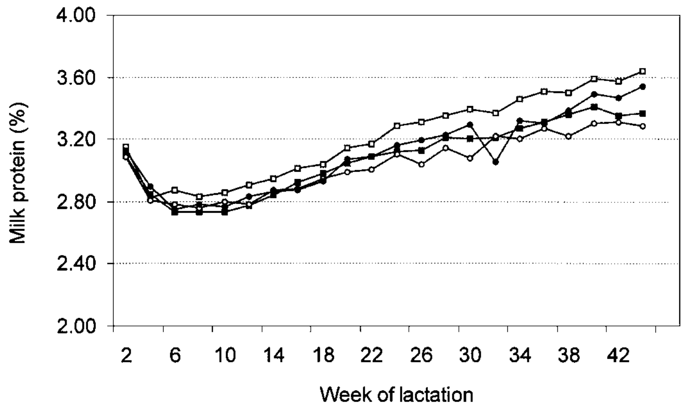

Figure 3. Milk protein content throughout lactation as influenced by dietary protein: 15.4% during lactation wk 1 to 16 and 16% during wk 17 to 44 (□), 17.4% during wk 1 to 16 and 16% during wk 17 to 44 (■), 17.4% during wk 1 to 16 and 17.9% during wk 17 to 44 (○), and 19.3% during wk 1 to 16 and 17.9% during wk 17 to 44 (●).

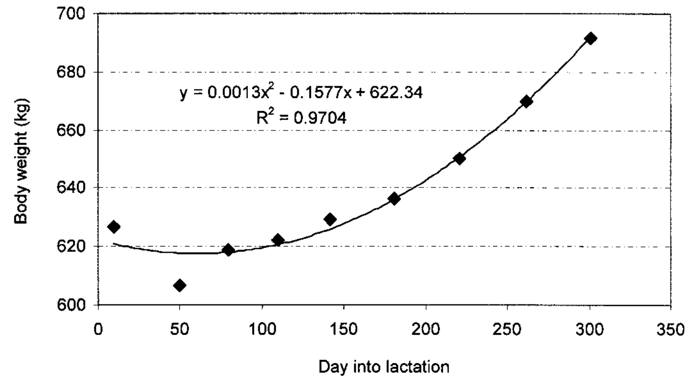

Figure 5. Average BW of cows from all treatments throughout lactation.

of extending the period of peak milk production, thus strengthening the demand for protein over a prolonged period. The high milk yield of cows fed 19.3% CP during wk 7 to 16 might be a reflection of this demand. Also, the lag in feed intake in early lactation is extended further with administration of bST. When Figure 1 is compared with the DMI curve described in Figure 2-1 in NRC (1989) (10), it is apparent that bST not only delays peak feed intake but also causes intake to be remarkably constant for the remainder of the lactation.

Using milk protein content (Figure 3) and the corresponding daily milk yield averaged biweekly, we calculated a milk protein secretion curve (Figure 4). The curve is nearly flat during the first 30 wk of lactation. Assuming that cows of the size used in this experiment can mobilize 15 kg of protein from body tissue in early lactation (first 5 to 6 wk) (9), and further that this 15 kg of protein is replenished in a linear fashion during wk 10 to 44 of lactation (Figure 5), an average deposition of 63 g of protein daily during this time period will result. Adding to that a small allowance of protein for deposit in fetal tissue and membranes [estimated as approximately 10 g daily at wk 30 and increasing to approximately 45 g daily at wk 44, assuming cows became pregnant at 100 DIM (10)], we found that the protein sink (secreted and deposited protein) remained remarkably constant over the first 30 wk of lactation, and decreased only slightly in the last 14 wk of lactation. Feed intake from wk 12 to 44 was also fairly constant (Figure 1); thus there is relatively little opportunity to decrease dietary protein until approximately wk 30, and then only slightly. The lactation curves of high producing cows receiving bST are much flatter and more persistent than the lactation curves of cows with lower genetic potential and without the benefit of bST.

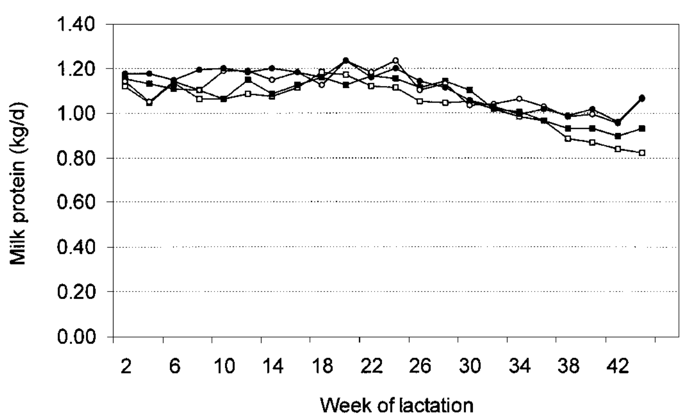

Figure 4. Secretion of milk protein throughout lactation as influenced by dietary protein: 15.4% during lactation wk 1 to 16 and 16% during wk 17 to 44 (□), 17.4% during wk 1 to 16 and 16% during wk 17 to 44 (■), 17.4% during wk 1 to 16 and 17.9% during wk 17 to 44 (○), and 19.3% during wk 1 to 16 and 17.9% during wk 17 to 44 (●).

Based on the lactation yield (Table 5), one has to conclude that the second highest protein treatment (17.4-17.9) was adequate and would allow higher net profit than feeding the highest protein treatment (19.3-17.9). On the other hand, considering the apparent higher peak production and the unusual decrease in milk production of the highest protein group (19.3-17.9) around wk 16, one might argue that a protein level >17.4% may be needed beginning at wk 7 until perhaps wk 30. Figure 6 is a constructed composite lactation curve that attempts to reflect the highest milk yields obtained from the top treatments during the segments of lactation while using the least amount of dietary protein needed to support maximum production. Compared with the lactation curve considered typical 10 yr ago [Figure 2-1 in (10)], modern cows receiving bST have a broader peak lactation and a more sustained

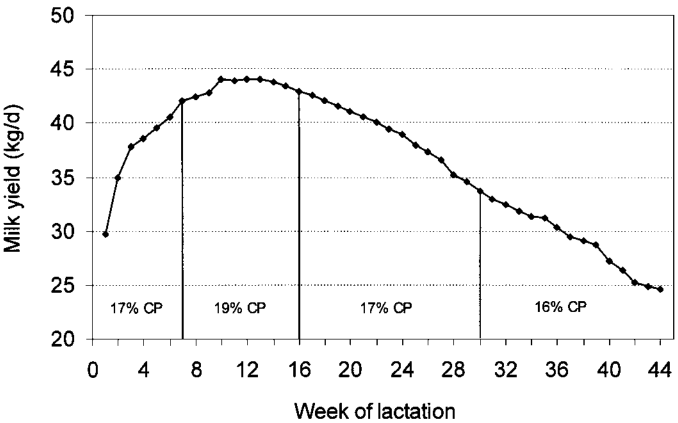

Figure 6. Lactation curve attained with treatments of different dietary protein amounts that resulted in the highest milk yields during different stages of lactation compared to Figure 2-1 in NRC (10).

lactation. The synthesized lactation in Figure 6 will result in 11,200 kg of milk. Although it may not be practical to consider as many changes in dietary protein during the lactation as illustrated in Figure 6, cows may not benefit from very high concentrations of dietary protein in the first 6 to 8 wk of lactation. Interestingly, Eastridge et al. (5) summarized the recommendations of four ration formulation programs, and all four programs called for the highest concentration of dietary protein, expressed as percentage of ration DM at d 60 of lactation. The dietary CP recommended by the programs at d 60 ranged from 18.1 to 20.0% for cows producing 54.5 kg of milk daily, about 23% higher than for the cows used in our study.

The relationship between feed intake and the relatively constant amount of protein that is deposited in milk and in fetal and uterine tissue throughout lactation supports the interest in a single diet formulation for the entire lactation. This of course assumes that mobilization of tissue protein in early lactation will cover most or all of the shortfall in dietary protein in the first weeks of lactation, and modest waste of excess protein in the last part of lactation is tolerable. While some uncertainty remains about what concentration of dietary protein maximizes profitability in early lactation with the diet ingredients used in this study, a single formulation for the entire lactation with cows of high genetic potential and receiving bST may not waste as much protein as once thought.

CONCLUSIONS

Nutrient management issues and costs associated with excessive protein supplementation point to the need to more closely match animal requirements with dietary allowance of protein. This study with high producing dairy cows essentially supports NRC (10) recommendations, except that this study illustrates that constant and sustained protein is required throughout lactation in high producing cows. Also, a special high protein concentration may not be helpful during the first 8 wk of lactation. We suggest that early lactation diets for high producing cows (~11,000 kg/308 d) contain a minimum of 17.5% CP, 35 to 37% of which is RUP. Dietary protein in later lactation as milk production declines should be reduced cautiously. For cows receiving bST and producing approximately 11,000 kg/lactation, this reduction should not occur before midlactation, and then not be reduced to below approximately 16% CP. This recommendation assumes that the supplemental protein offered throughout lactation will have approximately 50% RUP.

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