Effects of Dietary Crude Protein Concentration and Degradability on Milk Production Responses of Early, Mid, and Late Lactation Dairy Cows

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ABSTRACT

Three experiments were conducted to investigate the effect of crude protein (CP) concentration and ruminally undegraded protein (RUP) concentration on milk production and composition of dairy cows at three different stages of lactation. Experiments 1, 2, and 3 using 39, 40, and 39 Holstein cows were conducted for cows in early (wk 4 to 14 postpartum), mid (wk 19 to 29), and late (wk 34 to 44) lactation, respectively. Cows were assigned to one of four corn-based diets: high CP, medium RUP (control); low CP, low RUP; low CP, medium RUP; and low CP, high RUP. Percentages of CP in the high and low CP diets were, respectively, 17.4 and 15.2 for Experiment 1, 15.3 and 13.3 for Experiment 2, and 14.2 and 12.6 for Experiment 3. The RUP concentrations (percentages of CP) for low, medium, and high diets averaged 35.5, 41.4, and 46.5%, respectively. For Experiment 1, production of milk, 4% fat-corrected milk, milk fat, and milk protein was increased by the high protein diets versus the low protein diets. Production of milk and fat-corrected milk increased linearly as RUP in the diet increased. During Experiment 2, lactational responses were not affected by treatment. During Experiment 3, dry matter intake, body weight, and body weight change increased for cows fed the high protein diets versus those same measurements for cows fed the low protein diets. Milk fat and milk protein percentage decreased linearly as RUP in the diet increased. Because there was no effect of diet on milk production, decreasing CP in diets fed to cows in mid or late lactation can reduce the cost of the diet and waste N excreted from the cow.

(**Key words**: dairy cows, crude protein, protein degradability, ruminally undegraded protein)

Abbreviation key: **HRUP** = high RUP, **IP** = intake protein, **LRUP** = low RUP, **MP** = metabolizable protein, **MRUP** = medium RUP.

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INTRODUCTION

Excess CP in the diets of dairy cows contributes to growing environmental concerns related to N pollution of water resources (22). In addition, excess dietary CP can be costly, resulting in unnecessary feeding expenses. Diets with lower concentrations of CP but with properly balanced ruminally degradable CP may have both an economical and environmental impact. The first goal in formulating diets of lactating dairy cows for protein requirements is to meet the requirements of the microbes in the rumen. The second goal is to balance the metabolizable protein (**MP**) requirement of the cow. The MP requirement is defined as the sum of the microbial CP that flows to the small intestine and the dietary protein that escapes from the rumen undegraded and is subsequently absorbed in the small intestine. An additional goal, such as not exceeding the CP requirement of the cows so that N excretion is reduced, may need to be considered.

Research has shown improved milk production when CP is increased in the diets of lactating dairy cows (8, 14, 15, 24). Overall, milk production increased when dietary CP concentration was increased from 9 to 14% (DM basis); however, further increases in dietary CP concentrations often result in diminishing returns (7). Cows in early lactation fed diets with increasing percentages of RUP have been shown to increase milk production in some studies (5, 9, 14, 16), but not in others (6, 10, 11). Increased amounts of RUP in the diets of cows in mid (2, 20) or late lactation (19) did not result in higher milk production. This result could be explained because cows in early lactation have a greater demand for MP to meet the demands of high milk production, but, in later lactation, these demands decline. After peak milk production, the requirement for MP can be met while feeding lower CP concentration diets by maximizing DMI. However, in early lactation, meeting the MP requirements of the cow is limited by DMI, therefore requiring diets formulated with greater CP or RUP concentrations.

The objective of the present experiments was to determine the response of lactating dairy cows at different stages of lactation to diets with different CP concentrations and degradabilities. Diets were formulated to provide CP at two concentrations, and the ruminal protein degradability of the low CP diets was set at three concentrations.

MATERIALS AND METHODS

Cows, Treatments, and Management

Three completely randomized experiments were conducted using 52 multiparous Holstein cows. Experiments 1, 2, and 3 were conducted for cows in early (wk 4 to 14; 39 cows), mid (wk 19 to 29; 40 cows), and late (wk 34 to 44; 39 cows) lactation, respectively. Twenty-eight cows used in Experiment 1 were also used in Experiment 2, and 38 cows used in Experiment 2 were included in Experiment 3. The three experiments were conducted concurrently, and cows were selected based on their stage of lactation. Cows were assigned to one of four diets: high CP, medium RUP (control); low CP, low RUP (**LRUP**); low CP, medium RUP (**MRUP**); and low CP, high RUP (**HRUP**). Cows were fed the control diet during the 3- or 4-wk pretreatment periods (wk 1 to 3, 15 to 18, and 30 to 33). Ingredient and nutrient compositions of the diets for the early, mid, and late lactation experiments are shown in Tables 1, 2, and 3, respectively. Estimates of protein degradability of the feed ingredients were obtained in an in situ trial prior to the experiments, and these estimates were used to formulate CP degradabilities of the diets as described by Erdman et al. (12). Dietary protein concentrations and degradabilities were adjusted for each experiment by decreasing the amount of concentrate in the diet (DM basis) from 55% for the early lactation experiment (Table 1) to 45% for the midlactation experiment (Table 2) and to 35% for the late lactation experiment (Table 3). Corn silage was increased accordingly.

In all experiments, cows were housed in comfort stalls; rubber mats and wood shavings were used as bedding materials. Cows were turned out to the exercise lot from 0900 to 1300 h. Cows were milked twice daily at 0400 and 1600 h.

Measurements, Sampling, and Laboratory Analysis

Milk production was recorded at each milking. Morning and evening milkings were sampled twice weekly. Milk samples were composited daily and preserved using potassium dichromate until analyzed for fat and protein content by Environmental Systems Services (College Park, MD) using infrared procedures (4). Body weights of cows were taken every 2 wk. Feed intakes and orts for individual cows were recorded daily. The DM percentage of forage and concentrate was determined weekly, and the diets were adjusted accordingly to maintain a constant forage to concentrate ratio on a DM basis. For feed analysis, samples of concentrates and corn silage were composited at 4-wk intervals and analyzed for DM by oven-drying at 100°C for 24 h and by toluene distillation. The CP concentration was determined by a Kjeldahl method (4), and NDF was determined using the method of Robertson and Van Soest (18).

Ruminal DM and CP degradation of dietary ingredients was determined using an in situ nylon bag technique in 2 ruminally cannulated cows during the final week of the pretreatment period prior to Experi-

TABLE 1. Composition of diets fed to cows in early lactation (Experiment 1).

	Diet[1]			
Composition	Control	LRUP	MRUP	HRUP
Ingredient, % of DM				
Corn silage	45.0	45.0	45.0	45.0
Ground corn	17.8	13.4	21.6	12.5
Ground barley	17.8	29.4	21.6	25.3
Soybean meal, 48% CP	10.1	7.7	3.7	. . .
Fish meal	1.8	. . .	2.4	3.3
Dried distillers grains	1.0	. . .	. . .	7.5
Corn gluten meal	3.0	1.4	3.0	3.0
Dried brewers grains	1.0	. . .	. . .	0.9
Trace-mineralized salt[2]	0.5	0.5	0.5	0.5
Dicalcium phosphate	0.6	1.0	0.7	0.5
Limestone	0.8	0.8	0.7	0.7
Dynamate®[3]	0.6	0.7	0.7	0.7
Vitamin mix[4]	0.1	0.1	0.1	0.1
Nutrient				
DM, %	48.2	48.1	48.3	48.5
CP, % of DM	17.4	15.4	15.0	15.2
RUP,[5] % of DM	7.10	5.51	6.37	7.30
RDP,[5] % of DM	10.30	9.89	8.63	7.90
DM Degradability,[5] % of DM	56.8	57.2	56.1	54.8
NDF, % of DM	35.1	36.0	36.3	36.2
NE_L,[6] Mcal/kg	1.74	1.74	1.74	1.74

[1]LRUP = Low RUP, MRUP = medium RUP, and HRUP = high RUP.

[2]Contained 96% NaCl, 0.23% Fe, 0.23% Mn, 0.20% Zn, 0.10% Mg, 0.04% S, 0.023% Cu, 0.007% Co, and 0.007% I.

[3]Contained 22% S, 18% K, and 11% Mg (Pitman-Moore, Mundelein, IL).

[4]Contained 2,063,636 IU/kg of vitamin A, 454,545 IU/kg of vitamin D, and 227 IU/kg of vitamin E.

[5]Estimated using in situ procedures.

[6]Calculated from NRC (17).

TABLE 2. Composition of diets fed to cows in midlactation (Experiment 2).

Composition	Diet[1] Control	LRUP	MRUP	HRUP
Ingredient, % of DM				
Corn silage	55.0	55.0	55.0	55.0
Ground corn	14.5	11.0	17.7	10.2
Ground barley	14.5	24.0	17.7	20.7
Soybean meal, 48% CP	8.2	6.3	3.0	. . .
Fish meal	1.4	. . .	1.9	2.7
Dried distillers grains	0.8	. . .	. . .	6.2
Corn gluten meal	2.5	1.1	2.5	2.5
Dried brewers grains	0.8	. . .	. . .	0.8
Trace-mineralized salt[2]	0.5	0.5	0.5	0.5
Dicalcium phosphate	0.5	0.8	0.6	0.4
Limestone	0.6	0.7	0.5	0.5
Dynamate®[3]	0.5	0.5	0.5	0.5
Vitamin mix[4]	0.1	0.1	0.1	0.1
Nutrient				
DM, %	43.7	43.5	43.5	43.7
CP, % of DM	15.3	13.2	13.3	13.6
RUP,[5] % of DM	6.15	4.79	5.52	6.38
RDP,[5] % of DM	9.15	8.51	7.78	7.22
DM Degradability,[5] % of DM	56.5	56.9	56.0	54.9
NDF, % of DM	38.9	39.4	39.4	40.0
NE_L,[6] Mcal/kg	1.72	1.71	1.71	1.71

[1]LRUP = Low RUP, MRUP = medium RUP, and HRUP = high RUP.

[2]Contained 96% NaCl, 0.23% Fe, 0.23% Mn, 0.20% Zn, 0.10% Mg, 0.04% S, 0.023% Cu, 0.007% Co, and 0.007% I.

[3]Contained 22% S, 18% K, and 11% Mg (Pitman-Moore, Mundelein, IL).

[4]Contained 2,063,636 IU/kg of vitamin A, 454,545 IU/kg of vitamin D, and 227 IU/kg of vitamin E.

[5]Estimated using in situ procedures.

[6]Calculated from NRC (17).

ment 2 (wk 18) and prior to Experiment 3 (wk 33). Both cows were fed the control diet. Nylon bags were prepared and processed as described by Erdman et al. (12). Concentrate ingredients were incubated in the rumen for 0, 2, 6, 12, 18, 24, and 36 h. Corn silage samples were incubated in the rumen for 0, 2, 6, 12, 24, 36, and 48 h. Dry matter and CP disappearance data were fitted to the nonlinear model using the Marquardt iterative method as described previously by Erdman et al. (12). Predicted degradabilities of DM and CP were calculated for the fractional rate of passage of 0.05/h (12).

Statistical Analysis

Weekly means of feed intake, BW, milk production, and milk composition and biweekly means of BW change from each experiment (early, mid, and late) were used for statistical analysis. Data were analyzed for each experiment separately as repeated measures in time using the mixed procedure of SAS (21). All response parameters, except BW change, were covariately adjusted with the pretreatment observations from wk 3, 18, and 33 for Experiments 1, 2, and 3, respectively. For each experiment, the statistical model was Y = covariate + treatment + cow(treatment) + lactation week + treatment by lactation week, where cow(treatment) = random effect used to test treatment. The residual error was used to test lactation week and the interaction of treatment by lactation week. Covariate-adjusted least squares means are reported. A priori tests of treatment effects included the effect of dietary CP concentration (control vs. LRUP, MRUP, and HRUP). This test was used because of the impact of intake protein (**IP**) on RDP and RUP and because the NRC (17) assumes that recycled N is a function of IP. Linear and quadratic effects of increasing RUP in the diets of cows fed the low CP concentration were tested using or-

TABLE 3. Composition of diets fed to cows in late lactation (Experiment 3).

Composition	Diet[1] Control	LRUP	MRUP	HRUP
Ingredient, % of DM				
Corn silage	65.0	65.0	65.0	65.0
Ground corn	11.3	8.5	13.8	7.9
Ground barley	11.3	18.7	13.8	16.1
Soybean meal, 48% CP	6.4	4.9	2.4	. . .
Fish meal	1.1	. . .	1.4	2.1
Dried distillers grains	0.6	. . .	. . .	4.8
Corn gluten meal	1.9	0.9	1.9	1.9
Dried brewers grains	0.6	. . .	. . .	0.6
Trace-mineralized salt[2]	0.4	0.4	0.4	0.4
Dicalcium phosphate	0.4	0.6	0.5	0.3
Limestone	0.5	0.5	0.4	0.4
Dynamate®[3]	0.4	0.4	0.4	0.4
Vitamin mix[4]	0.1	0.1	0.1	0.1
Nutrient				
DM, %	39.6	39.7	39.7	39.8
CP, % of DM	14.2	12.4	12.5	12.9
RUP,[5] % of DM	5.55	4.34	5.04	5.78
RDP,[5] % of DM	8.65	8.06	7.46	7.12
DM Degradability,[5] % of DM	56.3	56.6	55.9	55.0
NDF, % of DM	38.6	38.9	39.4	39.9
NE_L,[6] Mcal/kg	1.69	1.69	1.69	1.69

[1]LRUP = Low RUP, MRUP = medium RUP, and HRUP = high RUP.

[2]Contained 96% NaCl, 0.23% Fe, 0.23% Mn, 0.20% Zn, 0.10% Mg, 0.04% S, 0.023% Cu, 0.007% Co, and 0.007% I.

[3]Contained 22% S, 18% K, and 11% Mg (Pitman-Moore, Mundelein, IL).

[4]Contained 2,063,636 IU/kg of vitamin A, 454,545 IU/kg of vitamin D, and 227 IU/kg of vitamin E.

[5]Estimated using in situ procedures.

[6]Calculated from NRC (17).

TABLE 4. Estimated degradation fractions and degradabilities of DM and CP in dietary ingredients as determined by in situ incubation.

Ingredient	Fraction[1]						Degradation rate[1]		Predicted degradability[2]	
	Soluble		Slowly degraded		Undegraded					
	(%)						(%/h)		(%)	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
DM										
Corn silage	43.0	3.5	48.6	7.6	8.4	9.7	1.9	0.9	55.5	2.6
Ground corn	17.1	2.7	82.2	2.5	0.7	1.5	6.1	2.4	60.8	6.6
Ground barley	21.3	2.8	58.8	4.0	19.9	2.6	11.3	4.8	60.9	4.3
Soybean meal	29.2	4.5	70.0	4.1	0.8	1.1	8.7	1.9	73.5	2.3
Fish meal	21.0	7.5	17.5	4.6	61.5	3.3	33.3	26.4	35.3	2.3
Dried distillers grains	23.2	4.8	67.4	14.8	9.4	11.5	4.0	0.9	52.9	3.6
Corn gluten meal	18.0	4.3	55.9	14.7	26.1	18.4	4.0	2.0	40.1	2.0
Dried brewers grains	21.3	4.1	52.2	14.8	26.5	18.4	6.0	3.3	46.1	2.9
CP										
Corn silage	66.1	2.0	25.8	13.3	8.1	11.4	0.5	0.4	67.8	2.6
Ground corn	23.3	5.2	76.7	5.2	0	0	4.0	2.0	56.2	6.8
Ground barley	28.7	2.2	62.4	3.6	8.9	4.7	10.1	5.1	68.1	5.5
Soybean meal	16.2	5.1	82.1	6.9	1.7	1.9	8.6	1.8	67.6	3.9
Fish meal	25.3	8.1	31.3	24.1	43.4	29.2	20.1	20.2	39.4	3.4
Dried distillers grains	13.4	6.7	53.9	19.4	32.7	22.1	4.1	1.8	34.7	3.2
Corn gluten meal	11.0	3.6	71.1	22.7	17.9	19.9	1.5	0.3	27.3	2.9
Dried brewers grains	25.4	5.5	67.2	8.2	7.4	9.2	5.7	2.9	59.0	2.6

[1]Data on DM and CP disappearance were fitted to the following equation: DM or CP disappearance = $R + (P - R)(1 - e^{-ct})$ where R = soluble fraction, (P − R) = slowly degraded fraction, c = rate of degradation of fraction (P − R), and t = incubation time (12).

[2]Degradability of DM and CP = $R + (P - R)(c/c + k)$, where R = soluble fraction, (P − R) = slowly degraded fraction, c = rate of degradation of fraction (P − R), and k = ruminal turnover rate calculated at 0.05/h (12).

thogonal polynomials. Because the CP concentration of the diets remained constant within the LRUP, MRUP, and HRUP diets, RDP decreased as RUP increased in the diets. Significance was declared at $P < 0.05$, and tendencies were noted at $0.05 < P < 0.10$.

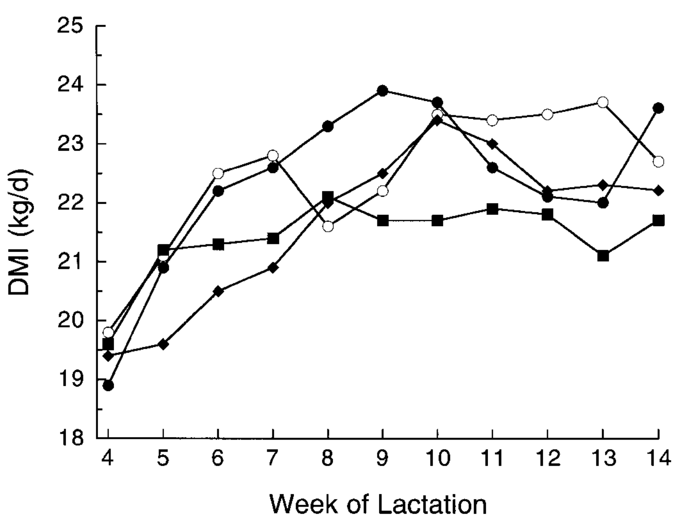

Figure 1. Least squares mean DMI of cows fed the control (○), low RUP (LRUP; ■), medium RUP (MRUP; ●), and high RUP (HRUP; ♦) diets during early lactation (Experiment 1). Dietary treatments were fed during wk 4 to 14 of lactation.

RESULTS

In situ ruminal degradation of DM and CP for individual ingredients is shown in Table 4. Measured in situ DM degradability was similar across all treatments. Care was taken in dietary formulation to ensure a constant DM fermentability of the diets so that energy supply for microbial protein production would be similar across all diets. Estimated in situ degradability of CP in Experiment 1 was 59, 64, 58, and 52% for the control, LRUP, MRUP, and HRUP diets, respectively. Because concentrate mixes used in Experiment 1 were also used in Experiments 2 and 3, differences in dietary RUP, RDP, and CP in Experiments 2 and 3 were the result of differences in the forage to concentrate ratio and degradabilities of the concentrate mixes used in Experiment 1.

Lactation responses from the early lactation experiment (Experiment 1) are presented in Table 5. Intake of CP averaged 3.84 kg/d for cows fed the control diet and 3.30 kg/d for cows fed the low CP diets (Table 5). Intake of RDP decreased linearly, and RUP increased linearly, for cows fed the low CP diets. No differences in DMI, BW, and DMI as a percentage of BW were found across protein degradabilities (LRUP, MRUP, and LRUP) or for the two concentrations of CP (control vs. low CP diets). Cows fed the control diet gained BW faster ($P < 0.04$) than

TABLE 5. Least squares means for intake, BW, and milk production and composition for cows in early lactation (Experiment 1).

	Diet[1]					Contrast[2]		
	Control	LRUP	MRUP	HRUP	SEM	P	L	Q
							P	
Cows, no.	10	9	10	10				
DMI,[3] kg/d	22.2	21.3	22.3	21.5	0.5	0.34	0.72	0.17
CP Intake,[3] kg/d	3.84	3.29	3.31	3.30	0.09	0.001	0.88	0.86
RDP Intake,[3] kg/d	2.28	2.11	1.90	1.71	0.05	0.001	0.001	0.87
RUP Intake,[3] kg/d	1.56	1.18	1.41	1.59	0.04	0.001	0.001	0.55
BW,[3] kg	594	581	588	584	8	0.27	0.76	0.51
DMI,[3] % of BW	3.84	3.78	3.76	3.70	0.14	0.53	0.64	0.89
BW Change,[4] kg/d	0.65	−0.28	0.12	0.31	0.26	0.04	0.07	0.67
Milk,[3,5] kg/d	37.6	32.7	35.9	36.1	1.1	0.02	0.03	0.23
4% FCM,[3] kg/d	39.8	32.9	37.4	37.5	1.5	0.02	0.03	0.20
Milk fat,[3] %	4.42	4.03	4.36	4.24	0.17	0.25	0.36	0.26
Milk fat,[3] kg/d	1.65	1.32	1.54	1.53	0.08	0.05	0.06	0.23
Milk protein,[3] %	2.93	2.83	2.87	2.78	0.05	0.10	0.53	0.34
Milk protein,[3,5] kg/d	1.09	0.92	1.03	1.00	0.03	0.001	0.06	0.06
Efficiency of milk N,[3] %	28.1	29.1	30.6	30.8	0.7	0.01	0.08	0.41

[1]LRUP = Low RUP, MRUP = medium RUP, and HRUP = high RUP.

[2]Probabilities of contrasts: effect of protein (P)(control vs. LRUP, MRUP, and HRUP) and linear (L) and quadratic (Q) effects of increasing RUP in low CP diets (LRUP, MRUP, and HRUP).

[3]Effect of week ($P < 0.05$).

[4]Data were not covariately adjusted.

[5]Interaction of treatment by week ($P < 0.05$).

did cows fed the low CP diets. In addition, cows tended to gain more BW ($P < 0.07$) as RUP concentration in the diet increased. Intake of DM increased ($P < 0.001$) over time (Figure 1) for cows in early lactation. Milk production was 2.7 kg/d lower for cows fed the low CP diets ($P < 0.02$) than for cows fed the control diet and increased linearly ($P < 0.03$) as RUP concentration increased in the diet. An interaction of treatment by week ($P < 0.05$) was detected for milk production as well as milk protein production; the milk production of cows fed the LRUP diet declined much faster than did the milk production of cows fed the other diets (Figure 2). Cows fed the high CP control diet produced 4.0 kg/d more 4% FCM ($P < 0.02$) than did cows fed the low CP diets. For cows fed the low CP diets, as RUP increased in the diet, 4% FCM increased linearly ($P < 0.03$). Cows fed the control diet produced more milk fat ($P < 0.05$) and milk protein ($P < 0.001$) than did cows fed the low CP diets. As RUP concentration increased in the low CP diets, milk fat and milk protein production tended to increase linearly ($P < 0.06$). In addition, milk protein production tended to change in a quadratic fashion ($P < 0.06$); the maximum milk protein production was achieved when cows were fed the intermediate concentration of RUP. Efficiency of N utilization in milk, expressed as a percentage of N intake, increased ($P < 0.01$) for cows fed the low CP diets compared with that of cows fed the control diet. As the concentration of RUP increased in the low CP diets, efficiency of N utilization in milk tended to improve ($P < 0.08$).

Lactation responses from the midlactation experiment (Experiment 2) are presented in Table 6. In-

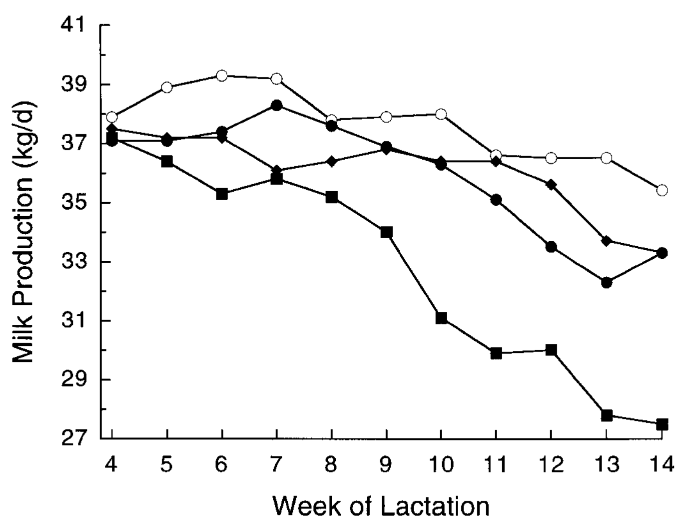

Figure 2. Least squares mean milk production of cows fed the control (○), low RUP (LRUP; ■), medium RUP (MRUP; ●), and high RUP (HRUP; ♦) diets during early lactation (Experiment 1). Dietary treatments were fed during wk 4 to 14 of lactation.

TABLE 6. Least squares means for intake, BW, and milk production and composition for cows in midlactation (Experiment 2).

	Diet[1]					Contrast[2]		
	Control	LRUP	MRUP	HRUP	SEM	P	L	Q
							P	
Cows, no.	10	10	10	10				
DMI,[3] kg/d	21.4	20.8	20.4	21.3	0.5	0.35	0.49	0.35
CP Intake,[3] kg/d	3.26	2.75	2.72	2.89	0.07	0.001	0.10	0.22
RDP Intake,[3] kg/d	1.96	1.76	1.59	1.54	0.04	0.001	0.001	0.20
RUP Intake,[3] kg/d	1.30	0.99	1.13	1.35	0.03	0.001	0.001	0.28
BW,[3] kg	631	618	624	627	5	0.21	0.21	0.82
DMI,[3] % of BW	3.35	3.45	3.30	3.39	0.08	0.73	0.60	0.18
BW Change,[4] kg/d	0.29	−0.04	0.15	0.19	0.34	0.58	0.62	0.83
Milk,[3] kg/d	25.7	24.5	25.5	26.0	0.6	0.60	0.11	0.74
4% FCM,[3] kg/d	27.7	26.4	26.5	27.3	1.0	0.25	0.56	0.79
Milk fat, %	4.48	4.51	4.30	4.35	0.15	0.60	0.46	0.48
Milk fat,[3] kg/d	1.18	1.11	1.09	1.13	0.05	0.26	0.79	0.71
Milk protein,[3] %	3.25	3.16	3.26	3.14	0.06	0.33	0.82	0.13
Milk protein,[3] kg/d	0.83	0.77	0.82	0.81	0.03	0.37	0.30	0.38
Efficiency of milk N,[3] %	26.0	28.8	29.7	28.0	1.0	0.01	0.54	0.28

[1]LRUP = Low RUP, MRUP = medium RUP, and HRUP = high RUP.

[2]Probabilities of contrasts: effect of protein (P)(control vs. LRUP, MRUP, and HRUP) and linear (L) and quadratic (Q) effects of increasing RUP in low CP diets (LRUP, MRUP, and HRUP).

[3]Effect of week ($P < 0.05$).

[4]Data were not covariately adjusted.

take of CP averaged 3.26 and 2.80 kg/d for cows fed the control and low CP diets, respectively. Intake of RDP decreased linearly, and RUP increased linearly, for cows fed the low CP diets; however, there were no treatment effects on DMI, BW, or milk production for these cows. Dry matter intake and milk production decreased ($P < 0.05$) with time and are presented in Figures 3 and 4, respectively. Efficiency of N utilization in milk, expressed as a percentage of N intake, increased ($P < 0.01$) for cows fed the low CP diets compared with that of cows fed the control diet; no effects caused by the change in CP degradability of the low CP diets were determined.

Lactation responses from the late lactation experiment (Experiment 3) are shown in Table 7. Intake of CP averaged 2.75 kg/d for cows fed the control diet and 2.35 kg/d for cows fed the low CP diets. Intake of RUP increased linearly as RUP concentration in the low CP diets increased. Intake of RDP decreased in a quadratic fashion for cows fed the low CP diets resulting in similar RDP intakes for cows fed the MRUP and HRUP diets. Dry matter intake of cows fed the control diet was 0.9 kg/d higher ($P < 0.02$) than that of cows fed the low CP diets. Dry matter intake of all cows decreased ($P < 0.05$) with time (Figure 5). Cows fed the control diet were heavier ($P < 0.001$) and had higher BW gains ($P < 0.05$) than cows fed the low CP diets. Cows fed the control diet produced 0.9 kg/d more milk than did cows fed the low CP diets, but this was not significant. Milk composition was not affected by CP concentration. With the exception of wk 34, cows fed the LRUP diet produced less milk than did cows fed the other diets (Figure 6). An increase in RUP from 35.0 to 44.8% of CP in the diet

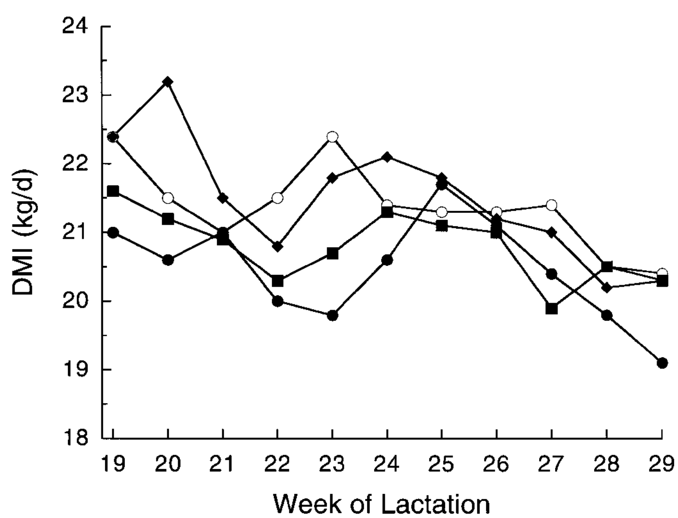

Figure 3. Least squares mean DMI of cows fed the control (o), low RUP (LRUP; ■), medium RUP (MRUP; ●), and high RUP (HRUP; ♦) diets during midlactation (Experiment 2). Dietary treatments were fed during wk 19 to 29 of lactation.

TABLE 7. Least squares means for intake, BW, and milk production and composition for cows in late lactation (Experiment 3).

	Diet[1]					Contrast[2]		
	Control	LRUP	MRUP	HRUP	SEM	P	L	Q
							P	
Cows, no.	11	9	10	9				
DMI,[3] kg/d	19.5	18.7	18.3	19.0	0.4	0.02	0.59	0.17
CP Intake, kg/d	2.75	2.33	2.28	2.46	0.06	0.001	0.16	0.11
RDP Intake,[3] kg/d	1.68	1.52	1.36	1.35	0.04	0.001	0.01	0.08
RUP Intake,[3] kg/d	1.07	0.81	0.92	1.11	0.03	0.001	0.001	0.19
BW,[3] kg	687	668	668	665	6	0.001	0.72	0.80
DMI,[3] % of BW	2.84	2.81	2.78	2.85	0.07	0.77	0.70	0.51
BW Change,[4] kg/d	1.02	0.25	0.40	0.50	0.24	0.03	0.45	0.92
Milk,[3] kg/d	16.8	15.1	16.2	16.4	0.7	0.21	0.19	0.53
4% FCM,[3] kg/d	17.7	16.5	17.4	16.7	0.8	0.30	0.87	0.39
Milk fat,[3] %	4.32	4.69	4.47	3.97	0.10	0.57	0.001	0.26
Milk fat,[3] kg/d	0.73	0.70	0.72	0.67	0.04	0.42	0.52	0.41
Milk protein,[3] %	3.52	3.63	3.56	3.47	0.06	0.55	0.05	0.84
Milk protein,[3] kg/d	0.59	0.53	0.57	0.56	0.03	0.23	0.35	0.40
Efficiency of milk N,[3] %	21.4	23.8	24.6	22.7	0.9	0.02	0.40	0.21

[1]LRUP = Low RUP, MRUP = medium RUP, and HRUP = high RUP.

[2]Probabilities of contrasts: effect of protein (P)(control vs. LRUP, MRUP, and HRUP) and linear (L) and quadratic (Q) effects of increasing RUP in low CP diets (LRUP, MRUP, and HRUP).

[3]Effect of week ($P < 0.05$).

[4]Data were not covariately adjusted.

decreased milk fat percentage ($P < 0.01$) and milk protein percentage ($P < 0.05$) linearly; no effects on milk fat or milk protein production were observed. Cows fed the low CP diets increased the efficiency of N utilization in milk ($P < 0.02$) over that of cows fed the control diet; however, there was no change in the efficiency of N utilization because of a change in the CP degradability of the low CP diets.

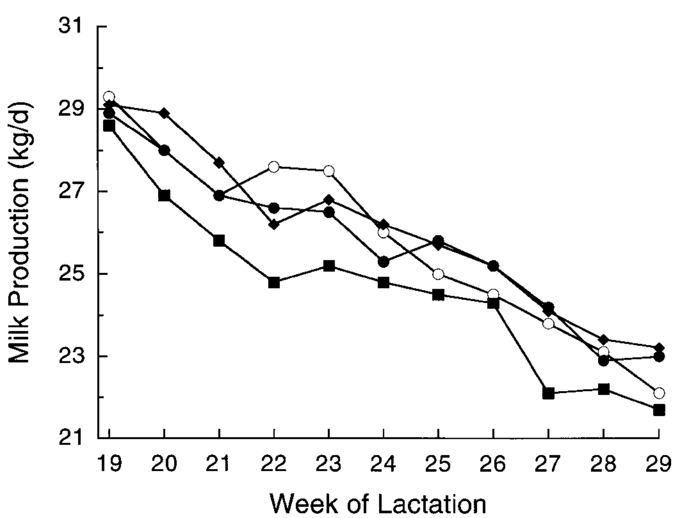

Figure 4. Least squares mean milk production of cows fed the control (o), low RUP (LRUP; ■), medium RUP (MRUP; ●), and high RUP (HRUP; ♦) diets during midlactation (Experiment 2). Dietary treatments were fed during wk 19 to 29 of lactation.

Observed intakes of IP, RDP, and RUP for cows on all treatments are compared with NRC (17) recommendations for the average cow fed the control diet for each respective experiment (Table 8). Comparisons were made with the NRC (17) requirements of the cows fed the control diet because this diet represents the potential production level. In Experiment 1, IP was less than NRC (17) recommendations for all diets, varying from 83% of the NRC requirement for the low CP diets to 97% of the NRC requirement for the control diet. In Experiments 2 and 3, cows fed the control diet met or exceeded recommendations, 111 and 105%, respectively. Cows fed the low CP diets ranged from 92 to 98% of the NRC (17) requirements for Experiment 2 and from 87 to 94% of the NRC requirements for Experiment 3. During early lactation (Experiment 1), all of the diets, including the control diet, did not provide enough RDP as recommended by the NRC (17). In the mid and late lactation experiments, the control diet provided sufficient RDP, but the low CP diets did not. In general, for all three experiments, the MRUP diets provided the NRC (17) recommended amount of RUP, the LRUP diets were deficient in RUP as recommended by the NRC, and the HRUP and control diets provided excess RUP as recommended by the NRC.

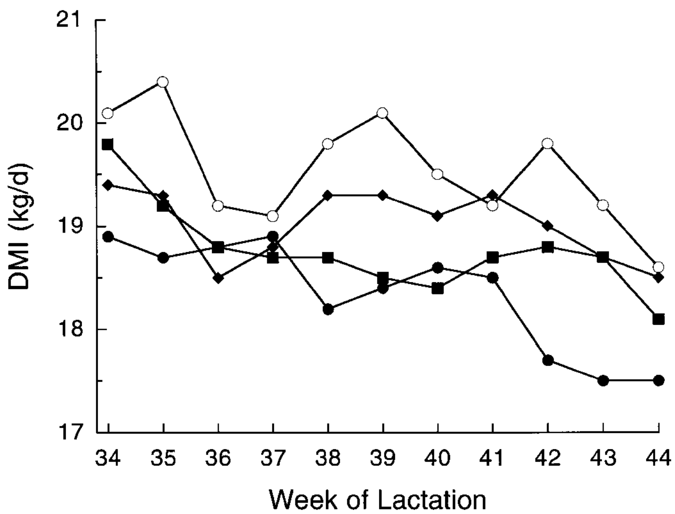

Figure 5. Least squares mean DMI of cows fed the control (o), low RUP (LRUP; ■), medium RUP (MRUP; ●), and high RUP (HRUP; ♦) diets during late lactation (Experiment 3). Dietary treatments were fed during wk 34 to 44 of lactation.

DISCUSSION

Cows fed the control diet in early lactation (Experiment 1) produced more milk than did cows fed the low CP diets, which was in agreement with previous research (8, 14, 15, 24) that showed that CP often is a limiting nutrient in early lactation. However, in later stages of lactation (Experiments 2 and 3), cows fed the higher CP diet (control) did not increase milk production over cows fed the low CP diets, indicating that diets can be formulated with lower concentrations of dietary CP and still maintain equivalent milk production compared with cows fed diets containing higher concentrations of CP.

To utilize diets with lower CP concentrations, it is thought that RUP in the diet should be increased to supply the small intestine of the cow with the additional protein needed to meet the requirements of high producing cows. In agreement with the results observed in Experiment 1, Forster et al. (14) showed that cows in early lactation fed diets with 14% CP and increasing RUP concentrations had increased milk production. Some past studies (1, 5, 9, 16) with varying concentrations of RUP agreed with those results, but others (6, 10, 13, 23) did not. In contrast to the effect of RUP on milk production in early lactation, cows fed increasing amounts of RUP in mid or late lactation did not increase milk production. In studies in which RUP was increased in the diet after peak milk production and peak DMI, there was no effect of the dietary treatments (2, 3, 19, 20). In most cases, the supply of CP in the diet easily meets the requirements for many cows in mid and late lactation. However, because CP requirements are driven by milk production, higher producing cows (>33 kg/d) in midlactation respond to RUP supplementation as demonstrated by Armentano et al. (3).

Dry matter intake is instrumental in meeting the RUP required by the animal. In these experiments, DMI met or exceeded DMI predicted by the NRC (17) for all diets except for the control and HRUP diets in Experiment 1. For those diets, the cows consumed 90.5 and 94.7% of predicted DMI, respectively (data not shown). The estimated intake of RDP for cows fed the control diet in early lactation (Experiment 1) was 90% of NRC (17) requirements (Table 8), partly because cows did not consume the DM predicted by the NRC (17). In addition, cows fed the control diet exceeded NRC (17) requirements for RUP intake by 11, 19, and 13% in Experiments 1, 2, and 3, respectively.

The low CP diets were formulated to determine whether RUP supplementation at CP intakes less than recommended to meet requirements could replace diets that provided greater CP intake. In early lactation (Experiment 1), it was unclear whether cows fed the LRUP diet were inhibited by a deficiency of RDP. Because the LRUP diet provided only 0.17 kg/d less RDP than did the control diet, it is more likely that cows fed the LRUP diet were inhibited by a lack of RUP. Cows fed the MRUP and HRUP diets in early lactation met or exceeded the NRC (17) requirements of the control diet for RUP

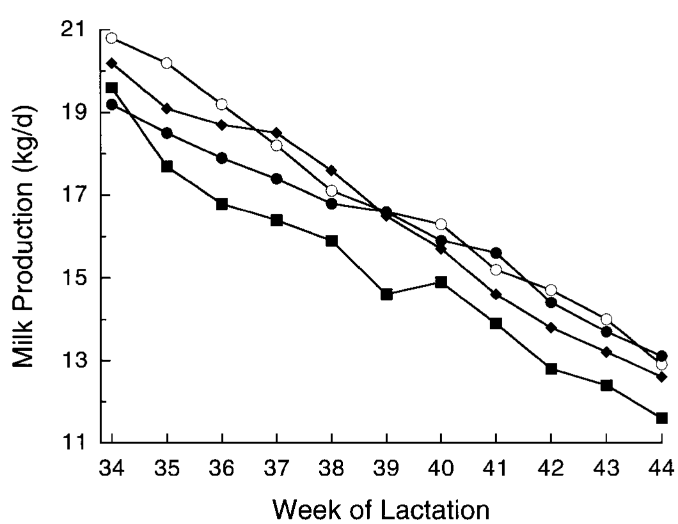

Figure 6. Least squares mean milk production of cows fed the control (o), low RUP (LRUP; ■), medium RUP (MRUP; ●), and high RUP (HRUP; ♦) diets during late lactation (Experiment 3). Dietary treatments were fed during wk 34 to 44 of lactation.

TABLE 8. Intake of intake protein (IP), RDP, and RUP expressed as kilograms per day and as a percentage of NRC (17) recommendations at each stage of lactation.[1]

		Diet[2]							
	NRC[3]	Control		LRUP		MRUP		HRUP	
		(kg/d)	(%[4])	(kg/d)	(%)	(kg/d)	(%)	(kg/d)	(%)
IP									
Experiment 1	3.96	3.84	97.2	3.29	83.1	3.31	83.8	3.30	83.5
Experiment 2	2.95	3.26	110.7	2.75	93.1	2.72	92.1	2.89	98.1
Experiment 3	2.64	2.75	104.6	2.33	88.3	2.28	86.7	2.47	93.6
RDP									
Experiment 1	2.54	2.29	89.9	2.11	82.8	1.90	74.8	1.70	66.8
Experiment 2	1.86	1.96	105.3	1.77	95.2	1.59	85.3	1.54	82.7
Experiment 3	1.68	1.69	100.2	1.51	89.5	1.37	81.1	1.36	80.4
RUP									
Experiment 1	1.41	1.56	110.6	1.17	83.2	1.41	100.2	1.59	112.8
Experiment 2	1.09	1.30	119.3	0.98	89.9	1.13	103.4	1.35	123.9
Experiment 3	0.95	1.07	112.6	0.81	85.4	0.92	97.0	1.10	115.5

[1]Experiment 1 = Early lactation, Experiment 2 = midlactation, and Experiment 3 = late lactation.

[2]LRUP = Low RUP, MRUP = medium RUP, and HRUP = high RUP.

[3]Recommendations of the NRC (18) for the average cow fed the control diet (Experiment 1: BW = 594 kg, milk production = 37.6 kg/d, milk fat percentage = 4.42%, and BW gain = 0.65 kg/d; Experiment 2: BW = 631 kg, milk production = 25.7 kg/d, milk fat percentage = 4.48%, and BW gain = 0.29 kg/d; Experiment 3: BW = 687 kg, milk production = 16.8 kg/d, milk fat percentage = 4.32, and BW gain = 0.73 kg/d).

[4]Nutrient intake expressed as a percentage of NRC (17) recommendations.

intake. The additional 0.18 kg/d of RUP supplied to the cows fed the HRUP diet over that supplied by the MRUP diet resulted in no additional milk production, and cows fed both diets, MRUP and HRUP, still produced 1.6 kg/d less milk than did cows fed the control diet, which met NRC (17) requirements. Because of the decreases in RDP as RUP increases, the HRUP diet provided 0.19 kg/d less RDP than did the MRUP diet but compensated by providing an additional 0.18 kg/d of RUP, resulting in equal milk production. Because cows fed the MRUP and HRUP diets received sufficient RUP according to the NRC (17) and still produced 1.6 kg/d less milk than did cows fed the control diet, it is likely that these cows did not receive adequate RDP in the diet, resulting in lower milk production.

Lack of milk production response to increased CP or RUP supplementation in the diets of cows in mid and late lactation (Experiments 2 and 3) indicated that requirements for RDP and RUP were met although the low CP diets were thought to be deficient in RDP. Therefore, the actual RDP requirement for cows past peak milk production might have been lower than that currently recommended by the NRC (17). Robinson and Kennelly (19) and Robinson et al. (20) have suggested that NRC (17) recommendations for RUP are excessive for cows in mid and late lactation. In those experiments (19, 20), intakes of RDP and RUP were in excess of NRC (17) recommendations; therefore, those diets exceeded MP requirements. In the current experiments, the low CP diets were deficient in RDP according to the NRC (17). The loss of MP provided by digestible microbial protein would have been replaced by the addition of dietary RUP.

Supplementation of RUP did not have an effect on increasing DMI in several studies using animal or plant protein sources (6, 9, 14, 19, 20), but intake of RUP has been noted to decrease DMI when animal proteins have been fed (10, 23). At high rates of DMI, cows consuming diets formulated at lower CP concentrations can meet MP requirements, negating any beneficial effect of supplying additional RUP in the diet. In addition, at a higher DMI, the rate of passage may increase, resulting in an increased supply of RUP because less time is available for protein degradation in the rumen (19, 20).

Results from Experiment 1 demonstrate the importance of supplying the high producing dairy cow with sufficient dietary RUP. In later stages of lactation after peak milk and DMI, CP and especially RUP requirements decline with milk production. If DMI is maximized throughout lactation, diets with lower CP concentrations could be fed to cows in mid and late lactation to reduce the cost of the diet and reduce the waste N excreted by the cow while maintaining milk production.

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