Performance of Holstein cows fed two levels of concentrate supplementation and ruminally undegraded protein[1]

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ABSTRACT

Two experiments were conducted to determine the effects of level of concentrate supplementation with two concentrates differing in concentration and type of ruminally undegradable protein (RUP) on dry matter intake (DMI) and milk production of Holstein cows in late (E1) and early (E2) lactation. In both trials, concentrates were fed at the rate of 1 kg per 2.5 or 1.5 kg of milk, constituting low (LCS) and high (HCS) levels of concentrate supplementation, respectively. No significant effect of type of concentrate was observed on DMI, milk production, milk composition or efficiency of milk production in either experiment. HCS resulted in lower hay DM consumption by cows in late (9.8 vs. 11.3 kg/d) and early (6.4 vs. 8.1 kg/d) lactation, but also in greater total DMI by late (17.7 vs. 15.6 kg/d) and early (19.6 vs. 16.2 kg/d) lactation cows. Similarly, milk production was greater when late (13.1 vs. 11.8 kg/d) and early (25.5 vs. 22.6 kg/d) lactation cows were fed the HCS. In E2, contrary to E1, cows produced milk of higher fat concentration (2.66 vs. 3.18%) when the LCS was fed. HCS resulted in lower efficiency of concentrate use for milk and 3.25%-fat-corrected milk production, particularly during early lactation. However, income over feed cost was higher for HCS during early lactation. Thus, the practice of supplementing concentrates at a high level can be justified economically under conditions similar to those of this trial.

Key words: ruminally undegraded protein, concentrate supplementation, tropical grass hay

RESUMEN

Suplementación con concentrados con proteína no degradable en el rumen y el desempeño de vacas Holstein

Se realizaron dos experimentos para determinar los efectos del nivel de suplementación con dos concentrados con diferente concentración y tipo de proteína no degradable en el rumen (PND) en vacas Holstein en etapa tardía (E1) y etapa temprana (E2) de lactancia. En ambos estudios, los concentrados se suplieron a razón de 1 kg por cada 1.5 y 2.5 kg de leche, constituyendo los niveles alto (AS) y bajo (BS) de suplementación, respectivamente. Las diferencias en consumo de materia seca (MS), producción de leche, composición de la leche y eficiencia de la producción de leche debido al tipo de concentrado no fueron significativas (P < 0.05) en ninguno de los dos experimentos. El AS resultó en menor consumo de MS

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de heno en vacas en etapa tardía (9.8 vs. 11.3 kg/d) y temprana (6.4 vs. 8.1 kg/d) de lactancia, pero también resultó en mayor consumo de MS total en vacas en etapa tardía (17.7 vs. 15.6 kg/d) y temprana (19.6 vs. 16.2 kg/d) de lactancia. Igualmente, alimentar con AS resultó en mayor producción de leche en la etapa tardía (13.1 vs. 11.8 kg/d) y temprana (25.5 vs. 22.6 kg/d) de lactancia. En el E2, contrario al E1, la concentración de grasa láctea fue mayor con el BS (2.66 vs. 3.18%). Si bien AS resultó en una menor eficiencia del uso de concentrado para producir leche, particularmente en el E2, también aumentó el ingreso monetario sobre el costo de los alimentos en la lactancia temprana. Por consiguiente, el AS es justificable en términos económicos bajo condiciones similares a las de este estudio.

Palabras clave: proteína no degradable en el rumen, suplementación con concentrado, heno de gramíneas tropicales

INTRODUCTION

In the Caribbean tropics, forage resources are rapidly becoming limiting and milk production is being transformed from an extensive pasture based system into a more intensive one. Traditional recommendations to farmers for efficient milk production have been to limit concentrate supplementation and to maximize pasture forage intake. Caro-Costas et al. (1979) reported that 0.4 ha of intensively managed mixed tropical grasses could support one mature cow producing about 3,100 kg/lactation (10 kg/d) of milk without supplemental concentrate. McDowell et al. (1975) reported that limited supplementation of concentrate at 1:2 (concentrate:milk) above 10 kg of milk daily production was more efficient, in terms of use of total digestible nutrients (TDN) from concentrates, than a traditional system of supplementation at the same rate irrespective of milk production level. According to their analysis, income over feed costs (IOFC) at the lower level of supplementation (1:2 above 10 kg of milk) gave the best returns irrespective of production level when cows had unrestricted access to high-quality pasture at a stocking rate of about 2.5 cows per hectare.

However, these recommendations have not been widely accepted and implemented by dairy farmers. On the contrary, there has been a continued trend toward a reduction in land dedicated to forage production (ORIL, 2003) and an increase in the use of concentrates for milk production. In a recent study of dairy farms in Puerto Rico (Ruiz et al., 2001), about 43% of commercial dairies supplemented concentrates at levels that were higher than 1 kg: 1.5 kg of milk and only 17% supplement at levels lower than 1:1.75. The question remains whether under the particular conditions for milk production in Puerto Rico (high milk price, low quality forages, low milk yield) the supplementation with concentrates at a high level is warranted.

The use of supplemental ruminally undegraded protein (RUP) has been recommended (NRC, 2001) for high production cows during early lactation. However, increasing the level of dietary RUP has produced mixed results, increasing milk production in some instances (Cunningham et al., 1996; Forster et al., 1983) and causing no change in others (Christensen et al., 1993; Ellison et al., 1997). Nitrogen efficiency in commercial dairy production is generally low, around 28 to 30% for high producing cows (Gustafsson et al., 2001; Jonker et al., 2002) and declining to levels below 22% for cows in late lactation (Kalscheur et al., 1999). Liberal use of protein in the diet of the dairy cow has the potential to improve milk production, particularly for high production cows in early lactation (Clark and Davis, 1980), and the potential to decrease nitrogen (N) losses from the farm due to more efficient N utilization. Inefficiencies can potentially be a source of contamination and increased feeding and production costs for the dairy. Therefore, the objectives of this study were to determine the effect of added RUP, at two levels of concentrate supplementation on feed consumption, milk production and efficiency of N utilization by early and late lactation cows in the tropics.

MATERIALS AND METHODS

Two experiments were conducted at the dairy farm of the Agricultural Experiment Station in Lajas, Puerto Rico, to evaluate effect of two factors: (1) level of concentrate supplementation, and (2) use of a concentrate with added ruminally-protected protein on performance of lactating Holstein cows. Experiment 1 (E1) was conducted with cows in late lactation from late July to September, and Experiment 2 (E2) with cows in early lactation from mid-November to January. High (HCS) and low (LCS) levels of concentrate supplementation were 1 kg:1.5 and 2.5 kg of milk, respectively. The daily air temperature range in Lajas is 16 to 35° C during July to September and 14 to 32° C from November to January. The in situ method was used to estimate rate of CP digestion in the concentrate calculated according to the equation proposed by Orskov and McDonald (1979). The percentage of ruminally undegraded protein (RUP) in the concentrate was estimated from the equation proposed by NRC (2001).

Experiment 1 (late lactation)

Eight cows in late lactation (191 to 235 days postpartum) were assigned to treatments according to a 4 × 4 Latin Square Design, replicated twice. Factors evaluated were HCS and LCS of a commercial dairy concentrate with (PPC) or without (DC) a commercial premix containing RUP. Experimental treatments were 1) DC at HCS; 2) PPC at HCS; 3) DC at LCS; and 4) PPC at LCS. Both concentrates were purchased from the same company and were delivered the same day to minimize variations in type or changing proportions of ingredients.

Cows were assigned to square (replication) using as criteria their age at calving and number of lactations. Experimental periods lasted 15 days, 10 of which were for adaptation to treatments and five for data collection. Concentrate allotment was adjusted every two days according to milk yield during the previous three days, up to a maximum daily allotment of 16 kg/cow. Half of the total daily concentrate allotment was offered at each of two meals (6:00 and 14:00 h). In addition to concentrate, cows were fed 50-day-old pangola grass hay (PGH) ad libitum.

Experimental cows were housed in individual pens with concrete floor and a shade cloth (80% light interception) overhead. Access to a dirt lot was allowed after the morning milking for about two hours daily. Concentrate allotment was fed individually in a stanchion barn next to the milking parlor. Pangola grass hay was provided in individual feeders inside each pen. During data collection (last five days of each period) weighed hay was offered in amounts sufficient to allow ad libitum intake. Wasted hay dropped to the floor was collected and weighed daily. Hay remaining in the feeder at the end of data collection (refusal) was collected and weighed for each cow. Hay intake was determined by subtracting dry matter (DM) of wasted hay and refusals from total hay DM offered during data collection. We assumed that all the concentrate offered was completely eaten by the cows. No evidence of concentrate refusals was observed for any of the experimental cows during the data collection periods.

Cows were milked twice daily at 4:00 and 14:30 h with production being recorded by using calibrated [Puerto Rico Dairy Herd Improvement Association (PRDHIA) Laboratory] milk meters. Milk samples to determine content of fat and protein were collected from four consecutive milkings at the end of each experimental period. These milk samples were analyzed at the PRDHIA Laboratory. Body weights were estimated from thoracic circumference by using a calibrated measuring tape on days 0 and 1 of the first experimental period, and subsequently on days 1 and 15 of each period.

Hay and concentrate samples were collected twice weekly during each period. Feed samples were dried in a convection oven at 65°C for 48 h to determine DM concentration. Organic matter concentration of feed samples was determined from ash content by incinerating samples at 600°C for six hours in a muffle furnace. Weekly composite samples of each feed were analyzed for chemical composition at the Dairy One Laboratory (Ithaca, NY).[4]

[4]Trade names in this publication are used only to provide specific information. Mention of a trade name does not constitute a warranty of equipment or materials by the Agricultural Experiment Station of the University of Puerto Rico, nor is this mention a statement of preference over other equipment or materials.

Experiment 2 (early lactation)

Eight Holstein cows in early lactation (34 to 77 days postpartum) were assigned to treatments according to a 4 × 4 Latin Square Design replicated twice. Cows were assigned to replicates according to number of lactations and level of production. As in E1, the four treatments evaluated were 5) DC at a HCS; 6) RPP at a HCS; 7) DC at a LCS; and 8) RPP at LCS. Concentrates used were purchased from the same commercial supplier as previously. Tifton 81 Bermuda grass hay (BGH) of about 50 to 60 days of regrowth was offered ad libitum to experimental cows. Management of the cows, sample collection and experimental procedure were similar to those described in E1.

Data from each experiment were analyzed separately using the GLM procedure of SAS (Littell et al., 1991). The effect of type and level of concentrate fed was determined by using orthogonal contrasts.

With knowledge of the purchase prices of the commercial concentrates and grass hays, cost of the ration was determined by multiplying unit feed cost by the amount of DM consumed under each treatment. To determine milk income, production was multiplied by the average price paid for milk at the farm (in Puerto Rico) during the year 1999. Income over feed costs was determined by subtracting ration cost from milk income.

RESULTS

Experiment 1 (late lactation)

Chemical composition of the commercial dairy concentrates used is presented in Table 1. The two concentrates were similar in CP, neutral detergent fiber (NDF), acid detergent fiber (ADF), and estimated TDN concentrations. Despite the fact that the concentration of soluble protein was higher in PPC, its estimated concentration of RUP was also 5.3 percentage units higher than in DC. The difference in estimated RUP between the two commercial concentrates was not as wide as expected, which is probably a consequence of the high estimated concentration of RUP in the DC generally. The PPC had a lower concentration of calcium (Ca) than that of the DC. This difference was consistent in the two trials and can be attributed to formulation errors during the elaboration of PPC by the commercial mill supplying the concentrate. Differences between concentrates in the concentration of other minerals were small and can be considered of little practical significance. Composition of the PGH used for the trial is typical of good 50- to 60-day-old commercial grass hays harvested in the tropics.

The use of PPC resulted in a small increase (Table 2) in the concentration of RUP in the protein consumed (42.41 vs. 45.88%). Calcium

TABLE 1. *Chemical composition of dairy concentrates without (DC) or with (PPC) added ruminally protected protein and of pangola grass hay (PGH) fed to Holstein cows in late lactation.*

	Commercial concentrates		
Component	DC	PPC	PGH
	%		
Crude protein	20.70	19.80	6.90
Soluble protein	14.00	22.00	23.00
RUP[1]	44.70	50.00	40.00
ADF	8.80	7.40	44.20
NDF	19.50	19.50	75.40
TDN	80.50	80.70	55.70
Ca	1.36	0.35	0.36
P	0.69	0.76	0.27
Mg	0.33	0.34	0.19
K	1.01	0.90	1.67
Na	0.25	0.22	0.24
S	0.18	0.23	0.17
Cl	0.36	0.46	0.91

[1]Ruminally undegraded protein, determined from in situ digestion as a percentage of total CP.

concentration of the diet consumed was the only other nutrient affected by type of concentrate. However, total intake of Ca was still adequate to meet maintenance and production requirements of experimental cows (NRC, 2001) receiving treatments with PPC at HCS and LCS.

The organic matter (OM) content of the consumed diets tended to be higher when the cows received the HCS (92.63 vs. 91.35%), primarily because of the lower mineral concentration of the concentrates compared to that of the PGH (Table 2). In addition, the CP concentration of the consumed diet was higher (12.85 vs. 10.61%) when the cows received the HCS due to the lower CP concentration of the PGH relative to that of the dairy concentrate. The level of concentrate supplementation also affected the concentration of fiber in the ration. When the cows received diets with HCS, concentrations of both NDF (47.34 vs. 57.87%), and ADF (28.10 vs. 34.16%) were lower than for diets with LCS.

Feeding a dairy concentrate with added RUP did not influence any of the consumption parameters evaluated (Table 3). This finding is not unexpected in view of the smaller than expected difference in the RUP between concentrates. The estimated RUP intake (0.87 kg/d) was also not affected by type of concentrate fed.

Level of concentrate supplementation did influence most of the parameters evaluated. Feeding at the HCS resulted in a decline in PGH DM

TABLE 2. *Chemical composition of the diet consumed by cows in late lactation supplemented at a high or low level with a dairy concentrate without (DC) or with (PPC) added ruminally protected protein.*

	High level		Low level	
Component	DC	PPC	DC	PPC
	% DM			
Crude protein	13.13	12.57	10.63	10.59
RUP[1]	42.55	46.77	42.28	45.00
Organic matter	92.09	93.18	91.14	91.56
NDF[1]	46.95	47.73	58.35	57.40
ADF	28.20	28.01	34.65	33.68
TDN	66.70	66.60	61.90	62.70
Ca	0.79	0.35	0.61	0.35
P	0.46	0.49	0.38	0.41
K	1.35	1.33	1.49	1.48
Mg	0.22	0.25	0.23	0.23
Na	0.24	0.23	0.25	0.24
Cl	0.68	0.71	0.76	0.78
S	0.18	0.20	0.17	0.19

[1]Ruminally undegraded protein, determined from in situ digestion as a percentage of total CP.

intake (9.8 vs. 11.3 kg/d), but increased intakes of concentrate DM (7.8 vs. 4.2 kg/d), total DM (17.6 vs. 15.6 kg/d), and OM (16.3 vs. 14.2 kg/d). As a consequence, it also resulted in a lower forage to concentrate ratio (55.4:44.6 vs. 72.2:27.8) in the ration. In spite of these results, the level of concentrate supplementation did not influence NDF intake (8.7 kg/d).

Feed consumption expressed as a percentage of body weight (BW) was similarly affected by level of concentrate supplementation. Increasing the level of supplementation decreased hay DM intake (1.79 vs. 2.12%), but increased total intakes of DM (3.21 vs. 2.92%). Intake of NDF as a percentage of body weight was greater for cows consuming the diet with LCS (1.52 vs. 1.69).

Milk production and composition parameters were not affected in a significant manner by the inclusion of a concentrate with added protected protein (Table 4). However, treatment differences were observed due to the level of concentrate supplementation. Diets with HCS resulted in higher daily productions of milk ($P < 0.01$) (13.1 vs. 11.7 kg), 3.25% FCM (14.2 vs. 12.1 kg/), milk fat (0.49 vs. 0.40 kg), and milk protein (0.43 vs. 0.37 kg) than diets with LCS. The concentrations of milk fat and protein were not influenced in a significant manner by the type of concentrate. There was a tendency toward higher protein (3.28 vs. 3.17%) and fat (3.78 vs. 3.45%) concentrations at the higher level of concentrate supplementation.

TABLE 3. *Daily intake of dry matter (DM), organic matter (OM), and NDF of cows in late lactation supplemented at a high or low level with a dairy cow concentrate without (DC) or with (PPC) added ruminally protected protein.*

	Concentrate supplementation					
	High level		Low level			
	DC	PPC	DC	PPC	SE	P<
Intake, % body weight						
Grass hay	1.79	1.80	2.20	2.05	0.09	0.05
DM (total)	3.25	3.18	3.00	2.85	0.10	0.06
OM	2.99	2.96	2.74	2.62	0.07	NS
NDF	1.53	1.52	1.75	1.64	0.10	0.05
Forage, % ration DM	54.80	56.00	73.10	71.40	1.30	0.01
Intake, kg/day						
Grass hay	9.80	9.90	11.60	11.10	0.49	0.05
Concentrate	7.90	7.70	4.20	4.30	—	0.01
DM (total)	17.70	17.60	15.80	15.40	0.49	0.01
OM	16.30	16.40	14.40	14.10	0.45	0.01
TDN	11.80	11.70	9.80	9.60	0.27	0.01
NDF	8.30	8.40	9.20	8.80	0.34	NS

The higher level of supplementation influenced negatively ($P < 0.01$) the efficiency of concentrate use for milk (1.67 vs. 2.75) and 3.25% FCM (1.93 vs. 3.02) production relative to that of the LCS (Table 5). Despite the lack of an effect of type of concentrate on production parameters, the efficiency of N use (ENU) was significantly ($P < 0.01$) higher when cows were fed PPC than when fed DC (19.5 vs. 21.5%), and when cows con-

TABLE 4. *Milk composition and production of cows in late lactation supplemented at a high or low level with a dairy concentrate without (DC) or with (PPC) added ruminally protected protein.*

	Concentrate supplementation					
	High level		Low level			
	DC	PPC	DC	PPC	SE	P<
Production, kg/day						
Milk	13.20	13.00	11.40	12.10	0.29	0.01
FCM-3.25%	14.40	14.10	11.70	12.60	0.41	0.01
Fat	0.50	0.49	0.39	0.42	0.02	0.01
Protein	0.43	0.43	0.36	0.38	0.01	0.01
Composition, %						
Fat	3.80	3.77	3.40	3.50	0.16	NS
Protein	3.26	3.30	3.18	3.17	0.04	0.10

TABLE 5. *Efficiency of production of cows in late lactation supplemented at a high or low level with a dairy concentrate without (DC) or with (PPC) added ruminally protected protein.*

	Concentrate supplementation					
	High level		Low level			
Criterion	DC	PPC	DC	PPC	SE	P<
Efficiency, kg/kg						
Milk/concentrate	1.65	1.69	2.70	2.80	0.040	0.01
Milk/DMI	0.75	0.74	0.72	0.80	0.030	NS
FCM-3.25%/concentrate OM	1.94	1.92	2.98	3.06	0.100	0.01
FCM-3.25%/OM	0.89	0.87	0.82	0.91	0.030	NS
N-milk/N-feed	0.18	0.19	0.21	0.24	0.005	0.01

sumed the LCS rather than HCS (18.5 vs. 22.5%). These results suggest that the quality of protein supplied by PPC was better, thus allowing for a more efficient utilization. The better efficiency of nitrogen use for LCS suggests that CP intake from HCS exceeded the requirements for maintenance and milk production of experimental cows.

Feeding at a HCS resulted in a higher ration cost ($4.08 vs. $3.42 cow per day) than when the LCS was fed (Table 6). However, the higher milk income obtained with HCS resulted in a similar daily IOFC for both HCS and LCS diets ($2.70 vs. $2.69).

TABLE 6. *Milk income over costs of ration consumed by cows in late lactation supplemented at a high or low level with a dairy concentrate without (DC) or with (PPC) added ruminally protected protein.*

	Concentrate supplementation			
	High level		Low level	
Criterion	DC	PPC	DC	PPC
Milk income, $/d[1]	6.86	6.71	5.93	6.29
Feed costs, $/d[2]				
Grass hay	1.96	1.98	2.32	2.22
Concentrate	2.14	2.08	1.14	1.16
Total ration	4.10	4.06	3.46	3.38
Income over feed costs, $/d	2.76	2.65	2.47	2.91

[1]Milk price during the year of the experiment multiplied by daily fluid milk production.

[2]Concentrate and hay cost, multiplied by mean daily consumption of experimental cows.

Experiment 2 (early lactation)

Chemical composition of the commercial dairy concentrates and the BGH used in E2 is presented in Table 7. Both concentrates had similar concentrations of ADF, NDF, TDN and minerals, except for calcium. The PPC had lower concentrations of CP and calcium than the DC. On the other hand, PPC had a higher concentration of soluble CP and RUP. The difference of 9.5 percentage units in RUP between the two concentrates was wider than that reported in E1. Composition of the BGH used was typical of 50- to 60-day-old grass hay and similar to that of the PGH used in E1.

Differences in CP concentration between the concentrates were reflected in the lower (15.28 vs. 13.06%) CP concentration of the consumed PPC ration compared to that of DC (Table 8). The percentage of RUP in the CP of the consumed rations was higher when cows received PPC (40.1 vs. 47.7%). However, the unexpected differences in CP between the two concentrates resulted in similar intakes of estimated RUP. Thus, any difference in production parameters between concentrates would not be attributable to differences in intake of RUP. Type of concentrate did not influence the concentrations of ADF, NDF, or of any of the minerals analyzed in the consumed rations, except for a lower concentration of calcium in the diet consumed by cows fed PPC (0.84 vs. 0.35%).

TABLE 7. *Chemical composition of dairy concentrates without (DC) or with (PPC) protected protein and of Bermuda grass hay (BGH) fed to Holstein cows in early lactation.*

	Commercial concentrates		
Component	DC	PPC	BGH
	%		
Crude protein	21.40	18.20	6.00
Soluble protein	17.50	20.50	16.00
RUP[1]	40.50	50.00	40.00
ADF	9.60	8.50	44.00
NDF	21.60	21.70	74.10
TDN	79.70	80.00	56.00
Ca	1.16	0.35	0.36
P	0.68	0.71	0.31
Mg	0.33	0.31	0.16
K	1.02	0.81	1.55
Na	0.22	0.28	0.24
S	0.18	0.24	0.16
Cl	0.36	0.46	0.85

[1]Ruminally undegraded protein, determined from in situ digestion as a percentage of total CP.

TABLE 8. *Chemical composition of the diet consumed by cows in early lactation supplemented at a high or low level with a lactating cow concentrate without (DC) or with (PPC) added ruminally protected protein.*

	High level		Low level	
Component	DC	PPC	DC	PPC
	% DM			
Crude protein	17.01	13.96	13.55	12.16
RUP[1]	40.20	48.10	40.10	47.40
Organic matter	92.48	94.04	92.30	93.53
ADF	19.40	20.81	27.11	26.07
NDF	30.00	33.51	43.95	42.68
TDN	72.80	71.30	68.10	68.00
Ca	0.93	0.35	0.75	0.35
P	0.57	0.57	0.49	0.51
K	1.17	1.07	1.35	1.17
Mg	0.28	0.26	0.25	0.24
Na	0.22	0.27	0.23	0.26
Cl	0.50	0.60	0.61	0.65
S	0.18	0.22	0.17	0.20

[1]Ruminally undegraded protein as a percentage of CP.

The level of concentrate supplementation had a greater effect on composition of the consumed ration than did the type of concentrate. Increasing the level of supplementation resulted in the consumption of rations that were higher in CP (15.48 vs. 12.85%), and lower in ADF (20.10 vs. 26.59%) and NDF (31.75 vs. 43.31%) concentration than when the LCS diets were fed. Mineral concentrations of diets consumed were little affected by the level of concentrate supplementation.

The type of concentrate used did not influence intake of hay DM, concentrate DM, or the forage to concentrate ratio ($P > 0.05$) (Table 9). However, when the PPC was fed there was a tendency ($P < 0.06$) toward increased daily total DM consumption (18.6 vs. 17.4 kg), and increased ($P < 0.05$) intake of OM (17.4 vs. 16.0 kg), particularly at the HCS.

Level of concentrate supplementation affected ($P < 0.01$) intake of hay, concentrate and total DM, OM, and the forage to concentrate ratio of the consumed rations. Hay consumption was higher (6.4 vs. 7.8 kg) when cows received the LCS. Feeding at the HCS resulted logically in higher intakes of concentrate DM (13.6 vs. 8.0 kg), and of total DM (20.1 vs. 15.8 kg), and OM (18.7 vs. 14.7 kg). The forage to concentrate ratio was notably higher (31.7:68.3 vs. 49.3:50.7) in association with LCS. The only parameters under evaluation not influenced by level of concentrate supplementation were intake of NDF (6.6 kg) and intake of NDF as a percentage of BW (1.24%).

TABLE 9. *Intake of DM, organic matter (OM), and NDF of cows in early lactation supplemented at a high or low level with a dairy concentrate without (DC) or with (PPC) added ruminally protected protein.*

	Concentrate supplementation					
	High level		Low level			
	DC	PPC	DC	PPC	SE	P<
Intake, % body weight						
Grass hay	1.01	1.32	1.47	1.51	0.10	0.02
DM (Total)	3.49	3.87	3.07	3.03	0.11	0.01
OM	3.23	3.64	2.83	2.83	0.10	0.01
NDF	1.06	1.30	1.28	1.30	0.07	NS
Forage, % ration DM	28.50	34.80	49.10	49.50	2.00	0.01
Intake, kg/day						
Hay	5.50	7.30	7.80	7.90	0.47	0.02
Concentrate	13.50	13.80	8.00	8.00	—	0.01
DM (Total)	19.00	21.20	15.80	15.90	0.47	0.01
OM	17.60	19.90	14.50	14.90	0.44	0.01
TDN	13.90	15.20	10.70	10.80	0.33	0.01
NDF	5.70	7.10	6.80	6.80	0.34	NS

Consumption of grass hay DM and of total DM as a percentage of BW tended to be higher when cows consumed PPC, particularly HCS. Intake of OM relative to BW was also higher ($P < 0.05$) when PPC was fed (3.23 vs. 3.03%). This difference was influenced by the observed difference in OM concentration between concentrates. As previously reported, intake of DM (3.68 vs. 3.05%) and OM (3.43 vs. 2.83%) as a percentage of BW was lower for the LCS, whereas consumption of hay DM (1.17 vs. 1.49%) was higher ($P < 0.05$).

Type of concentrate fed did not influence any of the milk production or composition criteria evaluated (Table 10). However, increasing the level of concentrate supplementation increased daily yields of milk (25.5 vs. 22.6 kg) and protein (0.76 vs. 0.66 kg), but decreased milk fat concentration (2.66 vs. 3.19%). The lack of an effect of level of concentrate supplementation on FCM yield was a consequence of the observed reduction in milk fat concentration at the HCS.

Results regarding efficiency of milk production of the cows in early lactation are presented in Table 11. Type of concentrate did not significantly influence any of these criteria; however, as in experiment 1 there was a tendency for the ENU to be higher (26 vs. 30%) when the PPC was consumed. All the efficiency parameters evaluated were affected ($P < 0.01$) by the level of concentrate supplementation. Supplementing concentrate at the lower level resulted in higher efficiencies

TABLE 10. *Milk composition and production of cows in early lactation supplemented at a high or low level with a dairy concentrate without (DC) or with (PPC) added ruminally protected protein.*

	Concentrate supplementation					
	High level		Low level			
	DC	PPC	DC	PPC	SE	P<
Production, kg/day						
Milk	24.80	26.30	22.60	22.60	0.72	0.01
FCM-3.25%	22.80	23.20	22.20	22.40	0.50	NS
Fat	0.68	0.67	0.71	0.72	0.02	NS
Protein	0.74	0.79	0.67	0.66	0.03	0.01
Composition, %						
Fat	2.77	2.55	3.17	3.20	0.09	0.01
Protein	3.00	3.01	2.95	2.91	0.04	NS

for utilization of concentrate DM(1.86 vs. 2.84), total DM (1.27 vs. 1.43), concentrate OM (1.77 vs. 2.98), and total OM (1.22 vs. 1.52) for milk production, and in higher ENU (24 vs. 31%).

In spite of the above differences, feeding at the HCS resulted in greater IOFC ($8.31 vs. $8.01; Table 12). This difference, although small, would represent about $11,000 more annual income after subtracting feeding costs for every 100 cows than when the LCS is fed.

DISCUSSION

Chemical composition of the concentrates used in the two experiments was very similar in terms of fiber, estimated TDN, and mineral concentrations. The major differences observed were the lower CP con-

TABLE 11. *Efficiency of production of cows in early lactation supplemented at a high or low level with a dairy concentrate without (DC) or with (PPC) added ruminally protected protein.*

	Concentrate supplementation					
	High level		Low level			
	DC	PPC	DC	PPC	SE	P<
Efficiency, kg/kg						
Milk/concentrate	1.83	1.89	2.85	2.84	0.07	0.01
Milk/DMI	1.31	1.23	1.45	1.42	0.03	0.01
FCM-3.25%/concentrate-OM	1.81	1.74	3.02	2.95	0.07	0.01
FCM-3.25%/OM	1.30	1.15	1.54	1.50	0.05	0.01
N-milk/N-feed	0.22	0.26	0.30	0.33	0.01	0.01

TABLE 12. *Milk income over costs of ration consumed by cows in early lactation supplemented at a high or low level with a dairy concentrate without (DC) or with (PPC) added ruminally protected protein.*

	Concentrate supplementation			
	High level		Low level	
	DC	PPC	DC	PPC
Milk income, $/d[1]	12.90	13.68	11.75	11.75
Feed Costs, $/d[2]				
Grass hay	1.11	1.47	1.57	1.58
Concentrate	3.65	3.73	2.15	2.17
Total ration	4.76	5.20	3.72	3.75
Income over feed costs, $/d	8.14	8.48	8.03	8.00

[1]Milk price during the year of the experiment multiplied by daily fluid milk production.
[2]Concentrate and hay cost, multiplied by mean daily consumption of experimental cows.

centration of the PPC and the lower RUP concentration as a percentage of CP of the DC in E2. The concentration of RUP was similar in PPC (50%) in the two experiments. Despite having used hay from two different grasses in E1 (PGH) and E2 (BGH), their chemical composition was very similar as a consequence of being harvested at a similar age. Increasing concentrate supplementation influenced intake of hay from both grasses negatively, and DMI positively in both experiments. For every one-kilogram increase in concentrate intake, grass hay intake of HCS relative to LCS declined 0.25 kg in early lactation and 0.42 kg in late lactation (Figure 1). These substitution values agree with those observed by Fike et al. (2003) upon increasing concentrate level fed to Holstein cows consuming Bermuda grass pasture and producing less than 20 kg/d of milk. On the other hand, the present substitution values are lower than those reported by Yang et al. (2001) when cows consuming high quality forages (alfalfa) were supplemented.

In both experiments, increasing concentrate supplementation increased total DMI. When the cows were fed HCS, DMI increased 0.76 and 0.57 kg per kilogram of concentrate consumed during early and late lactation, respectively, relative to that of LCS. Furthermore, with HCS, mean intake of OM increased by 2.1 and 4.0 kg/d during early and late lactation, respectively, relative to LCS. These results agree with those of Fike et al. (2003), who found that increased concentrate supplementation of cows grazing tropical pastures resulted in greater OM intake despite indications of higher forage substitution with increased stocking rate. The effect of concentrate supplementation in increasing

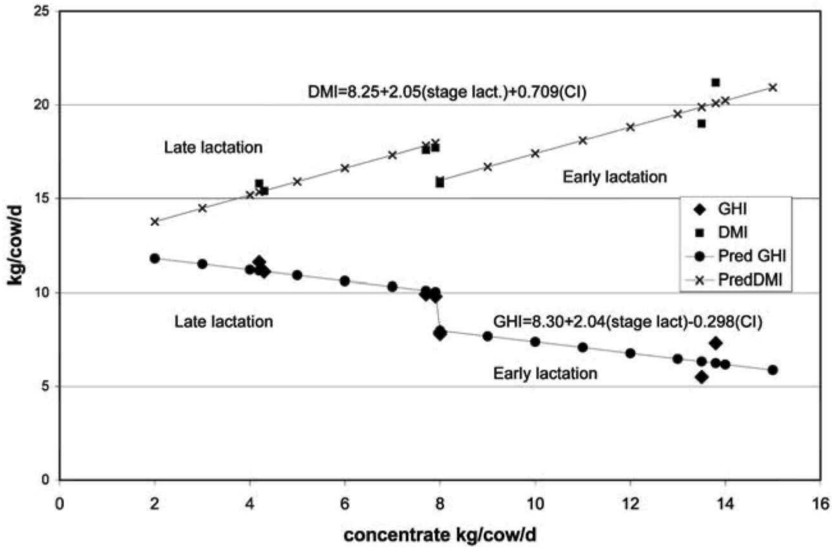

FIGURE 1. Daily grass hay DM intake (GHI) and total DM intake (DMI) relative to concentrate intake (CI) by cows in early and late lactation.

DM and OM intakes appears to vary inversely as the quality of the forage increases. Yang et al. (2001) found no effect on DMI and only a tendency for increased intake of OM when the proportion of a mixture of alfalfa and barley silages was reduced from 55 to 35% of the ration DM and concentrate supplementation was correspondingly increased.

For cows consuming similar amounts of concentrate, DMI was higher for cows in late lactation; grass hay DM intake being about 2 kg/d greater. This finding is indicative of the greater appetite and intake capacity associated with late lactation (NRC, 2001) relative to early lactation, when intake capacity is limited. Although mean DMI was higher for cows in early lactation than for those in late lactation, this difference is related to the lower NDF concentration of the rations consumed by cows in early lactation.

Further evidence of the higher intake capacity of cows in late lactation was provided by their NDF intake. Fill or intake capacity has been defined as the fiber intake capacity of the cow (Mertens, 1994). In neither of the two trials did experimental rations influence NDF intake. However, cows in late lactation consumed greater amounts of NDF relative to BW (1.61 vs. 1.24%) than those in early lactation. These differences amounted to approximately 2 kg of extra DMI when cows consumed similar amounts of concentrate (Figure 1).

At both stages of lactation, type of concentrate fed did not influence any of the production parameters evaluated; this despite the large differences in calcium concentration observed between concentrates. It appears that cows, particularly those in early lactation, were able to compensate for any deficiency with calcium released from bone and prevent any adverse effect on production during the short 15-day experimental period. These results are not surprising, since differences in RUP concentration of the diets due to concentrate type were small. Increasing the level of concentrate supplementation improved daily milk production by 1.3 and 2.9 kg for cows in late and early lactation, respectively. Fike et al. (2003) also reported increases of milk yield of about 3.1 kg/d (18.7%) when concentrate supplementation of Holstein cows grazing Tifton 85 Bermuda grass increased from 0.33 to 0.5 kg/kg of milk. The production responses to higher levels of concentrate supplementation decrease as forage quality increases. These same authors reported differences in milk yield of only 1.9 kg/d (10%) with supplementation when the cows grazed rhizoma peanut. Yang et al. (2001) found that increasing the forage to concentrate ratio from 35:65 to 55:45 caused only a 1.1 kg (4.5%) reduction in milk yield when alfalfa was the main forage. However, in other cases, production response to supplementation relative to no supplementation can be large even when high quality forages are fed (Bargo et al., 2002).

An increase in FCM with supplementation was observed for cows in late lactation, but not for cows in early lactation, because of lower milk fat concentration associated with HCS in early lactation. This effect in early lactation was not unexpected, but surprisingly there was some evidence of a reverse tendency for cows in E1. During late lactation, estimated energy consumption for cows on LCS was only marginally adequate to meet maintenance and production demands. Furthermore, cows receiving the HCS consumed diets with forage-to-concentrate ratios high enough to prevent any milk fat decrease. No production response to increased concentrate supplementation was observed in dairy cows producing between 14 and 17 kg of milk daily and consuming Bermuda grass pasture when pasture herbage availability was not limited (Fike et al., 2003). Thus, the lower milk fat concentration when cows in late lactation received the LCS could have been associated with low energy intake.

The efficiency of nitrogen use for milk production was the only variable measuring production efficiency that was significantly affected by type of concentrate consumed (Tables 5 and 11). When cows received PPC, the ENU was higher. This result cannot be explained entirely by the amount of RUP consumed, but is probably also influenced by the nature and quality of the RUP mix in PPC.

One effect of HCS was to increase the CP concentration in the consumed diet by early lactation cows relative to that of the LCS (Table 8). It also resulted in the reduction in the ENU (Tables 5 and 11). This finding is particularly evident for cows in early lactation, when increasing dietary CP concentration from 12.2 to 17.0% resulted in a decline in the ENU from 33 to 22%. Relevant to the explanation of this result are the data presented by Gustafsson et al. (2001) showing an increase in ENU of 1.5 to 2.0% units per unit decrease in dietary CP. They also suggest that a level of N efficiency of 28 to 30% is adequate for most dairy cows.

Feeding at a HCS not only resulted in greater milk production but also in favorable IOFC outcome compared to that of LCS (Tables 6 and 12). At worst, feeding the HCS to late lactation cows resulted in an IOFC that was similar to those obtained for the cows receiving the LCS. Thus, it is comprehensible that dairy farmers on the Island, who receive a high price for their milk, commonly feed high levels of concentrate supplementation to maximize their milk production and IOFC.

Under the conditions of this study, there was no effect of PPC on the production variables evaluated with Holstein cows in early and late lactation. Increasing the level of concentrate supplementation resulted in a reduction of grass hay DM intake in early and late lactation, but greater total DMI and milk production, even for cows in late lactation. Most importantly, feeding the HCS improved IOFC for cows in early lactation, thus lending support to the common practice of feeding high levels of concentrates to cows of high productive potential to maximize milk yield and farm income in Puerto Rico.

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