Effects of a Polymer-Coated Urea Product on Nitrogen Metabolism in Lactating Holstein Dairy Cattle

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ABSTRACT

The purpose of this study was to evaluate the impact of polymer-coated urea on nitrogen retention, rumen microbial growth, and milk production and composition. Coated urea (CU) that is more slowly hydrolyzed to ammonia than unprotected urea could potentially be used more efficiently by rumen microorganisms. Eight cows were offered each of three diets in a randomized crossover design. Each treatment period consisted of a 14-d adjustment period and a 5-d collection period. Diets were formulated to maintain milk production while reducing plasma urea nitrogen concentrations and urinary nitrogen excretion. Diets consisted of corn silage, mixed grass/legume haylage, chopped alfalfa hay, corn meal, protein, vitamin and mineral supplements, in a total mixed ration and fed ad libitum. The diets contained 17.9%, 18.1%, and 16.4% CP and 0, 0.77%, and 0.77% CU (dry matter basis) and are denoted as CP18-CU, CP18+CU, and CP16+CU, respectively. Individual feed intakes were measured, and total fecal, and urine collections were conducted. Cows were milked twice daily at 0500 and 1700 h, and the milk sampled for composition and milk urea N analysis. Dry matter intake averaged 23.5 ± 0.2 kg/d and was not altered by diet. Also, milk fat and true protein were not altered by diet and averaged 3.72 and 3.07%, respectively. Milk yield was highest for diets CP18-CU and CP18+CU. Significant differences were observed in N intake and excretion in urine, feces, and milk between dietary treatments. Cows fed CP16+CU consumed 11% less N than in CP18-CU. Cows fed CP18+CU showed the highest excretion of N in urine, and together with CP16+CU, the lowest N excretion in feces. Nitrogen excretion in milk was lower for cows fed CP16+CU.

Calculated N balance was not significantly different between diets nor was it significantly different from zero. Efficiency of N capture in milk protein as a function of N intake was higher for animals on CP16+CU. Urinary excretion of purine derivatives was not different between diets, and estimated microbial CP was also similar. Coated urea was not effective at reducing nitrogen excretion by dairy cattle.

(**Key words:** coated urea, nitrogen metabolism, nitrogen balance, nitrogen excretion)

Abbreviation key: CU = coated urea, DOM = digestible organic matter, MCP = microbial crude protein, MUN = milk urea nitrogen.

INTRODUCTION

Nonprotein nitrogen can be used effectively as a source of nitrogen for the rumen microbes in diets for dairy and beef cattle. The amount of NPN that can be used is limited because of the rapid hydrolysis of the nitrogen in the NPN sources to ammonia in the rumen. This rapid breakdown to ammonia can occur at a much faster rate than ammonia utilization by the rumen bacteria, resulting in accumulation and escape of ammonia from the rumen (Satter and Roffler, 1975). The net result is that a potentially large part of the nitrogen from NPN sources is wasted and not utilized by rumen bacteria. Slow-release NPN compounds, which have been fed to ruminants, include isobutylidene diurea, acetylurea, biuret, starea, tung- and linseed-oil-coated urea and formaldehyde treated urea (Mudd, 1977; Tamminga and Hellemond, 1977; Miller, 1979; Owens et al., 1980;). These compounds have not been as advantageous as urea because a substantial part of the NPN in them may leave the rumen without being converted to ammonia, reducing its incorporation into microbial protein, and also because the ammonia formation from these compounds in the rumen, though slower than urea, was still too fast to optimize microbial protein

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Table 1. Ration ingredients (on DM basis) given as % of total DM.

Feedstuffs	CP18-CU	CP18+CU	CP16+CU
Corn silage	27.59	27.68	29.40
Grass/legume haylage	15.70	15.76	15.76
Western alfalfa hay (chopped)	6.79	6.81	6.82
Ground corn	23.77	26.83	29.40
Soy hulls	2.42	2.34	1.28
Wheat middlings	0.00	5.11	2.64
Dried distiller's grains with solubles	6.79	0.43	0.00
Canola meal	4.24	0.00	0.00
Soybean meal, solvent extracted	3.69	4.73	5.11
Corn gluten meal 60% CP	1.27	0.64	0.00
SoyPlus ¹	2.55	3.32	3.41
Fish meal, menhaden	0.55	0.72	0.43
Blood meal, porcine	1.10	0.81	0.60
Urea	0.30	0.13	0.09
Optigen 1200 ²	0.00	0.77	0.77
Molasses	0.42	0.43	0.68
Megalac ³	0.76	1.15	1.07
Limestone	1.06	1.11	1.11
Salt	0.38	0.38	0.38
Potassium magnesium sulfate	0.25	0.34	0.38
Magnesium oxide	0.17	0.17	0.17
Dicalcium phosphate	0.08	0.26	0.34
Trace mineral mix	0.04	0.04	0.04
Vitamin ADE mix	0.04	0.04	0.04
Lysine HCl	0.00	0.00	0.09

¹West Central Soy, Ralston, IA.²CPG Nutrients, Syracuse, NY.³Church & Dwight, Princeton, NJ.

production by rumen bacteria (Owens and Zinn, 1988; Henning et al., 1993).

Because ammonia produced in the rumen is used for microbial growth, which is also dependent on energy availability, it is important that the rate of ammonia production in the rumen be coordinated with the rate of carbohydrate digestion. If the rates of rumen ammonia production and carbohydrate digestion are not synchronized, ammonia concentrations in the rumen will fluctuate after feeding (Newbold and Rust, 1992; Henning et al., 1993). It was hypothesized that coated urea (CU) would reduce nitrogen excretion in lactating Holstein dairy cattle by improving nitrogen utilization by rumen microbes without any adverse effects on DMI, milk production, and milk composition. To test this hypothesis, the objectives of this study were to evaluate the impact of feeding polymer-CU (Optigen 1200 Controlled Release Nitrogen; CPG Nutrients, Inc., Syracuse, NY) 1) on nitrogen excretion in urine, feces, milk, and calculated nitrogen balance, 2) rumen microbial crude protein (MCP) production, and 3) DMI, milk production, and milk composition.

MATERIALS AND METHODS

Animals and Diets

All animal procedures were approved by the University of Vermont Institutional Animal Care and Use

Committee. Eight multiparous lactating Holstein dairy cows ranging from 55 to 144 DIM were used for this experiment. Three dietary treatments were assigned to every cow in a randomized crossover design with three experimental periods. Diets contained either 0.0 or 0.77% DM of CU, respectively (Table 1). Coated urea was part of a concentrate mix provided by CPG Nutrients, Inc. The CU product used contained 97% urea and 3% coating by weight. The forages used were corn silage, grass/legume haylage, and western alfalfa hay (Table 2). Diets were TMR mixed and fed two times a day at 0700 and 1600 h and offered ad libitum. All diets were formulated to be isoenergetic (1.76 Mcal estimated NE_L per kilogram DM; NRC, 1989). CP18-CU and CP18+CU were formulated to be isonitrogenous, and CP16+CU was formulated to contain more forage (55% vs. 50%) and have less nitrogen to test for efficiency of N utilization (Table 2).

Experimental Period and Data Collection

Each experimental period consisted of a total of 19 d. The first 14 d were for adaptation to the diet and the last 5 d for sample collection. Cows were weighed at the beginning and end of each adaptation and collection period. For the adaptation period, cows were housed in a tie stall barn and milked twice daily at 0500 and 1700 h. Feed was weighed and offered twice daily at 0700

Table 2. Chemical composition of the diets and forages.

Nutrient (% DM)	CP18-CU	CP18+CU	CP16+CU	Corn silage	Grass/ legume haylage	Alfalfa hay
DM %	52.0	51.6	50.9	33.1	31.1	85.7
CP %	17.9	18.1	16.4	7.8	16.8	17.4
NE _L (Mcal/kg DM) ¹	1.8	1.8	1.8	1.6	1.1	1.3
NDF %	35.9	35.5	34.2	43.7	62.2	45.9
ADF %	24.2	21.9	21.1	26.2	38.1	35.6
NFC ²	35.2	35.5	38.9			
NSC	30.4	32.4	34.8			
Starch %	26.9	29.0	31.4			
Sugar %	3.5	3.5	3.4			
Ether extract %	4.1	3.7	3.1			
Ash %	6.9	7.2	7.4			

¹Estimated using NRC, 1989.²NFC = Nonfiber carbohydrates.

and 1600 h. Refusals were collected and weighed after the morning feeding for individual cows. This schedule was continued through the 5-d collection period, which was conducted in a separate room designed for total urine and fecal collection. Cows were moved into this room on d 12 of the adaptation period and were allowed 2 d to adapt to the room before the 5-d collection period started. Daily fecal and urine production were measured daily at 0800 h and recorded. Urine was collected through indwelling urinary catheters (28 French, 100 ml balloon, latex foley catheters; Harvet, Spring Valley, WI 54767) into containers acidified with 1 L of 6 N sulfuric acid to prevent ammonia from volatilizing. Feces (5 kg), urine (150 ml), milk (75 ml), feed (5% wt/wt) and refusals (5% wt/wt) were sampled each day from each cow and frozen.

Laboratory Analyses

Feces, feed, and refusals were dried for 24 h at 105°C in a forced-air oven to determine DM content. They were later ground with a Wiley mill through a 3-mm screen. Feces, feed, and refusals were analyzed for CP using the Kjeldahl N methods (AOAC, 1990) at the University of Vermont and for ADF, NDF, lignin, ash, ether extract, NSC (AOAC, 1990), starch, and sugar content (Smith, 1969, as modified by Hall et al., 1999) at the West Virginia University Rumen Profiling Laboratory. Urinary N was also determined by Kjeldahl N methods. Milk composition was analyzed using near infrared spectrophotometry by the Vermont DHI laboratory. Milk urea N (MUN) and urine uric acid were determined using Sigma kits #640 and 685 (Sigma Diagnostics, St. Louis, MO), respectively (Butler et al., 1996; Valladares et al., 1999). Urine allantoin was determined according to Chen and Gomes (1992).

Nitrogen Balance Calculations

Nitrogen balance (retention) was calculated as intake N – fecal N – urinary N – milk N. Milk N was determined as milk true protein/6.38 plus milk urea and ammonia nitrogen content. MCP in g/d was determined according to the following equation: MCP (g/d) = 3.99 × 0.856 × mmoles of purine derivatives excreted (Vagnoni et al., 1997).

In Situ Determinations of Rumen Degradation Rates

Two in situ studies were conducted to determine the rumen degradation of dietary components (Weakley et al., 1983). In the first study, protein degradation of dried and ground samples from the three experimental diets was measured. In the second study, protein and starch degradation of the concentrate mixes (not dried or ground) for each experimental diet was measured. In the first study, bags with 25-cm² surface area were used and filled with 2 g of sample each. In the second study the surface area of the bags used was 100 cm², and each was filled with 5-g samples. The pore size for all bags was 50 ± 15 μm. In both studies, two lactating Holstein dairy cows fitted with rumen cannulas were used. Duplicate bags for each of the three experimental diets were removed from the rumen after the times indicated below. The bags were immediately rinsed with cold water until the rinse water was clear. Bags were then dried for 24 h at 105°C in a forced-air oven and analyzed for CP and starch as above.

In Vitro Urea Release

An in vitro study was conducted to evaluate the rate of urea release from the CU product isolated from the concentrate mixes that had been used in the animal feeding experiments. Coated urea product obtained di-

Table 3. Production and output variables, given as least squares means with pooled SE. Differing superscripts between diet means indicate significant differences ($P \leq 0.05$).

	CP18-CU	CP18+CU	CP16+CU	SE
DMI, kg/d	23.6 ^a	23.6 ^a	23.1 ^a	0.23
Milk yield, kg/d	35.6 ^a	34.8 ^{ab}	33.8 ^b	0.44
Milk fat, %	3.8 ^a	3.6 ^a	3.8 ^a	0.05
Milk true protein, %	3.1 ^a	3.1 ^a	3.1 ^a	0.02
Feces, kg of DM/d	7.8 ^a	7.7 ^{ab}	7.3 ^b	0.11
Urine, L/d	23.2 ^a	25.2 ^b	22.8 ^a	0.42
Milk/CP intake, kg/kg	8.4 ^a	8.2 ^a	8.8 ^b	0.11

rectly from the manufacturer was used as negative control, and uncoated urea was used as positive control. The samples (600 mg of each) were placed in separate beakers containing 100 ml of 39°C distilled water and incubated at 39°C on a rocking platform at 24 oscillations per minute. The solutions were sampled (10 μ l) at the indicated times. The samples were analyzed for urea nitrogen using Sigma kit #640.

Statistical Analyses

The mixed models procedure of SAS (Littell et al., 1996) was used for statistical analyses. The initial model used was an analysis of variance model with main effects for diet, period, and cow, with daily observations for a cow given as repeated measures within the period and all appropriate interactions. Interaction terms and period effects were tested and dropped from the model if they were not significant ($P > 0.20$). DIM was included as a covariate in the initial analysis for production and digestibility measurements. If it was not significant ($P > 0.20$), it was dropped from the model.

RESULTS

The diets did not affect milk fat percentage or milk true protein percentage (Table 3). Fat content of the milk approximated 3.7% across diets and is an indicator of good rumen fermentation and fiber digestion. Protein content of the milk was in agreement with Vermont's average milk protein percentage for the Holstein breed (3%, Table 3). Milk production was lower for CP16+CU when compared to CP18-CU ($P \leq 0.05$). DMI were similar for all diets and very close to initial predictions when formulating the diet (23.5 kg DM). No disruptions in DMI were observed during the switch from the adaptation to the collection period.

Urine production was 2.0 and 2.4 L/d higher for animals fed CP18+CU compared to CP18-CU and CP16+CU, respectively ($P \leq 0.05$, Table 3). The extra urine volume that was produced probably provided a vehicle for urinary nitrogen excretion, which was also

higher for CP18+CU ($P \leq 0.05$, Table 4). Water consumption was not recorded for any of the diets.

Significant differences in N intake were achieved by diet formulation. Significant differences were observed in N excretion in urine, feces, and milk between diets (Table 4). Calculated N balance was not different between diets nor was it different from zero ($P > 0.05$). CP18+CU had the highest urinary N excretion of all diets. CP18-CU and CP16+CU did not differ in terms of urinary N excretion. MUN, in agreement with urinary nitrogen, was highest for CP18+CU ($P \leq 0.05$), and was not different for diets CP18-CU and CP16+CU (Table 4). CP18+CU and CP16+CU had lower fecal N excretions than CP18-CU ($P \leq 0.05$, Table 4).

Urinary excretion of allantoin was not affected by diet (Table 4). However, urine uric acid excretion levels did change across diets. Allantoin and uric acid were used to estimate the flow of MCP to the abomasum of the cows. Because allantoin is the major purine derivative, MCP production in the rumen was not different across diets and averaged 1.7 kg/d.

Animals fed CP16+CU were more efficient in terms of protein utilization (Table 3). They produced about 0.5 kg more milk for each kilogram of crude protein consumed. The efficiency of microbial crude protein production per unit of digested organic matter consumed was not affected by diet and averaged 112.7 ± 2.6 g CP per kilogram of digestible organic matter (DOM) (Table 4).

Total tract apparent DM and CP digestibilities were higher for CP18+CU when compared to CP18-CU (Table 5). Apparent ADF digestibility was lower for both CP18+CU and CP16+CU (Table 5). Apparent digestibilities for other feed components (organic matter, NDF, starch, sugar, and NSC) did not differ across diets ($P > 0.05$).

To evaluate whether the different diets had resulted in different rumen availabilities of energy and nitrogen as a result of protein and starch degradation, two in situ studies were conducted. The rumen rate of degradation of dry matter in the total mixed rations of the three diets was similar when they had been dried and

Table 4. Components of nitrogen balance, milk urea N, urinary excretion of purine derivatives, and estimated microbial CP flow from the rumen (MCP), given as least-squares means with pooled SE. Differing superscripts between diet means indicate significant differences ($P \leq 0.05$).

	CP18-CU	CP18+CU	CP16+CU	SE
N balance measures				
N intake (g/d)	683.4 ^a	687.9 ^a	614.8 ^b	8.12
N in feces (g/d)	231.2 ^a	209.9 ^b	197.3 ^b	3.45
N in urine (g/d)	259.9 ^a	302.2 ^b	245.4 ^a	5.08
N in milk (g/d)	181.8 ^a	177.2 ^{ab}	171.8 ^b	2.16
N balance (g/d)	11.1 ^a	-1.7 ^a	-0.3 ^a	6.35
Milk urea N (mg/dl)	19.8 ^a	23.1 ^b	19.8 ^a	0.40
% of N intake in				
Feces	33.9 ^a	20.7 ^b	32.4 ^{ab}	0.43
Urine	38.2 ^a	44.7 ^b	40.5 ^a	0.75
Milk	25.5 ^a	25.8 ^a	28.0 ^b	0.27
Purine derivatives				
Allantoin (mmoles/d)	278.9 ^a	290.2 ^a	267.1 ^a	7.97
Uric acid (mmoles/d)	87.4 ^{ab}	93.0 ^a	82.6 ^b	2.06
MCP (g/d)	1706.1 ^a	1784.6 ^a	1631.5 ^a	41.01
Microbial CP (g)/digested OM (kg)	112.4 ^a	115.8 ^a	110.8 ^a	2.59

ground (Figure 1a). The only significant effect was due to time spent in the rumen. The effects of diet and individual cows were not significant. The rumen rate of crude protein degradation of the three diets was also similar, and time was the only significant factor (Figure 1b). The rate of passage of a particular diet would be a major determinant of the extent of degradation of the DM and CP in the rumen. Thus, the in situ degradation or disappearance of the total mixed rations is not likely to be a complete indication of the potential degradation in vivo.

Rumen rates of degradation of DM and starch in the three concentrate mixes over time were not different ($P > 0.05$; Table 6). However, the rate of degradation of CP in the rumen was lower for CP16+CU when compared to the rates for the other two diets (Table 6). The intercepts represent the insoluble components (DM, CP, or starch) that were not washed out during the initial rinse.

Preliminary data had indicated that the release rate of urea from the coated product should be approximately 20% of uncoated urea (S. M. Emanuele, unpub-

Table 5. Apparent total tract digestibilities, given as least squares means with pooled SE. Differing superscripts between diets means indicate significant differences ($P \leq 0.05$).

Digestibility (%)	CP18-CU	CP18+CU	CP16+CU	SE
DM	65.9 ^a	69.3 ^b	67.6 ^{ab}	0.71
OM	68.4 ^a	69.2 ^a	70.0 ^a	0.72
CP	66.1 ^a	69.3 ^b	67.6 ^{ab}	0.60
NDF	48.8 ^a	49.9 ^a	47.5 ^a	1.11
ADF	49.2 ^a	44.2 ^b	43.2 ^b	1.45
Starch	88.2 ^a	88.8 ^a	88.1 ^a	1.02
Sugar	82.8 ^a	83.9 ^a	83.4 ^a	1.00
NSC	87.5 ^a	87.4 ^a	89.4 ^a	1.02

Figure 1. DM (A) and CP (B) disappearance (% of initial) of dietary treatments at different times of incubation in the rumen of cattle. Data are given as means with vertical bars representing one standard error. CP18-CU (◆), CP18+CU (■), CP16+CU (▲).

Table 6. Equation parameters for DM, CP, and starch degradation of concentrate mixes in the rumen as a linear function of time. Differing superscripts indicate significant differences between slopes for diets ($P \leq 0.05$).

Parameter	CP18-CU	CP18+CU	CP16+CU	SE
DM remaining				
Intercept	79.40	74.50	85.40	1.60
Slope	2.13	2.33	2.00	0.18
CP remaining				
Intercept	80.20	69.50	70.00	1.65
Slope	1.79 ^a	1.85 ^a	1.21 ^b	0.16
Starch remaining				
Intercept	99.80	88.60	102.70	2.70
Slope	3.27	3.63	2.90	0.30

lished results). To evaluate whether the coating on the urea product had been damaged during mixing at the feed manufacturer, in delivery and unloading from storage, and/or during mixing into the TMR, rates of urea release were determined in vitro. Urea release from the CU used in the feeding experiment was 83% as extensive as uncoated urea after 1 h of incubation in water (Figure 2). The CU, which had not been mechanically handled, had released 67% as much urea as uncoated urea in 1 h (Figure 2). Both samples of CU released their urea rapidly in distilled water. Slower release rates into rumen fluid would be predicted (S. M. Emanuele, unpublished results). However, relative differences in release rates between CU samples would be expected to be the same.

DISCUSSION

Urinary nitrogen excretion was higher for CP18+CU when compared to the CP18-CU, which suggests that

Figure 2. Urea release from polymer-coated products in vitro in distilled water compared to uncoated urea. Uncoated urea (○), coated urea used in animal experiments (■), and negative control—coated urea not mixed in diets (△) shown as means and standard errors of duplicate incubations.

the nitrogen in CU was released more rapidly than expected (6 to 10 h) and was not captured in MCP. This could have been due to damage of the polymer coating during feed mixing or transport. Cows fed urea at levels equivalent to those of CU in this study (0.27 g urea per kilogram of BW) died due to ammonia toxicity within 2.5 h of feeding (Davis and Roberts, 1959). This suggests that if the coating had been completely destroyed, ammonia toxicity would have been likely to occur. No evidence of ammonia toxicity was observed in the current study. Increased urinary nitrogen excretion could also be a consequence of lower than expected rumen starch digestibilities across all diets, which would reduce MCP synthesis from CU.

Urine was the most prevalent route for excretion of nitrogen, followed by feces (Table 4). In a study by MacGregor et al. (1983), milk was the main route for nitrogen excretion, followed by feces. Urinary excretion of nitrogen will rise when there is ammonia accumulation in the rumen or high levels of deamination occurring in the body, due to excess protein fed or an unbalanced amino acid profile. MUN levels across diets corresponded to the urinary nitrogen levels, being higher for CP18+CU and similar for CP18-CU and CP16+CU (Table 4). The efficiency of nitrogen use for milk protein synthesis was not altered with the inclusion of CU in the diets (Figure 3). Nitrogen balance was similar for all diets and not different than zero (Table 4), suggesting that inclusion of CU did not alter whole animal nitrogen metabolism. Both urine N and MUN excretion are indicative of the blood urea levels, which in turn is indicative of the rumen ammonia levels.

One indicator of the efficiency of rumen nitrogen use is the amount of MCP flow from the rumen, which is a consequence of microbial growth and its washout from the rumen (Sniffen and Robinson, 1987). In this study, estimated MCP flow from the rumen was not different across diets and averaged 1707 g/d (Table 4). MCP was also not different across diets when expressed in relation to DOM (113 g MCP per kilogram of DOM; Table

Figure 3. Milk protein as a function of crude protein intake. Each point represents one cow and one day. CP18-CU (●), CP18+CU (○), CP16+CU (☆).

3). NRC (2001) predicts MCP yields of 150 to 225 g MCP per kilogram of DOM with ruminal N balances of +20 and -20%, respectively.

In a study by Timmermans et al. (2000), testing the effects of several dietary factors, MCP flow to the duodenum ranged from 765 to 1925 g/d, DMI ranged from 15.5 to 26 kg/d, and N intakes ranged from 428 to 832 g/d. Klusmeyer et al. (1990) fed cows two concentrations of nitrogen, 390 g/d (11% CP) and 500 g/d (14% CP) and found no changes in MCP flow from the rumen (2110 g MCP per day). Stokes et al. (1991) fed different levels of NSC and RDP to Holstein cows and found no differences in microbial efficiencies in terms of MCP/DOM; the average was 150 g MCP per kilogram of DOM. These authors did see a reduction (-700 g/d) in MCP flow from the rumen for cows eating a diet low in NSC (24%) and low in RDP (9%).

Uric acid and allantoin comprised 24 and 76%, respectively, of the purine derivatives found in urine across all diets in the current study. Similarly, Johnson et al. (1998) reported uric acid in urine representing 23.5% of total purine derivatives excreted in urine of lactating cows. A very wide range of values (12 to 42%) of uric acid excretion as a percentage of total purine derivatives in urine are reported in the literature (Lindberg and Murphy, 1991; Giesecke et al., 1994; Gonda and Lindberg, 1997; Vagnoni and Broderick, 1997; Vagnoni et al., 1997; Valladares et al., 1999).

Animals produced between 8.2 to 8.8 kg of milk for every kilogram of CP intake (Table 3). The highest efficiency was for CP16+CU, while CP18-CU and CP18+CU did not differ statistically. CP16+CU had a higher NSC content and lower protein content than CP18-CU. The

extra NSC may have allowed for more rumen ammonia to be captured and utilized by the rumen microbes, increasing its efficiency of conversion into milk. However, these efficiencies are lower than the 9 and 11.6 kg of milk per kilogram of CP intake reported when different sources of carbohydrates and proteins were fed (McCarthy et al., 1989).

Cows fed CP18+CU had higher apparent total-tract digestibilities of CP and DM compared to CP18-CU and lower ADF digestibility (Table 5). Cows on CP16+CU also had lower ADF digestibility than CP18-CU. Differences in nutrient digestibilities between diets may be due to the use of different feedstuffs across diets to achieve the desired chemical composition. Starch digestibility was not different across diets but was lower than expected (88% vs. 92 to 95%). This could explain the lack of effects of CU inclusion in diets and also the reduced milk yield per kilogram of CP intake.

One possible explanation for the lack of response to feeding CU is that the release rate was more rapid than expected due to mechanical damage of the coating. In vitro release rates were very rapid (Figure 2). If CU was released faster than expected, then ammonia would accumulate at a time when energy was not yet available to the microbes, and ammonia would escape the rumen and end up being excreted as urea.

Rumen rates of starch degradation were not different across diets but were slower than expected (Figure 4). These rates approximate those observed for medium ground corn and were slower than the rates observed for fine ground corn by Callison et al. (2001, Figure 4). After 10 h of in situ incubation, the extent of starch degradation was 48, 31, and 25% for CP18+CU, CP18-

Figure 4. Rumen starch digestibilities of concentrate mixes compared to estimates calculated from degradation of corn meal differing in grind size (Calliston et al., 2001). CP18-CU (△), CP18+CU (□), CP16+CU (◇), fine ground corn meal (◆), medium ground corn meal (▲), coarse ground corn meal (■).

CU, and CP16+CU, respectively. Consequently, energy may not have been available to the microbes at the time when ammonia from the CU was present.

CONCLUSIONS

Inclusion of coated urea did not affect DMI. Coated urea increased urinary N excretion in cows fed CP18+CU. It also increased urinary N excretion in cows fed CP16+CU above what would have been expected from their reduced CP intake. These changes in urinary N excretion are paralleled by changes in MUN and lack of responses in MCP to dietary manipulation. The most likely explanations for these observations are either a partial breakdown of the polymer coating of coated urea and rapid release of the urea or a lower rumen starch digestibility than formulated, which affected microbial N utilization, or a combination of both. Urea was released at a faster rate in vitro than expected from the coated urea capsules, and starch was degraded slower than expected for all three diets, which supports the idea that a combination of both factors was responsible for the results obtained in this experiment in terms of N utilization by the animals. Improvements in these aspects may allow for similar approaches to increase efficiency of N utilization by ruminant animals.

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