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*J Anim Sci* 2001. 79:753-760.

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# Optimization of rate and efficiency of dietary nitrogen utilization through the use of animal by-products and(or) urea and their effects on nutrient digestion in Holstein steers<sup>1</sup>

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**ABSTRACT:** The objective of this N balance study was to determine the potential for improving the efficiency and rate of dietary N utilization in Holstein steers by feeding an amino acid-balanced mixture of animal by-product protein sources in combination with urea. The Beef NRC 1996 Model Level 2 was used to formulate a corn-based (86:14 concentrate-hay) control diet with soybean meal as the primary N supplement that would provide ME and metabolizable protein (MP) allowable ADG of 1.4 kg in 250-kg steers with an estrogenic implant and fed an ionophore. A combination of porcine meat and bone meal, fish meal, hydrolyzed feather meal, and blood meal was also formulated as an undegradable intake protein (UIP) blend to complement those amino acids (AA) derived from microbial protein synthesis. Four steers with an average initial BW of 259 kg were assigned in a 4 × 4 Latin square design to treatments consisting of control, two levels of UIP inclusion (2.6 and 5.2%; DM basis) in combination with urea, and a negative control “urea diet” containing no UIP and no SBM. The steers were fed at hourly

intervals 95% of ad libitum intake and were injected with 500 µg of estradiol-17β twice daily. Nitrogen intakes were 155, 160, 162, and 145 g/d, and N balances were 47, 51, 42, and 47 g/d when the 0, 2.6, 5.2% UIP and the urea diets were fed, respectively. Nitrogen balance was reduced with the 5.2% UIP diet ( $P < 0.05$ ), and was less than the capacity estimate derived from abomasal casein infusion studies. Apparent N digestibilities averaged 69%, but DM, OM, and nonstructural carbohydrate digestibilities were significantly reduced for the urea diet. Feeding 5.2% UIP in the diet reduced ( $P < 0.05$ ) the biological value from 46 to 38%, which was accompanied by a significant elevation of plasma urea N. Results indicate that genetic capacity for N retention was approximately 51 g/d. Results demonstrate that use of an AA-balanced blend of animal by-product protein sources did not improve the efficiency of dietary N usage when added to corn-based diets formulated with the Beef NRC 1996 Model Level 2 to meet nutrient requirements of rapidly growing steers. Using urea as the only N supplement achieved equal rate and efficiency of N use.

Key Words: Animal By-products, Digestion, N Balance, Protein Efficiency, Steers, Urea

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J. Anim. Sci. 2001. 79:753–760

## Introduction

A major goal in the 21st century is to increase the efficiency of dietary CP use by beef cattle to reduce

the excretion of N metabolites that may impact the environment (Spears, 1996). The challenge is to match the amount and spectrum of AA reaching the small intestine with the protein and AA requirements. Balance and quantity of postruminal AA supply can be altered by increasing net microbial protein synthesis, manipulating supplemental protein source, or feeding ruminally protected AA (Merchen and Titgemeyer, 1992). Titgemeyer et al. (1989) concluded that combinations of protein sources may be best able to supply AA to the ruminant animal in optimal proportions. Abomasal casein infusion studies with similar cattle suggest that the capacity for N retention may be higher (58 to 64 g/d; Moloney et al., 1998, Robinson, 1998) than previous estimates of 45 to 50 g/d, increasing the potential value of enhancing postruminal AA supply.

<sup>1</sup>The authors express their gratitude to the Austrian Science Foundation (FWF) for financial support of this research in the form of the Erwin Schroedinger Scholarship for W. F. Knaus. Gratitude is also expressed to Moyer Packing Company, Souderton, PA, to Taylor By-Products, Inc., Wyalusing, PA, and to Agway, Inc., Syracuse, NY, for providing animal by-product materials. A portion of the financial support for this work was provided by the Fats and Proteins Research Foundation, Bloomington, IL. Thanks are expressed to Hector Castillo for advice on statistical analysis; to Bill English, Susanne Pelton, and Lisa Furman for technical assistance; to Kathleen Knaus for editing assistance; and to Joanne Parsons for her practical support.

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Received May 1, 2000.

Accepted October 12, 2000.

The Beef NRC 1996 Model Level 2 can be used to formulate "AA-balanced" mixtures of animal by-products that complement the amount and(or) pattern of AA derived from microbial protein. Supplementation of corn-based diets with this mix has been shown to improve retention rates and efficiency of dietary N usage in growing steers (Knaus et al., 1998; Robinson, 1998). The objectives of this study were to test the hypotheses that feeding increasing amounts of an AA-balanced UIP mixture would increase N balance and improve efficiency of N use in estradiol-treated Holstein steers, provide validation of the Beef NRC 1996 Model Level 2, and compare results with a negative control diet that contained urea as the only N supplement. An AA-balanced blend of porcine meat and bone meal, fish meal, hydrolyzed feather meal, and blood meal was used in combination with urea. Rate and efficiency of N retention, plasma metabolite and insulin concentrations, and nutrient digestion responses were measured in Holstein steers.

## Materials and Methods

### *Animals and Diets*

Four Holstein steers with an average BW of 215 kg were purchased from a commercial feedlot and transported to the Beef Unit of the Cornell University Animal Science Teaching and Research Center. Anabolic implants were removed, and after 3 wk the animals were brought to the Cornell University Large Animal Research and Teaching Unit. They were housed in four individual metabolism stalls in a monitor room under environmentally controlled thermoneutral conditions and acclimated for 2 wk before the onset of treatment. The metabolism stalls were constructed of galvanized pipe (3.8 cm in diameter) over rubber-padded concrete flooring and a metal grate for fecal collections. Stalls were about 2.3 m long  $\times$  1.1 m wide. The Cornell University Institutional Animal Care and Use Committee approved all procedures involving the steers used in this study.

The Beef NRC 1996 Model Level 2 (NRC, 1996), which uses the Cornell Net Carbohydrate and Protein System (Ainslie et al., 1993) as its structure, was used to formulate a corn-based (86:14 concentrate-hay) control diet that would meet the ruminal requirements for 250-kg steers having a finished weight of 550 kg, given an estrogen implant, and fed an ionophore. This diet contained soybean meal as a protein supplement and, based on the supply of ME and metabolizable protein (MP), allowed for an ADG of 1.4 kg. The Beef NRC 1996 Model Level 2 analysis predicted that the rumen would be balanced for N and would show a slightly positive (11 g/d) balance for peptides. The control diet was offered on an ad libitum basis for 2 wk prior to the onset of the treatment period to determine voluntary feed intake for each animal. Fresh feed was offered hourly via automatic rotary feeders, and feed refusals were weighed daily.

The Beef NRC 1996 Model Level 2 was also used to formulate a supplement to provide the optimal AA pattern needed to complement those AA derived from microbial protein, using a mixture of meat/bone meal, fish meal, feather meal, and blood meal. Except for the meat/bone meal, all animal by-product materials originated from the same processing plant and were assumed to be of a quality similar to those used in the experiment conducted by Knaus et al. (1998).

Steers were allocated to treatments (diets) arranged factorially in a 4  $\times$  4 balanced Latin square design. Treatments consisted of the addition of the UIP mixture to the corn-based diet at 0, 2.6, and 5.2% of the total mixed ration and one diet that included urea as the only N supplement and no SBM or UIP mix (urea diet). The ingredients and chemical composition of the diets are presented in Table 1, and the model predictions for the diets using the Beef NRC 1996 Model Level 2 with predicted and actual DM intakes are shown in Table 2. All diets were isocaloric based on their ME-allowed ADG values and were balanced for ruminal N. Bacterial N balance was kept positive at 3 to 5 g/d (Table 2). Metabolizable protein from bacteria was predicted to be the same for all three levels of UIP inclusions, but the MP from UIP would gradually increase with the addition of UIP.

An ionophore (Rumensin Elanco, Indianapolis, IN; 33 mg/kg feed) was added to all diets to help reduce the risk of acidosis (Stock et al., 1995). The control diet was fed hourly in equal portions via automatic rotary feeders for 14 d. The amount of feed offered daily was fixed at 95% of the ad libitum intake for each steer, as determined before the onset of the trial, and was maintained at that level throughout the treatment period. The first 7 d of each treatment period were allowed for adaptation to the diet. Nitrogen balance collections were conducted from d 8 to 14. Feed refusals were measured daily. Water was freely available throughout the study. The animals were weighed every 14 d to estimate growth rate. Beginning 2 wk before the initiation of the dietary treatments, the steers were injected s.c. in the front shoulder twice daily with 500  $\mu$ g of estradiol-17 $\beta$  to mimic the effects of an anabolic implant. The injection site was alternated between right and left shoulder after every injection. Subcutaneous injection was used to avoid the reducing payout effect of an implant. Estradiol-17 $\beta$  was chosen as the anabolic agent because it is used in many commercially available implants.

### *Sample Collection and Analysis*

Total feces, urine, and feed refusals were collected at 0900 daily during the N balance collection periods. Continuous suction of the urine using a rubber funnel system attached to the ventral portion of the abdomen allowed collection of urine into a plastic carboy. Urine acidity was reduced to pH < 2 by adding 200 mL of 12 N H<sub>2</sub>SO<sub>4</sub> to the collection reservoir in order to prevent ammonia N loss. Urine volume was recorded daily, and

**Table 1.** Ingredient and chemical composition of diets fed to Holstein steers<sup>a</sup>

Item	Undegraded intake protein, % <sup>b</sup>			Urea diet
	0	2.6	5.2	
	----- % of DM -----			
<b>Ingredient</b>				
Chopped grass hay	14.1	14.7	15.1	15.9
Cracked corn	70.7	73.6	75.8	79.8
Soybean meal	12.7	5.9	—	—
Meat and bone meal	—	0.89	1.78	—
Fish meal	—	0.65	1.30	—
Hydrolyzed feather meal	—	0.53	1.06	—
Blood meal	—	0.53	1.06	—
Urea	—	0.70	1.4	1.8
Salt and trace minerals	1.2	1.2	1.2	1.2
Limestone	1.3	1.3	1.3	1.3
<b>Chemical composition</b>				
OM, %	96.2	96.2	96.2	96.4
CP, %	13.9	14.7	15.4	13.5
Soluble protein, % of CP	16.8	37.0	42.5	52.0
NE, Mcal/kg				
Maintenance	1.98	2.00	1.97	2.05
Gain	1.33	1.34	1.32	1.39
NDF, %	18.4	17.8	19.8	17.6
ADF, %	11.7	10.6	12.4	11.2
NSC, %	60.9	61.4	58.3	61.8
Calcium, %	0.30	0.43	0.46	0.35
Phosphorus, %	0.40	0.41	0.41	0.36
Magnesium, %	0.18	0.17	0.17	0.17
Potassium, %	0.83	0.65	0.61	0.59
Sodium, %	0.32	0.39	0.36	0.39

<sup>a</sup>DM basis.<sup>b</sup>Levels represent the portion of added UIP expressed as a percentage of diet DM.

10% aliquots (by volume) were collected and composited for each steer for all 7 d within a collection period. Subsamples of urine were stored at  $-18^{\circ}\text{C}$ .

The wet weight of feces was measured, and feces were homogenized with 37% vol/vol formaldehyde solution (0.25 mL/kg wet feces) to retard spoilage. Feed refusals

and 10% aliquots of the feces were dried in a forced-air oven at  $65^{\circ}\text{C}$  to a constant weight. Orts, feed, and fecal samples were ground to pass through a 1-mm screen using a Wiley mill. Feed refusals and fecal samples were composited during grinding for each animal within each collection period.

**Table 2.** NRC (1996) Model (Level II) predictions for diets fed to 250-kg Holstein steers based on the predicted and the actual dry matter intake<sup>a</sup>

Item	Undegraded intake protein, % <sup>b</sup>			Urea diet
	0	2.6	5.2	
Predicted DMI, kg/d	6.14	6.18	6.21	6.25
Actual DMI, kg/d	6.94	6.83	6.75	6.79
Diet CP, % of DM	13.9	14.6	15.3	13.1
DIP, % of CP	67.3	64.6	61.4	73.9
Total NSC, % of DM	61.5	62.1	62.3	64.8
ME allowed ADG, kg/d	1.38 (1.66)	1.39 (1.60)	1.37 (1.54)	1.32 (1.51)
MP allowed ADG, kg/d	1.37 (1.72)	1.49 (1.76)	1.59 (1.81)	1.24 (1.46)
MP balance, g/d <sup>c</sup>	-3 (18)	30 (47)	64 (79)	-23 (-16)
Bacterial N balance, g/d	3 (3)	3 (3)	2 (3)	4 (5)
Peptide balance, g/d	11 (11)	-5 (-7)	-18 (-20)	-31 (-34)
MP from Bacteria, g/d	419 (467)	423 (460)	419 (449)	439 (475)
MP from UIP, g/d <sup>d</sup>	223 (273)	253 (293)	287 (320)	166 (190)

<sup>a</sup>Numbers in parentheses represent predictions based on the actual DMI.<sup>b</sup>Levels represent the portion of UIP expressed as a percentage of diet DM.<sup>c</sup>MP balance = Metabolizable protein absorbed – metabolizable protein requirement.<sup>d</sup>MP from UIP = The amount of metabolizable protein that is from undegradable intake protein.

Each steer was surgically fitted with a jugular vein catheter between 0900 and 1200 on d 14 of each treatment. Venous blood samples were collected in heparinized tubes at 60-min intervals over a 6-h period beginning at 1300 and were immediately centrifuged at 0 to 4°C and 3,000 × *g* for 20 min. The plasma was separated and frozen at -18°C. Blood sample collections encompassed six feed offerings to assess any feeding interval-related effects that might occur.

Nitrogen contents of feed, feed refusals, feces, and urine were determined by Kjeldahl analysis (AOAC, 1990) on duplicate samples. Chemical compositions of feedstuffs, total diets, orts, and feces were determined at the Northeast Dairy Herd Improvement Association Forage Testing Laboratory (Ithaca, NY). Nonstructural carbohydrate (NSC) content was calculated by difference (NSC = DM - CP - NDF - crude fat - ash). Because metabolic CP contains 7% N (Van Soest, 1994), fecal N was multiplied by the factor 14 to express it as CP. Amino acid concentration of the meat/bone meal treatment was determined by the supplier on oxidized and hydrolyzed samples using a modification of the Pico-Tag method (Millipore Corp., 1990).

Plasma glucose concentrations were measured using the Sigma kit (Procedure #510, Sigma Diagnostics, St. Louis, MO) for colorimetric determination. Plasma urea N (PUN) was measured by the Chaney and Marbach (1962) method using the Sigma kit (Procedure #640B Sigma Diagnostics, St. Louis, MO). Plasma NEFA concentrations were determined with a modification of an enzymatic colorimetric kit (NEFA-C, Cat. No. 990-75401, Wako Pure Chemical Industries, Dallas, TX). Plasma insulin concentrations were determined by a double antibody RIA system (McGuire et al., 1995).

### Statistical Analysis

All statistical analyses were conducted using Model 1 of the LSMLMW Analysis of Variance computer program (Harvey, 1990). Data were analyzed as a completely randomized 4 × 4 Latin square design. The model sums of squares were partitioned into the main effects of animal, period, and treatment. Only differences between UIP-diet least-squares means (i.e., those between the 0, 2.6, and 5.2% UIP diets and differences between the 0% UIP and the urea diet) were analyzed using the Bonferroni-Holm test procedure (Holm, 1979) when treatment effects were significant. All data are presented as least squares means. Differences were considered to be significant when *P* < 0.05.

## Results and Discussion

**Composition of Diets.** Dietary ingredient quantities and nutrient profiles of the diets are listed in Table 1. The Beef NRC 1996 Model Level 2 recommended proportions of 34, 25, 20.5, and 20.5 of meat/bone meal, fish meal, feather meal, and blood meal, respectively. Diets were practically isocaloric, as intended, but CP

**Table 3.** Amino acid concentration of meat and bone meal from pork<sup>a</sup>

Amino acids	Meat and bone meal
Arginine	4.21
Cystine	0.51
Glycine	8.49
Histidine	1.14
Isoleucine	1.65
Leucine	3.45
Lysine	3.18
Methionine	0.86
Phenylalanine	2.04
Threonine	1.99
Tryptophan	0.32
Valine	2.45
TSAA <sup>b</sup>	1.37

<sup>a</sup>Expressed as g/100 g DM.

<sup>b</sup>Total sulfur amino acids (methionine + cystine).

level was elevated from 13.9% in the control diet up to 15.4% when 5.2% UIP was included; CP was determined to be 13.5% for the urea diet. These values are in agreement with the predictions made using the Beef NRC 1996 Model Level 2 (Table 2). The bacterial N balance of the rumen was predicted to be slightly positive, but the peptide balance was predicted to decline as SBM was replaced by UIP and urea. Diets were also formulated in such a manner that bacterial MP would be approximately the same for all three UIP levels, so that microbial protein synthesis would not be impaired by the addition of UIP.

At the actual DMI observed, the Beef NRC 1996 Model Level 2 predicted a small (18 g/d; 3.9%) depression of microbial protein synthesis when 5.2% UIP was included in the diet, as compared with the 0% UIP control diet. A small increase in microbial protein synthesis was predicted for the urea diet when compared with the 0% UIP control diet (8 g/d, 1.7%). This is explained by the increase in percentage of chopped hay from 14% to 16% in the control and urea diets, respectively. The model predicts an increase in ruminal pH, and that is translated into a small increase in MP from bacteria. Based on the results of the AA analyses (Table 3), the meat/bone meal diet was of a higher quality (better AA balance) than the meat and bone meal used in previous work by Knaus et al. (1998).

**Feed Intake and Body Weight Gain.** The average BW at the beginning of Period 1 was 259 kg. Average ad libitum DMI of the control diet before the onset of the experiment was 7.35 kg, exceeding the Beef NRC 1996 Model Level 2 estimation by 1.21 kg (Table 2). Feed refusals were rare and insignificant when animals were offered the experimental diets; thus, palatability was apparently not an issue even when UIP was added to the diet at 5.2%. Average daily gain was close to predicted levels for the control diet (1.43 kg/d) as well as for the diet containing 2.6% UIP (1.45 kg/d), but, when the UIP inclusion was 5.2% or when urea was the only

N supplement, ADG was reduced to 1.30 and 1.11 kg/d, respectively. Experiments conducted by Sindt et al. (1994) indicated that young (7 to 10 mo of age), large-framed calves may gain faster and more efficiently during the early finishing period when dry rolled corn-based diets are supplemented with a combination of escape protein and urea as compared with urea alone, but not later in the finishing period. However, in a growth trial carried out by Milton et al. (1997a), steers with an initial average BW of 335 kg fed soybean meal-supplemented high-grain diets gained 13% faster ( $P < 0.01$ ) and were 9% ( $P < 0.01$ ) more efficient at converting feed to gain than steers receiving urea.

**Digestibility.** Both DM digestibility and OM digestibility of the UIP diets averaged between 2 to 4 percentage units higher than for the urea diet. There were no trends for increasing or decreasing differences as the percentage of UIP increased from 0 to 5.2%. Differences were numerically largest between the control (0% UIP) and the urea diet. Bohnert et al. (1998) observed a linear decrease in apparent total-tract OM disappearance as poultry by-product meal was increased in a diet for steers. When feather meal or a combination of feather meal and bone meal supplied the supplemental protein in diets for lactating cows, apparent total-tract OM digestibility was reduced by 7% (Waltz et al., 1989). The differences in apparent digestibility of the OM between the control (0% UIP) diet and the urea diet are similar to the results obtained by Milton et al. (1997a), in which an improvement in total-tract OM digestion (5%,  $P = 0.12$ ) was found when high-grain diets were supplemented with soybean meal as compared with urea.

In contrast to the linear decrease of the apparent total-tract digestion of N as supplemental feather meal plus blood meal was increased in dairy rations (Cunningham et al., 1994), no significant difference between diets was observed with regard to the apparent digestibility of N in the study reported here. Apparent N digestibility was 1 percentage unit lower in the control (0% UIP) diet when compared with the other three diets. Waltz et al. (1989) noted a lower total-tract N digestibility for dairy diets containing feather meal and a combination of feather meal and blood meal. Knaus et al. (1998) and Robinson (1998) observed a significant improvement in apparent N digestibility when an AA-balanced combination of animal by-product protein sources was added to a corn-based diet fed to Holstein steers under similar experimental conditions.

There were quite substantial numerical differences in digestibility of ADF and NDF between diets, but, due to the wide variation, none of them were statistically significant. In an experiment conducted with lactating Holstein cows (Lines and Weiss, 1996), apparent digestibilities of DM, N, and fiber fractions were not affected by a diet supplemented either with urea, soybean meal, or a combination of fish meal and blood meal.

The apparent digestibility of the dietary NSC fraction of the urea diet was reduced as compared with the control diet ( $P = 0.04$ ). Milton et al. (1997a) observed a

5% ( $P < 0.10$ ) increase in total-tract starch digestion when steers were fed diets supplemented with soybean meal compared with urea, but this increase might have been associated with the numerically lower starch intake of soybean meal-supplemented diets. In the study reported here, the reduced DM, OM, and NSC digestibility for the urea diet as compared with the control, could also, at least in part, be due to the higher content of cracked corn in the urea diet. Milton et al. (1997b) compared effects of urea supplementation in dry-rolled corn diets and speculated, based on results, that a deficiency of available AA and peptides may have limited microbial growth. He also referenced the work by Russell et al. (1992). In summary, a deficiency of available AA and peptides (Table 2) may have limited microbial growth when the urea diet was fed, leading to the reduced ruminal fermentation of NSC. The NSC percentage (DM basis) was not different among these diets, but differences in soluble fiber or diet composition may have also contributed to apparent digestibility differences. The difference in ADG between the urea and UIP diets was probably caused by a combination of limited microbial digestive activity and, therefore, limited microbial growth and lack of UIP.

**Nitrogen Utilization.** The actual daily CP intake was 966, 998, 1,013, and 907 g for the control, 2.6% UIP, 5.2% UIP, and the urea diet, respectively. Average daily N intake was 5 and 7.5 g higher for the diets containing 2.6% and 5.2% UIP, respectively, than the control diet. Nitrogen intake of the urea diet was 9.5 g/d, or 6% less than that observed with the control diet. Fecal N excretion remained constant for all three UIP diets but was 11% less ( $P = 0.09$ ) when urea was the only N supplement. The inclusion of 5.2% UIP in the diet resulted in a significant elevation of urinary N excretion compared with the control and 2.6% UIP diets. This contributed to a significantly lower daily N retention when comparing the 5.2% UIP and control diets, whereas N retention for the control and 2.6% UIP diets were not significantly different. Nitrogen retention was numerically higher in the 2.6% UIP diet (3.4 g/d, or 7%) than with the control diet, suggesting that the 2.6% UIP came closest to meeting MP and amino acid requirements. The reduced efficiency of N retention observed with the 5.2% UIP diet suggests that it created excess MP and available amino acids in these steers (based on biological value; Table 4). This is the classical response expected.

The rates and efficiency of N retention observed in this experiment are comparable to values observed in an experiment conducted with similar cattle, similar environment, similar experimental design, and similar diet composition (Knaus et al., 1998), but N retentions of 64 (Robinson, 1998) and 58 g/d (Moloney et al., 1998) have recently been reported for Holstein steers weighing 250 kg and receiving an abomasal infusion of casein. The addition of dietary UIP in the study described here should have accommodated the estimated genetic capacity for N retention (58 to 64 g/d) that is

**Table 4.** Effects of increasing amounts of a dietary animal by-product protein mixture in combination with urea or urea alone on apparent digestibility and nitrogen metabolism

Item	Undegraded intake protein, % <sup>a</sup>			Urea diet	Pooled standard error
	0	2.6	5.2		
No. of animals	4	4	4	4	
Average daily gain, kg/d	1.43	1.45	1.30	1.11	0.28
DMI, kg /d	6.94	6.83	6.75	6.79	0.15
DMI, % of initial BW	2.68	2.64	2.61	2.62	0.06
Apparent digestibility, %					
Dry matter	74.8 <sup>d</sup>	73.2	74.1	71.1 <sup>e</sup>	1.2
Organic matter	75.4 <sup>d</sup>	73.7	74.7	71.5 <sup>e</sup>	1.2
Nitrogen	67.8	68.9	69.0	69.3	0.8
ADF	54.5	46.7	56.4	45.7	6.2
NDF	46.7	38.4	50.1	37.4	8.9
NSC <sup>f</sup>	94.0 <sup>d</sup>	94.0	92.3	88.8 <sup>e</sup>	2.0
N intake, g/d	155	160	162	145	6
Fecal N, g/d	49.8	49.7	50.3	44.5	2.4
Urine N, g/d	57.5 <sup>b</sup>	59.2 <sup>b</sup>	69.6 <sup>c</sup>	54.1	3.7
N retention, g/d	47.2 <sup>bc</sup>	50.6 <sup>c</sup>	42.2 <sup>b</sup>	46.5	3.1
N retention, % of N intake	30.8 <sup>bc</sup>	31.9 <sup>b</sup>	26.4 <sup>c</sup>	32.0	2.0
Biological value (N retention, % of N digested)	45.5 <sup>b</sup>	46.4 <sup>b</sup>	38.2 <sup>c</sup>	46.3	2.5

<sup>a</sup>Levels represent the portion of UIP expressed as a percentage of diet DM.

<sup>b,c</sup>UIP diet means within a row with different superscripts differ ( $P < 0.05$ ).

<sup>d,e</sup>Control diet and urea diet means within a row with different superscripts differ ( $P < 0.05$ ).

<sup>f</sup>Nonstructural carbohydrate.

suggested from the results of these other two studies conducted in our laboratory. There is no apparent reason why this did not occur. Abomasal casein infusion does not increase the efficiency of N retention in growing Holstein steers and is additive with effects of bovine somatotropin treatment for increasing rate of N retention (Houseknecht et al., 1992). We speculate that abomasal casein infusion may stimulate protein synthesis and(or) accretion in the gut or liver beyond what may occur with the diets used in the study reported here. This is based on the observation that net flux of essential amino acids across the hind limb did not parallel the sequential increase in whole-body N balance observed with the two highest levels of casein infusion used by Robinson (1998). The portal-drained viscera and the liver exhibit relatively high levels of protein turnover

and contributions to whole-body fractional protein synthesis.

The reduced efficiency of N retention observed with the 5.2% UIP diet is explained by the higher rate of urinary N excretion. Sixty-two percent of absorbed N was excreted in the urine when the diet contained 5.2% UIP, but only 54% and 55% of absorbed N was excreted in the urine when the diet contained 2.6% or no added UIP. The efficiency values for N utilization in the control, 2.6% UIP, and urea diets were similar to those observed by Robinson (1998) in Holstein steers of almost equal BW fed a similar protein supplement mixture at similar levels.

The supplementation of a corn-based diet with 2.6% of a very similar blend of animal by-products in previous work by Knaus et al. (1998) resulted in a significant

**Table 5.** Effects of increasing amounts of a dietary animal by-product protein mixture in combination with urea or urea alone on plasma urea nitrogen, glucose, NEFA, and insulin concentrations

Item	Undegraded intake protein, % <sup>a</sup>			Urea diet	Pooled standard error
	0	2.6	5.2		
No. of animals	4	4	4	4	
Plasma urea N, mg/dL	9.1 <sup>b</sup>	9.5 <sup>b</sup>	11.6 <sup>c</sup>	9.5	0.6
Glucose, mg/dL	103.6	98.4	99.3	97.6	3.0
NEFA, mM	78.9	78.0	79.9	86.6	10.1
Insulin, ng/mL	1.8	2.1	1.8	1.7	0.3

<sup>a</sup>Levels represent the portion of UIP expressed as a percentage of diet DM.

<sup>b,c</sup>UIP diet means within a row with different superscripts differ ( $P < 0.05$ ).

improvement of the N balance in Holstein steers weighing 410 kg. When more than 2.6% of the animal by-product mix was added to the diet, no change in the efficiency of dietary N utilization was apparent. Robinson (1998) observed a significant increase in N retention from a corn-based diet, when 7.5% of the animal by-product blend was incorporated in the diet and fed to Holstein steers weighing 270 kg. When comparing efficiencies of dietary N utilization derived from various experiments of very similar design, feeding regimen, and animal BW, the DMI level is a crucial factor. As in dairy cows (Volden, 1999), feeding level has a marked effect on the efficiency of bacterial protein synthesis, ruminal escape of dietary protein, and amount of AA passing to the small intestine. The DMI in the study reported in this paper was about 40% higher than that observed by Robinson (1998) and about 7% above the DMI in the experiment conducted by Knaus et al. (1998). The DMI, calculated as a percentage of initial BW, was about 0.8 percentage unit higher than that observed by Robinson (1998) and was about 1.1 percentage units higher than that observed in the earlier experiment of Knaus et al. (1998).

The urea diet achieved rates and efficiency of N retention equivalent to those observed with the control diet, despite predictions of a negative MP balance of 16 g/d, a negative peptide balance of 34 g/d and a lower ADG when compared with the control diet (Table 4). The MP from UIP was 30% less with the urea diet than with the control, and inadequate dietary UIP may have contributed to the numerically, but not statistically significant, 8% lower ADG observed.

In vitro studies by Russell et al. (1983) indicated that microorganisms that ferment NSC derive 66% of their N from peptides or AA and 34% of their N from ammonia. When peptides and AA are no longer available, the N must be derived from ammonia (Russell et al., 1992). The cattle used in this experiment apparently were able to shift to a higher use of ammonia when the urea diet was fed as compared with the control diet. Efficiency of N use was equivalent, suggesting efficient incorporation of ammonia into rumen bacterial mass without the presence of sufficient amounts of AA and peptides.

*Blood Measurements.* In general, PUN concentrations were moderately high for all treatments. This reflects the CP content of the diet and the amount of DMI. The significant elevation of PUN observed when 5.2% UIP was added to the diet is in agreement with the N balance data. It presumably reflects the less-efficient total N utilization that could be a result of an excessive supply of UIP. This would lead to a surplus of ammonia in the rumen, a surplus amount and/or an improper spectrum of AA being absorbed from the small intestine or a combination of these, thus increasing urea synthesis. These results are also in agreement with previous observations by Knaus et al. (1998), in which concentrations of PUN were significantly increased when the UIP supplement was fed at 5.2% or beyond.

Concentration of PUN was not different for the urea diet when compared with the control diet. This suggests, along with the equivalent levels of N balance and efficiency of N retention achieved by these diets, that urea can be used effectively as the only N supplement to achieve adequate supply of MP and AA to meet absorbable AA requirements. Plasma glucose was slightly lower for the urea diet than for the control diet ( $P = 0.12$ ), which could be connected to the significantly diminished DM and OM apparent digestibility that led to a reduced energy supply. Glucose concentrations were high on average but were similar to values observed in previous experiments with similar cattle (Robinson, 1998). No difference was detected between diets with regard to plasma NEFA and insulin concentrations. Beermann et al. (1991) observed a significant decrease in plasma NEFA concentrations when lambs were abomasally infused with casein. Contrary to the results from the present study, Ragland-Gray et al. (1997) and Guerino et al. (1991) reported that plasma insulin concentration was increased when steers were abomasally infused with casein.

These results suggest that supplementing corn-based diets with AA-balanced mixtures of animal by-products may not improve the efficiency of dietary N utilization when diets are formulated to meet requirements. Results from studies in which improvements were observed (Titgemeyer et al., 1989; Gibb et al., 1992; Cecava and Hancock, 1994) may reflect complementary effects on the AA pattern of control diets that did not meet metabolizable AA requirements. The efficiency of N usage from the urea diet suggests that ruminal bacteria must have the capability to increase the proportion of ammonia used to synthesize microbial protein when lesser amounts of AA and peptides are available (Russell et al. 1992).

## Implications

The supplementation of corn-based diets with AA-balanced combinations of porcine meat and bone meal, fish meal, feather meal, and blood meal did not significantly enhance N digestibility, N balance, and efficiency of N utilization in estradiol-treated Holstein steers. Results imply that N balance estimates of capacity for protein accretion in similar steers is overestimated when using abomasal casein infusion and N balance response. Feeding soybean meal or urea as the only protein supplement achieves maximum efficiency of N utilization when feed intake is not impaired and rumen conditions allow for maximum synthesis of microbial protein. Efforts to reduce N excretion per unit of animal product while maximizing production efficiency are important for protection of the environment. Results of this study confirm that using the Beef NRC 1996 model to formulate diets provides efficient utilization of N for cattle growth and avoids the overfeeding of protein and unnecessary return of N to the environment.

## Literature Cited

- Ainslie, S. J., D. G. Fox, T. C. Perry, D. J. Ketchen, and M. C. Barry. 1993. Predicting amino acid adequacy of diets fed to Holstein steers. *J. Anim. Sci.* 71:1312–1319.
- AOAC. 1990. *Official Methods of Analysis*. 15th ed. Association of Official Analytical Chemists, Arlington, VA.
- Beermann, D. H., T. F. Robinson, T. M. Byrem, D. E. Hogue, A. W. Bell, and C. L. McLaughlin. 1991. Abomasal casein infusion and exogenous somatotropin enhance nitrogen utilization by growing lambs. *J. Nutr.* 121:2020–2028.
- Bohnert, D. W., B. T. Larson, M. L. Bauer, A. F. Branco, K. R. McLeod, D. L. Harmon, and G. E. Mitchell, Jr. 1998. Nutritional evaluation of poultry by-product meal as a protein source for ruminants: Effects on performance and nutrient flow and disappearance in steers. *J. Anim. Sci.* 76:2474–2484.
- Cecava, M. J., and D. L. Hancock. 1994. Effects of anabolic steroids on nitrogen metabolism and growth of steers fed corn silage and corn-based diets supplemented with urea or combinations of soybean meal and feather meal. *J. Anim. Sci.* 72:515–522.
- Chaney, A. L., and E. P. Marbach. 1962. Modified reagent for determination of urea and ammonia. *Clin. Chem.* 8:130–132.
- Cunningham, K. D., M. J. Cecava, and T. R. Johnson. 1994. Flows of nitrogen and amino acids in dairy cows fed diets containing supplemental feather meal and blood meal. *J. Dairy Sci.* 77:3666–3675.
- Gibb, D. J., T. J. Klopfenstein, and M. H. Sindt. 1992. Combinations of rendered protein meals for growing calves. *J. Anim. Sci.* 70:2581–2589.
- Guerino, F., G. B. Huntington, R. A. Erdman, T. H. Elsasser, and C. K. Reynolds. 1991. The effects of abomasal casein infusions in growing beef steers on portal and hepatic flux of pancreatic hormones and arterial concentrations of somatomedin-C. *J. Anim. Sci.* 69:379–386.
- Harvey, W. R. 1990. *User's Guide to LSMLMW*. Mixed Model Least-Squares and Maximum Likelihood Computer Program. Polykopy Ohio State University, Columbus, OH.
- Holm, S. 1979. A simple sequentially rejective multiple test procedure. *Scand. J. Stat.* 6:65.
- Houseknecht, K. L., D. E. Bauman, D. G. Fox, and D. F. Smith. 1992. Abomasal infusion of casein enhances nitrogen retention in somatotropin-treated steers. *J. Nutr.* 122:1717–1725.
- Knaus, W. F., D. H. Beermann, T. F. Robinson, D. G. Fox, and K. D. Finnerty. 1998. Effects of a dietary mixture of meat and bone meal, feather meal, blood meal, and fish meal on nitrogen utilization in finishing Holstein steers. *J. Anim. Sci.* 76:1481–1487.
- Lines, L. W., and W. P. Weiss. 1996. Use of nitrogen from ammoniated alfalfa hay, urea, soybean meal, and animal protein meal by lactating cows. *J. Dairy Sci.* 79:1992–1999.
- McGuire, M. A., D. E. Bauman, D. A. Dwyer, and W. S. Cohick. 1995. Nutritional modulation of the somatotropin/insulin-like growth factor system: response to feed deprivation in lactating cows. *J. Nutr.* 125:493–502.
- Merchen, N. R., and E. C. Titgemeyer. 1992. Manipulation of amino acid supply to the growing ruminant. *J. Anim. Sci.* 70:3238–3247.
- Millipore Corp., 1990. Liquid chromatography analysis of amino acids in feeds and foods using a modification of the Pico-Tag method. Technical Bulletin, Millipore Corp., Milford, MA.
- Milton, C. T., R. T. Brandt, Jr., and E. C. Titgemeyer. 1997a. Effects of dietary nitrogen source and concentration in high-grain diets on finishing steer performance and nutrient digestion. *J. Anim. Sci.* 75:2813–2823.
- Milton, C. T., R. T. Brandt, Jr., and E. C. Titgemeyer. 1997b. Urea in dry-rolled corn diets: Finishing steer performance, nutrient digestion, and microbial protein production. *J. Anim. Sci.* 75:1415–1424.
- Moloney, A. P., D. H. Beermann, D. Gerrard, T. F. Robinson, and K. D. Finnerty. 1998. Temporal change in skeletal muscle IGF-1 mRNA abundance and nitrogen metabolism responses to abomasal casein infusion in steers. *J. Anim. Sci.* 76:1380–1388.
- NRC. 1996. *Nutrient Requirements of Beef Cattle*. 7th ed. National Academy Press, Washington, DC.
- Ragland-Gray, K. K., H. E. Amos, M. A. McCann, C. C. Williams, J. L. Sartin, C. R. Barb, and F. M. Kautz. 1997. Nitrogen metabolism and hormonal responses of steers fed wheat silage and infused with amino acids or casein. *J. Anim. Sci.* 75:3038–3045.
- Robinson, T. F. 1998. Effect of undegradable intake protein on amino acid absorption and utilization by the growing steer. Ph.D. dissertation, Cornell Univ., Ithaca, N.Y.
- Russell, J. B., J. D. O'Connor, D. G. Fox, P. J. Van Soest, and C. J. Sniffen. 1992. A net carbohydrate and protein system for evaluating cattle diets: I. Ruminant fermentation. *J. Anim. Sci.* 70:3551–3561.
- Russell, J. B., C. J. Sniffen, and P. J. Van Soest. 1983. Effect of carbohydrate limitation on degradation and utilization of casein by mixed rumen bacteria. *J. Dairy Sci.* 66:763–775.
- Sindt, M. H., R. A. Stock, and T. J. Klopfenstein. 1994. Urea vs. urea and escape protein for finishing calves and yearlings. *Anim. Feed Sci. Technol.* 49:103–117.
- Spears, J. W. 1996. Beef nutrition in the 21st century. *Anim. Feed Sci. Technol.* 58:29–35.
- Stock, R. A., S. B. Laudert, W. W. Stroup, E. M. Larson, J. C. Parrott, and R. A. Britton. 1995. Effect of monensin and monensin and tylosin combination on feed intake variation of feedlot steers. *J. Anim. Sci.* 73:39–44.
- Titgemeyer, E. C., N. R. Merchen, and L. L. Berger. 1989. Evaluation of soybean meal, corn gluten meal, blood meal and fish meal as sources of nitrogen and amino acids disappearing from the small intestine of steers. *J. Anim. Sci.* 67:262–275.
- Van Soest, P. J. 1994. *Nutritional Ecology of the Ruminant*. 2nd ed. Comstock Publishing Associates, a division of Cornell University Press, Ithaca and London.
- Volden, H. 1999. Effects of level of feeding and ruminally undegraded protein on ruminal bacterial protein synthesis, escape of dietary protein, intestinal amino acid profile, and performance of dairy cows. *J. Anim. Sci.* 77:1905–1918.
- Waltz, D. M., M. D. Stern, and D. J. Illg. 1989. Effect of ruminal protein degradation of blood meal and feather meal on the intestinal amino acid supply to lactating cows. *J. Dairy Sci.* 72:1509–1518.

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