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1997

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# Limiting Amino Acids in Meat and Bone and Poultry By-Product Meals<sup>1</sup>

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**ABSTRACT:** In situ, digestion, and growth studies were conducted to evaluate four meat and bone meals and six poultry by-product meals as sources of escape protein and to predict the first-limiting amino acid for growing calves. Escape protein values, determined by 12-h in situ incubation, ranged from 41.7 to 51.0% of CP for meat and bone meals; poultry by-product meals ranged from 32.0 to 39.8%. True protein digestion in the gastrointestinal tract of lambs differed among protein sources ( $P < .05$ ), ranging from 79 to 95%. In each of three growth trials, 60 steers ( $258 \pm 24$ ,  $241 \pm 23$ , and  $230 \pm 16$  kg for Trials 1, 2, and 3, respectively) were supplemented with 4 of the 10 protein sources along with a urea supplement. Protein sources were fed at 30, 40, 50, and 60% of the supplemental CP,

with urea supplying the remainder. Protein efficiency differed among treatments ( $P < .10$ ), ranging from .61 to 1.55. Amino acid composition was determined for each protein source, and the individual metabolizable amino acids were regressed on the protein efficiency values. Escape protein values were correlated ( $R^2 = .75$ ) with protein efficiency but had a negative slope. Metabolizable methionine was the only amino acid moderately correlated ( $R^2 = .40$ , slope = 1.9) to protein efficiency, whereas other amino acids either correlated poorly or had negative slopes. These data indicate that the protein value of meat and bone meal and poultry by-product meal is limited by the amount of metabolizable methionine they contain.

Key Words: Meat and Bone Meal, By-Products, Protein, Amino Acids, Methionine, Beef Cattle

J. Anim. Sci. 1997. 75:3294-3300

## Introduction

Meat and bone meal (MBM) and poultry by-product meal (PBM) are rendered animal by-products that are potential sources of escape protein for ruminants. However, using MBM as an escape protein source has had variable results (Stock et al., 1981). Meat and bone meal varies in ruminal escape protein, amino acid composition, and amino acid availability (Knabe et al., 1989; Gibb et al., 1991). This may be the result of heat damage during rendering (Leibholz, 1979; Batterham and Darnell, 1986; Knabe et al., 1989) and/or the type of tissues rendered (Eastoe and Long, 1960; Atkinson and Carpenter, 1970). Gibb et al. (1991) reported higher escape protein values for MBM made from bones than MBM made from viscera or deadstock. Generally, bone decreases protein content and decreases the amount of essential amino acids (Knabe et al., 1989; Gibb et al., 1991).

This research was conducted to evaluate a variety of MBM and PBM products as sources of escape protein for growing calves. Escape protein, CP digestibility, and ash content of these products were evaluated as predictors of protein efficiency, and the first-limiting amino acid in MBM and PBM was predicted.

## Materials and Methods

Four samples of MBM and six samples of PBM were obtained from commercial renderers across the United States. Products were selected to be variable in composition and represent the variety of products available on the market.

*In Situ Study.* Samples of MBM and PBM were incubated in situ to determine escape protein (Wilkinson et al., 1995). Approximately 4 g of each protein source was placed in each of four Dacron<sup>®</sup> bags (10 × 20 cm; 50- $\mu$ m pore size; du Pont, Wilmington, DE). Each bag was sealed by wrapping the top around a #8 rubber stopper and secured with a #18 rubber band. The bag was then folded over the rubber band and a second rubber band was added. Sample bags were placed in four polyester bags 36 × 42 cm made of mesh material and closed with a nylon zipper. To facilitate

<sup>1</sup>Published with the approval of the director as paper no. 11614, journal series, Nebraska Agric. Res. Div.

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Received December 11, 1996.

Accepted July 18, 1997.

Table 1. Basal diet for the lamb digestion trial

Ingredient	%, DM
Ensiled corncobs	72.70
Alfalfa pellets	15.00
Ground corn	10.00
Urea	1.48
Dicalcium phosphate	.26
Salt	.30
Ammonium sulfate	.17
Trace minerals	.04 <sup>a</sup>
Vitamins	.03 <sup>b</sup>
Selenium	.02 <sup>c</sup>

<sup>a</sup>Contains 10% Mg, 6% Zn, 4.5% Fe, 2% Mn, .5% Cu, and .3% I.

<sup>b</sup>15,000 IU vitamin A, 3,000 IU vitamin D, and 3.75 IU vitamin E per gram of premix.

<sup>c</sup>Premix contains .06% Se.

hydration, all bags were soaked in 39°C water for 20 min before ruminal incubation. Two nylon bags were placed in the liquid phase of the ruminal ventral sac of each of two mature ruminally cannulated crossbred steers (534 kg) maintained on a grass hay diet.

Following 12 h of ruminal incubation (Wilkerson et al., 1993), bags were removed from the rumen and washed by hand until the rinse water was clear. Total N (AOAC, 1975) was determined before and after ruminal incubation to estimate the amount of ruminal escape protein for each source without correction for microbial attachment. Protein sources were additionally analyzed for ash content (AOAC, 1975).

Residue remaining after incubation was composited by protein source and analyzed for amino acid content along with the original protein source. Samples were hydrolyzed in 6 N HCl, and amino acid content of hydrolyzates was determined by ion-exchange chromatography (AOAC, 1975). Separate samples were oxidized with performic acid for analysis of cystine and methionine (AOAC, 1975). A separate analysis for tryptophan was also conducted using the procedure of Lewis et al. (1976) modified for manual analysis. All analyses were conducted in duplicate.

The GLM procedure of SAS (1985) was used to analyze the protein degradation data. The experiment was of a completely randomized design, and the statistical model included protein source and error. Least significant differences (SAS, 1985) were used to separate treatment means. For each amino acid, concentration was compared before and after ruminal digestion using means comparison and Pearson Correlation Analysis (SAS, 1985).

**Digestion Study.** Twenty-four crossbred wether lambs ( $31.8 \pm 3.6$  kg) housed in individual metabolism crates were fed a basal diet (Table 1) containing ensiled corncobs and alfalfa pellets. The basal diet was fed to all lambs at 1.9% of BW (DM basis) throughout the trial. This maintenance diet was balanced to provide a minimum of 10% CP, 52% TDN, .42% Ca, and .18% P. Urea was included in the

basal diet to ensure that rumen NH<sub>3</sub> was not limiting digestion and provided 44% of the basal dietary CP.

The study consisted of three periods, each containing a 14-d adaptation period and a 7-d fecal collection period. Within each period, lambs were assigned randomly to treatment protein; two lambs were assigned to each of the 10 protein sources, soybean meal (**SBM**), or an unsupplemented control. Lambs were re-randomized to treatment protein between periods. Supplemental protein sources were fed at 3.75% of the basal diet DMI as units of additional CP. Therefore, the supplemental DMI in addition to the basal diet was dependent on the CP content of the treatment protein source. All diets containing treatment proteins were isonitrogenous and contained 13.75% CP, and the unsupplemented control diet contained 10% CP. Treatment protein sources were individually weighed and hand-mixed into the basal diet at the time of feeding.

Lambs were weighed before the trial to enable feeding of diets on an equal percentage of BW. Lambs were fitted with fecal collection bags to allow for total fecal collection. Feces was collected daily and weighed, and a 10% subsample was taken. Subsamples were composited by lamb for the 7-d collection period. Feed, feces, and orts were oven-dried (60°C) and analyzed for DM and CP content (AOAC, 1975). True protein digestibility was calculated by difference from unsupplemented-control sheep as outlined by Blasi et al. (1991). Results were analyzed as a randomized complete block design using the GLM procedure of SAS (1985) with the model containing protein source, period, and source  $\times$  period interaction. Least significant differences (SAS, 1985) were used to separate treatment means.

**Growth Trials.** In each of three growth studies, diets of 44% sorghum silage (7.1% CP, 68% TDN), 44% corncobs (2.3% CP, 48% TDN), and 12% supplement (DM basis, Tables 2, 3, and 4) were individually fed to 60 crossbred steer calves ( $258 \pm 24$ ,  $241 \pm 23$ , and  $230 \pm 16$  kg for Trials 1, 2, and 3, respectively). Steers were supplemented with 4 of the 10 protein sources along with a urea control in each of the three studies. Trials 2 and 3 included a replicated protein source from the previous trial so that protein sources could be compared across trials. If the protein efficiency of the replicated protein source was not statistically different between the two trials, protein efficiencies were combined for analysis.

Protein sources were fed to supply 30, 40, 50, or 60% of the supplemental N, with urea supplying the remainder. Therefore, regardless of the assigned level, all steers consumed a diet containing 11.0% CP (DM basis). Steers were assigned randomly to treatment and level of treatment protein with 12 steers per treatment and three steers per level. Steers were individually fed, at an equal percentage of body weight, once daily with Calan electronic gates (American Calan, Northwood, NH). The percentage of body

Table 2. Supplement composition for growth Trial 1<sup>a</sup>

Ingredient	Treatment				
	Urea	MBM1 <sup>b</sup>	MBM2 <sup>b</sup>	MBM3 <sup>b</sup>	PBM1 <sup>b</sup>
Meat and bone meal 1	—	71.06	—	—	—
Meat and bone meal 2	—	—	50.32	—	—
Meat and bone meal 3	—	—	—	50.32	—
Poultry by-product meal 1	—	—	—	—	42.66
Soyhulls	71.64	16.97	37.71	37.71	45.37
Urea	16.16	7.00	7.00	7.00	7.00
Dicalcium phosphate	7.23	—	—	—	—
Salt	2.50	2.50	2.50	2.50	2.50
Ammonium sulfate	1.67	1.67	1.67	1.67	1.67
Trace minerals <sup>c</sup>	.42	.42	.42	.42	.42
Vitamins <sup>d</sup>	.25	.25	.25	.25	.25
Selenium <sup>e</sup>	.13	.13	.13	.13	.13

<sup>a</sup>Values are expressed as percentage of DM; supplement was fed at 12% of DMI.

<sup>b</sup>Supplements that were mixed with urea supplement to supply 30, 40, 50, or 60% of supplemental protein.

<sup>c</sup>10% Mg, 6% Zn, 4.5% Fe, 2% Mn, .5% Cu, .3% I, .05% Co.

<sup>d</sup>30,000 IU of vitamin A, 6,000 IU of vitamin D, and 7.5 IU of vitamin E per gram of premix.

<sup>e</sup>Premix contained .06% Se.

weight fed was adjusted as needed to minimize orts while maintaining intake near ad libitum. Average intake was 2.1, 2.3, and 2.1% of body weight for Trials 1, 2 and 3, respectively.

Weight data were collected before feeding on three consecutive days at the beginning and end of each 84-d trial. Efficiency of protein utilization was determined for each protein source using the slope-ratio technique (Klopfenstein et al., 1985) with the urea-supplemented steers as the control. Protein efficiencies, calculated as the units of gain obtained greater than the control steers per unit of protein consumed greater than the control diet, were determined for

each treatment using the NLIN procedure of SAS (1985). Slopes (protein efficiencies) were compared using a two-tailed *t*-test (Steel and Torrie, 1980).

In situ escape protein data, amino acid degradation data, and true CP digestibility data were used to calculate the amount of each metabolizable amino acid supplied from each protein source (Wilkerson et al., 1993). To determine the first-limiting amino acid, metabolizable amino acid supplies were regressed (SAS, 1985) on protein efficiency values. Escape protein, CP digestibility, and ash content values were also regressed on protein efficiency to determine their ability in predicting protein efficiency.

Table 3. Supplement composition for growth Trial 2<sup>a</sup>

Ingredient	Treatment				
	Urea	PBM1 <sup>b</sup>	PBM2 <sup>b</sup>	PBM3 <sup>b</sup>	PBM4 <sup>b</sup>
Poultry by-product meal 1	—	42.66	—	—	—
Poultry by-product meal 2	—	—	44.67	—	—
Poultry by-product meal 3	—	—	—	41.23	—
Poultry by-product meal 4	—	—	—	—	49.91
Soyhulls	71.64	45.37	43.36	46.80	38.12
Urea	16.16	7.00	7.00	7.00	7.00
Dicalcium phosphate	7.23	—	—	—	—
Salt	2.50	2.50	2.50	2.50	2.50
Ammonium sulfate	1.67	1.67	1.67	1.67	1.67
Trace minerals <sup>c</sup>	.42	.42	.42	.42	.42
Vitamins <sup>d</sup>	.25	.25	.25	.25	.25
Selenium <sup>e</sup>	.13	.13	.13	.13	.13

<sup>a</sup>Values are expressed as percentage of DM; supplement was fed at 12% of DMI.

<sup>b</sup>Supplements that were mixed with urea supplement to supply 30, 40, 50, or 60% of supplemental protein.

<sup>c</sup>10% Mg, 6% Zn, 4.5% Fe, 2% Mn, .5% Cu, .3% I, .05% Co.

<sup>d</sup>30,000 IU of vitamin A, 6,000 IU of vitamin D, and 7.5 IU of vitamin E per gram of premix.

<sup>e</sup>Premix contained .06% Se.

Table 4. Supplement composition for growth Trial 3<sup>a</sup>

Ingredient	Treatment				
	Urea	PBM4 <sup>b</sup>	PBM5 <sup>b</sup>	PBM6 <sup>b</sup>	MBM4 <sup>b</sup>
Poultry by-product meal 4	—	49.91	—	—	—
Poultry by-product meal 5	—	—	52.69	—	—
Poultry by-product meal 6	—	—	—	54.98	—
Meat and bone meal 4	—	—	—	—	52.58
Soyhulls	71.64	38.12	35.34	33.05	35.45
Urea	16.16	7.00	7.00	7.00	7.00
Dicalcium phosphate	7.23	—	—	—	—
Salt	2.50	2.50	2.50	2.50	2.50
Ammonium sulfate	1.67	1.67	1.67	1.67	1.67
Trace minerals <sup>c</sup>	.42	.42	.42	.42	.42
Vitamins <sup>d</sup>	.25	.25	.25	.25	.25
Selenium <sup>e</sup>	.13	.13	.13	.13	.13

<sup>a</sup>Values are expressed as percentage of DM; supplement was fed at 12% of DMI.

<sup>b</sup>Supplements that were mixed with urea supplement to supply 30, 40, 50, or 60% of supplemental protein.

<sup>c</sup>10% Mg, 6% Zn, 4.5% Fe, 2% Mn, .5% Cu, .3% I, .05% Co.

<sup>d</sup>30,000 IU of vitamin A, 6,000 IU of vitamin D, and 7.5 IU of vitamin E per gram of premix.

<sup>e</sup>Premix contained .06% Se.

**Results and Discussion**

*In Situ Study.* After 12 h of ruminal incubation, escape protein values differed ( $P < .05$ ), ranging from 32.0 to 51.0% of the CP escaping ruminal degradation (Table 5). Meat and bone meal sources ranged from 41.7 to 51.0% of the CP escaping ruminal degradation, whereas PBM sources ranged from 32.0 to 39.8%. Crude protein ranged from 45.0 to 67.9%, and percentage ash ranged from 12.3 to 40.5%. Crude protein was negatively correlated to ash content ( $R^2 = .72$ ; slope =  $-1.01$ ) because soft tissue is higher in CP than bone. Escape protein, however, was positively correlated with ash content ( $R^2 = .51$ ; slope =  $.58$ ), indicating greater escape values for MBM and PBM

made from bone than when made from soft tissue. This is in agreement with the findings of Gibb et al. (1991), in which CP was lower but escape values were higher for MBM made from bones than when it was made from viscera or deadstock.

Ruminal incubation of these protein sources increased essential amino acid concentration ( $P < .05$ ) as a ratio of the CP escaping ruminal degradation (Table 6), with the exception of tryptophan, which decreased in concentration. This decrease in tryptophan, also observed by Goedeken et al. (1990), suggests preferential degradation of tryptophan in the rumen. The increase in concentration of other essen-

Table 5. Crude protein, escape protein<sup>a</sup>, and ash content of meat and bone meals and poultry by-product meals

Item	Crude protein, % N	escape, %	Ash, %
Meat and bone meal 1	45.0	51.0 <sup>b</sup>	40.5
Meat and bone meal 2	58.5	45.2 <sup>bc</sup>	24.7
Meat and bone meal 3	58.4	44.3 <sup>c</sup>	30.4
Meat and bone meal 4	56.1	41.7 <sup>c</sup>	25.3
Poultry by-product meal 1	66.0	34.3 <sup>de</sup>	16.3
Poultry by-product meal 2	63.4	39.8 <sup>cd</sup>	19.8
Poultry by-product meal 3	67.9	38.7 <sup>cd</sup>	12.3
Poultry by-product meal 4	58.5	33.9 <sup>de</sup>	22.0
Poultry by-product meal 5	56.3	32.0 <sup>e</sup>	24.0
Poultry by-product meal 6	53.5	32.0 <sup>e</sup>	19.3
SE	—	2.0	—

<sup>a</sup>Expressed as a percentage of CP remaining after 12-h incubation in situ.

<sup>b,c,d,e</sup>Values within a column with unlike superscripts differ ( $P < .05$ ).

Table 6. Amino acid composition<sup>a</sup> of meat and bone meal and poultry by-product meal sources before and after 12 hours of ruminal in situ incubation

Amino acid	Before 12-h incubation	After 12-h incubation	r <sup>b</sup>
Arg	6.67 ± .56	7.40 ± .73 <sup>c</sup>	.40
His	1.60 ± .13	1.65 ± .25	.35
Ile	2.34 ± .26	2.75 ± .48 <sup>c</sup>	.75
Leu	5.63 ± .38	6.70 ± .67 <sup>c</sup>	.01
Lys	4.80 ± .41	5.16 ± .74	.64
Met	1.30 ± .23	1.48 ± .40 <sup>c</sup>	.97
Phe	3.11 ± .18	3.59 ± .45 <sup>c</sup>	.33
Thr	3.36 ± .28	3.94 ± .44 <sup>c</sup>	.40
Trp	.45 ± .09	.37 ± .09 <sup>c</sup>	.38
Val	3.23 ± .15	3.77 ± .25 <sup>c</sup>	.37
Cys	1.00 ± .25	1.48 ± .46 <sup>c</sup>	.23

<sup>a</sup>Expressed as a percentage of CP before or after 12-h ruminal in situ incubation.

<sup>b</sup>Pearson correlation coefficient for amino acid before and after 12-h incubation.

<sup>c</sup>Amino acid content after 12-h incubation differs from content before incubation ( $P < .05$ ).

Table 7. Crude protein digestibility of test proteins by lambs

Item	Apparent diet CP digestibility, %	True supplement CP digestibility, % <sup>a</sup>
Unsupplemented control	69.3 <sup>b</sup>	—
Soybean meal	77.1 <sup>e</sup>	95.4 <sup>b</sup>
Meat and bone meal 1	75.5 <sup>cde</sup>	88.0 <sup>bc</sup>
Meat and bone meal 2	73.4 <sup>c</sup>	79.1 <sup>c</sup>
Meat and bone meal 3	73.9 <sup>cd</sup>	80.9 <sup>c</sup>
Meat and bone meal 4	75.1 <sup>cde</sup>	86.0 <sup>bc</sup>
Poultry by-product meal 1	76.0 <sup>cde</sup>	89.9 <sup>bc</sup>
Poultry by-product meal 2	74.7 <sup>cde</sup>	84.6 <sup>bc</sup>
Poultry by-product meal 3	76.7 <sup>de</sup>	92.9 <sup>b</sup>
Poultry by-product meal 4	75.9 <sup>cde</sup>	88.5 <sup>bc</sup>
Poultry by-product meal 5	76.7 <sup>de</sup>	93.2 <sup>b</sup>
Poultry by-product meal 6	75.2 <sup>cde</sup>	86.6 <sup>bc</sup>
SEM	.9	3.3

<sup>a</sup>Calculated by difference from apparent CP digestibility of urea control.

<sup>b,c,d,e</sup>Means within a column with different superscripts differ ( $P < .05$ ).

tial amino acids may be due to preferential bacterial degradation of nonessential amino acids and nucleic acids in the rumen. Although Weakley et al. (1984) and Goedecken et al. (1990) reported that amino acid profiles were not altered extensively during in situ incubation, this work agrees with that of Varvikko (1986) and Crooker et al. (1981), who reported certain amino acids were more resistant to degradation than others. Amino acid concentrations before incubation were poorly correlated to amino acid concentrations after incubation (Table 6), with the exception of methionine, isoleucine, and lysine, which were highly correlated ( $r = .97, .75, \text{ and } .64$ , respectively,  $P < .05$ ). These data indicate that the amino

acid profile of dietary MBM and PBM protein before digestion was different from the amino acid profile of ruminal escape protein.

**Digestion Study.** Protein sources differed ( $P < .05$ ) in apparent diet CP and true supplemental CP digestibilities (Table 7). True supplemental CP digestibilities, calculated by difference from the unsupplemented control, ranged from 95.4% for SBM to 79.1% for one MBM source. True CP digestibilities for MBM and PBM sources averaged 87.0%, which is similar to the true CP digestibility of 86.4% for MBM calculated by Loerch et al. (1983) from duodenal and ileal flow. Escape protein and ash content were poorly correlated to digestibility ( $R^2 = .27$  for escape and  $R^2 = .12$  for ash), suggesting that neither is related to CP digestibility in lambs. Variation in CP digestibility of MBM and PBM, like feather meal, is likely influenced by differences in rendering time and temperature (Aderibigbe and Church, 1983). The content of poorly digestible hair, feathers, and collagen in MBM and PBM may also reduce CP digestibility (Knabe et al., 1989). Overheating during processing and inclusion of hair, feathers, and collagen has been blamed for reduced CP digestibility, and these are likely the causes of variation in CP digestibility among these products.

**Growth Trials.** Steers consuming MBM and PBM treatments gained faster ( $P < .05$ ) than steers fed the urea diet (Table 8). Intake was similar within trial because all animals were fed at an equal percentage of BW. Differences in gain would therefore be due to the ruminal escape protein supplied by MBM and PBM sources. Results from the three growth trials were pooled because efficiency of protein utilization was similar ( $P > .30$ ) for replicated treatments. The three trials were designed to be similar: similar cattle selected from a herd of 800, feedstuffs used were from

Table 8. Daily gain and dry matter intake of steers fed urea, meat and bone meal, or poultry by-product meal supplements<sup>a</sup>

Item	Trial 1		Trial 2		Trial 3	
	ADG, kg/d	DMI, % BW	ADG, kg/d	DMI, % BW	ADG, kg/d	DMI, % BW
Urea	.35 <sup>b</sup>	2.1	.43 <sup>b</sup>	2.3	.23 <sup>b</sup>	2.1
Meat and bone meal 1	.41 <sup>bc</sup>	2.1	—	—	—	—
Meat and bone meal 2	.40 <sup>bc</sup>	2.1	—	—	—	—
Meat and bone meal 3	.43 <sup>bc</sup>	2.1	—	—	—	—
Meat and bone meal 4	—	—	—	—	.31 <sup>bc</sup>	2.1
Poultry by-product meal 1	.50 <sup>c</sup>	2.1	.57 <sup>c</sup>	2.3	—	—
Poultry by-product meal 2	—	—	.57 <sup>c</sup>	2.3	—	—
Poultry by-product meal 3	—	—	.58 <sup>c</sup>	2.3	—	—
Poultry by-product meal 4	—	—	.63 <sup>c</sup>	2.3	.37 <sup>c</sup>	2.1
Poultry by-product meal 5	—	—	—	—	.36 <sup>c</sup>	2.1
Poultry by-product meal 6	—	—	—	—	.38 <sup>c</sup>	2.1
SEM	.04	—	.04	—	.03	—

<sup>a</sup>Expressed as the average of levels fed.

<sup>b,c</sup>Values within a column with unlike superscripts differ ( $P < .05$ ).

Table 9. Protein efficiency of test proteins

Item	Protein efficiency <sup>a</sup>
Meat and bone meal 1	.61 <sup>b</sup>
Meat and bone meal 2	.70 <sup>b</sup>
Meat and bone meal 3	.76 <sup>b</sup>
Meat and bone meal 4	.79 <sup>bc</sup>
Poultry by-product meal 1	1.12 <sup>bc</sup>
Poultry by-product meal 2	1.15 <sup>bc</sup>
Poultry by-product meal 3	1.19 <sup>bc</sup>
Poultry by-product meal 4	1.55 <sup>c</sup>
Poultry by-product meal 5	1.12 <sup>bc</sup>
Poultry by-product meal 6	1.54 <sup>c</sup>
SEM	.25

<sup>a</sup>Calculated as kg of gain above urea control per kg of natural protein above control.

<sup>b,c</sup>Means with different superscripts differ ( $P < .10$ ).

the same batch, diets were similar, the same facilities were used, and trial lengths were equal. The urea control diet served as an internal standard, and, even though daily gains differed among trials (.23 to .43 kg/d for the urea controls), the gains of by-product-supplemented calves relative to the urea were the values used to calculate protein efficiency values. For example, the average gain response to by-products was .16 kg/d in Trial 2 and .13 kg/d in Trial 3, even though urea control gains varied from .43 to .23 kg/d (Table 8). After combining data across trials, protein efficiency values from the 10 by-products differed among sources ( $P < .10$ ; Table 9), ranging from .61 to 1.55.

Although escape protein was related to protein efficiency (Table 10), the relationship was negative. An increase in escape protein increases the supply of amino acids to the animal; the quality of this amino acid supply determines how closely it complements microbial protein in meeting an animal's amino acid requirements. Regression of amino acid supply on protein efficiency indicated that most amino acids

Table 10. Regression on protein efficiency

Item	R <sup>2</sup>	Slope
N escape	.75	-.05
Ash	.45	-.03
N digestibility	.20	.03
Arginine	.59	-.50
Cystine	.45	-1.22
Histidine	.00	.09
Isoleucine	.11	.95
Leucine	.13	-.48
Lysine	.00	.06
Methionine	.40	1.95
Phenylalanine	.02	-.34
Threonine	.04	-.51
Valine	.46	-1.30
Tryptophan	.03	2.42

were either poorly correlated to protein efficiency or had a negative slope (Table 10). Methionine, however, was moderately correlated ( $R^2 = .40$ ) to protein efficiency with a positive slope. This suggests that as the level of metabolizable methionine increased in MBM and PBM products, protein efficiency also increased.

During periods of rapid growth, microbial protein production is not sufficient to meet an animal's protein requirements (Klopfenstein et al., 1978). The value of an escape protein source then becomes its ability to complement microbial amino acid production to meet an animal's amino acid requirements. Several researchers have reported that ruminal microbial protein is limiting in methionine and lysine (Nimrick et al., 1970; Fenderson and Bergen, 1975; Richardson and Hatfield, 1978). Like blood meal, MBM is a good source of lysine. However, MBM may contain between 50 and 65% collagen (Eastoe and Long, 1960), which is devoid of tryptophan and low in methionine (Atkinson and Carpenter, 1970).

## Implications

Meat and bone meals and poultry by-product meals are variable in escape protein, ash content, and crude protein digestibility. Twelve-hour in situ escape protein and crude protein digestibility alone are poor indicators of protein efficiency in steers gaining .23 to .63 kg/d. Although meat and bone meals and poultry by-product meals improved average daily gain of growing steers relative to urea, differences in protein efficiency seemed to be related to the amount of metabolizable methionine supplied by each product.

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