Combinations of Rendered Protein Meals for Growing Calves[1]

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ABSTRACT: Complementary responses between rendered protein meals were investigated in this study. In a preliminary trial using 12 mature wethers in two replications, there was no difference ($P > .20$) in N digestibility between meat and bone meal (MBM; 96.7%), feather meal (FTH; 89.8%), and soybean meal (SBM; 98.7%). In a 112-d growth trial, individually fed calves (n = 120; 230 kg) received graded levels of FTH, MBM, 50:50 MBM-FTH (CP basis), or SBM with or without tryptophan (Trp) supplementation. Additions of Trp increased plasma Trp levels ($P < .05$) but failed to improve efficiency of protein utilization ($P > .35$). Pooled results showed that this efficiency was greater ($P < .05$) for FTH (1.47) than for MBM (1.04), FTH:MBM (.80), or SBM (.66). A trial was conducted to determine whether Trp addition reduces growth response to FTH:MBM (50:50) combinations. Calves (n = 230; 285 kg) were blocked by sex and weight into six replications and received FTH:MBM supplying 35% of the supplemental CP fed alone or with a high or low level of Trp supplement. Negative (urea only) and positive controls were included. Calves receiving FTH:MBM combinations gained faster ($P < .10$) and were more efficient ($P < .10$) than urea-supplemented calves. Performance was not altered by Trp addition. Calves (n = 120; 230 kg) were individually fed in two replications (43 or 48% CP MBM in Replications 1 and 2, respectively) of a growth trial to determine whether there was a complementary response between blood meal (BM) and MBM. There was no complementary response between MBM and BM in either replication. Addition of graded levels of BM linearly ($P < .01$) increased ADG. Results indicate that there is no complementary response between MBM and BM or FTH.

Key Words: Beef Cattle, Protein Degradation, Feather Meal, Blood Meal, Meat Meal

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Introduction

Complementary responses in growing calves between dietary blood meal (**BM**) and feather meal (**FTH**; Goedeken et al., 1990a,b; Blasi et al., 1991) and BM and corn gluten meal (Stock et al., 1981) are likely a result of improved ratios among limiting amino acids. Blood meal is high in lysine and FTH and corn gluten meal are high in sulfur amino acids, both of which have been identified as limiting in microbial protein (Nimrick et al., 1970; Williams and Smith, 1974). Relative to FTH, meat and bone meal (**MBM**) is also a good source of metabolizable lysine and is more economical than BM. The amino acid profile of metabolizable protein may also be improved by combining MBM and FTH.

Commercial MBM proteins can contain between 50 and 65% collagen (Eastoe and Long, 1960), which is devoid of tryptophan (**Trp**) and low in methionine (Atkinson and Carpenter, 1970a). The Trp that is present in MBM is poorly digested in swine (Knabe et al., 1989) and may be limiting in calves because of preferential degradation in the rumen of cattle (Goedeken et al., 1990a).

The following trials were conducted to determine whether there is a complementary effect between MBM and FTH or between MBM and BM and to establish whether Trp limits growth in FTH- or MBM-supplemented calves.

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Materials and Methods

Trial 1

Twelve Suffolk × Finn wethers ($\bar{x}$ BW 60 ± 9 kg) receiving a diet based on ensiled corncobs and alfalfa pellets were randomly assigned to receive one of the following supplemental proteins (Table 1): FTH, MBM, soybean meal (**SBM**), or a urea control (six wethers per treatment). Urea was used to supply 20% of dietary CP in all diets to ensure adequate ruminal ammonia levels. Sheep were weighed before the trial to enable diets to be fed on a percentage of BW basis. The trial was replicated twice with sheep re-randomized to protein supplements between trials. Each period consisted of a 10-d adaptation period and a 7-d fecal 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 urea-supplemented sheep as outlined by Blasi et al. (1991). Results were analyzed as a completely randomized design using the GLM procedure of SAS (1982) with model effect as protein source and replication.

Approximately 1 g of each protein source was placed in Dacron bags (7.5 × 12.5 cm^2; 50-μm pore size) and incubated for 12 h in the rumen of a steer fed a corncob-based diet to estimate ruminal escape values (Goedeken et al., 1990b). Each sources was analyzed in duplicate. Escape values of proteins were estimated as the percentage of N remaining after 12 h of incubation in situ without correction for microbial attachment.

Feeds were hydrolyzed in 6 *N* HCl (AOAC, 1975), and amino acid content of hydrolyzates was determined by ion-exchange chromatography. Separate samples were oxidized with performic acid for analysis of cystine and methionine. A separate analysis for Trp was also conducted using the procedure of Lewis et al. (1976) modified for manual analysis.

Trial 2

One hundred twenty crossbred (Hereford, Angus, Red Poll, Pinzgauer) steers ($\bar{x}$ 235 ± 28 kg, age = 8 mo) were individually fed a 50:50 sorghum silage-corncob base diet. A protein supplement made up 10.32% of the total diet DM (Table 2). Feather meal, MBM, FTH:MBM (50:50 mix on a CP basis), or SBM supplied 25, 33, 41, or 49% of the supplemental CP. A urea control supplement was used as the zero level of each test protein and was mixed with the given levels of test protein to maintain an 11.5% CP diet. Each level of each protein was fed with or without 9 g of Promate T® (24% L-tryptophan, Showa Denko, Tokyo, Japan), which supplied an estimated 2 g of Trp at the small intestine. The Trp did not degrade in situ. Thirty calves received each supplement; this resulted in six calves at each level of test protein, three with and three without Trp supplementation. Calves were randomly assigned to supplement source and level.

The trial was conducted for 100 d during November to February. Diets were formulated to meet NRC (1984) requirements for CP, energy, vitamins, and minerals for .7 kg/d of gain. Diets were fed daily, and all calves received the same amount as a percentage of BW. This was adjusted as needed to minimize orts while maintaining intake near ad libitum. Calves were housed in a barn open to the south in pens of 30. Individual feeding was accomplished with Calan gates (American Calan, Northwood, NH).

To verify that Trp was being absorbed postruminally, plasma from each calf was analyzed for Trp concentration. Blood was drawn from each calf by jugular venipuncture before the morning feeding on d 56 of the trial. Blood was placed immediately on ice until it was centrifuged at 5,000 × *g* for 15 min to remove blood cells. Three milliliters of plasma from each calf was deproteinized with .75 mL of a 4% trichloroacetic acid solution. Plasma Trp was analyzed as outlined by Lewis et al. (1976).

Initial and final weights were the average of three consecutive daily weights. All calves were implanted with Compudose® (Elanco Products, Indianapolis, IN) before the trial. Average daily gain was analyzed using the GLM procedure of SAS (1982) with protein source, level of protein, and Trp supplementation as model effects. The residual mean square was the test term. Efficiency of protein utilization was determined for each protein source using the slope-ratio technique (Klopfenstein et al., 1985) with the urea-supplemented calves as the control. Protein efficiency was calculated as the units of gain obtained greater than the control calves per unit of protein consumed greater than the control diet. Slopes (protein efficiencies) were statistically compared using a two-tailed *t*-test (Steel and Torrie, 1980). The GLM procedure of SAS (1982) was used to measure statistical difference in plasma Trp concentrations. The model included protein source, level of supplementation, Trp supplementation, and source × Trp interaction as sources of variation. The residual mean square was the test term.

Trial 3

A 66-d growth trial was conducted to investigate a possible negative effect of Trp supplementation to FTH:MBM combinations. One hundred ninety-five heifers ($\bar{x}$ BW 297 ± 39 kg) and 35 steers ($\bar{x}$ BW

Table 1. Diets fed in Trial 1[a]

Ingredient	Treatment			
	Feather meal	Meat and bone meal	Soybean meal	Urea control
Ensiled cobs	68.66	68.64	69.03	68.73
Alfalfa pellets	15.74	15.47	15.55	15.49
Urea	.90	.90	.90	1.98
Ground corn	9.03	3.78	4.05	12.16
Dicalcium phosphate	1.15	1.15	1.15	1.15
Salt	.25	.25	.25	.25
Ammonium sulfate	.17	.17	.17	.17
Trace minerals[b]	.04	.04	.04	.04
Vitamins[c]	.03	.03	.03	.03
Feather meal	4.31	—	—	—
Meat and bone meal	—	9.58	—	—
Soybean meal	—	—	8.82	—

[a]Expressed as percentage of DM.
[b]10% Mg, 6% Zn, 4.5% Fe, 2% Mn, .5% Cu, .3% I, .05% Co.
[c]15,000 IU of vitamin A, 3,000 IU of vitamin D, and 3.75 IU of vitamin E per gram of premix.

279± 47 kg) of mixed breeding (age = 12 mo) were blocked by sex and weight into six replications (five replications of heifers, one replication of steers). All calves received a basal diet of 15.72% corn silage, 32.0% sorghum silage, and 46.0% ammoniated wheat straw. Cattle were randomly allotted within block to receive one of five dietary treatments (Table 3): 1) urea control, 2) 50:50 MBM-FTH combination supplying 30% of the supplemental CP, 3) same as Treatment 2 plus 9 g of Promate T added to supply a daily intake of approximately 2 g of Trp, 4) same as Treatment 2 plus 18 g of Promate T added to supply a daily intake of approximately 4 g Trp, and 5) positive control in which FTH:MBM supplied 50% of the supplemental CP. Intakes (kilograms/day) were kept equal across treatments within replications. The quantity fed was based on the pen of calves with the lowest intake (maximum amount of feed that would be completely consumed in 24 h). Calves were implanted with Compudose at trial initiation. Initial and final weights were the average of two consecutive daily weights. Average daily gain and gain to feed ratio were statitically analyzed as a randomized complete block design with replication and treatment in the model.

Table 2. Supplements fed in Trial 2

Ingredient	Treatment[a]			
	Feather meal[b,c]	Meat and bone meal[b,c]	Soybean meal[b]	Urea control
Ground corn	39.74	.59	4.85	63.10
Urea	10.76	9.98	10.18	20.06
Limestone	2.71	—	2.71	2.33
Dicalcium phosphate	7.66	—	6.98	8.63
Ammonium sulfate	—	1.55	1.07	2.23
Salt	2.91	2.91	2.91	2.91
Trace minerals[d]	.48	.48	.48	.48
Vitamins[e]	.10	.10	.10	.10
Selenium[f]	.16	.16	.16	.16
Feather meal	35.48	—	—	—
Meat and bone meal	—	84.23	—	—
Soybean meal	—	—	70.56	—

[a]Each supplement fed with and without Promate T. Values expressed as percentage of DM.
[b]Supplements mixed with urea supplement so test proteins supplied 25, 33, 41, or 49% of supplemental protein.
[c]Supplements mixed 50:50 to make the fifth treatment.
[d]10% Mg, 6% Zn, 4.5% Fe, 2% Mn, .5% Cu, .3% I, .05% Co.
[e]15,000 IU of vitamin A, 3,000 IU of vitamin D, and 3.75 IU of vitamin E per gram of premix.
[f]Premix contained .06% selenium.

Table 3. Supplements fed in Trial 3

Ingredient	Treatment[a] MBM:FTH 30	MBM:FTH 30-9	MBM:FTH 30-18	MBM:FTH 50	Urea control
Ground corn	21.60	19.20	16.88	—	53.12
Urea	11.32	11.29	11.30	5.11	20.34
Ammonium sulfate	4.58	4.57	4.57	4.48	4.70
Salt	4.77	4.75	4.76	4.79	4.70
Limestone	.70	.70	.70	—	1.72
Dicalcium phosphate	5.79	5.77	5.78	—	14.24
Trace minerals[b]	.80	.80	.80	.80	.78
Vitamins[c]	.16	.16	.16	.16	.15
Selenium[d]	.26	.26	.25	.26	.25
Promate T[e]	—	2.25	4.51	—	—
Feather meal	16.04	16.00	16.01	26.87	—
Meat and bone meal	33.98	34.25	34.28	57.53	—

[a]MBM:FTH 30: combination of meat and bone meal and feather meal (50:50 CP basis) supplying 30% of the supplemental CP. MBM:FTH 30-9: same as MBM:FTH 30 with Promate T added to supply approximately 9 $g \cdot animal^{-1} \cdot d^{-1}$. MBM:FTH 30-18: same as MBM:FTH 30 with Promate T added to supply approximately 18 $g \cdot animal^{-1} \cdot d^{-1}$. MBM:FTH 50: same as MBM:FTH 30 but supplying 50% of the supplemental CP. Values expressed as percentage of DM.
[b]10% Mg, 6% Zn, 4.5% Fe, 2% Mn, .5% Cu, .3% I, .05% Co.
[c]15,000 IU of vitamin A, 3,000 IU of vitamin D, and 3.75 IU of vitamin E per gram of premix.
[d]Premix contained .06% selenium.
[e]Contains 24% L-tryptophan.

Trial 4

Two replications of a growth trial were conducted to determine whether a complementary effect exists between BM and MBM and whether the type of MBM used influences this response. In the first replication, 60 crossbred (Hereford, Angus, Red Poll, Pinzgauer) steers ($\bar{x}$ BW 224 ± 36 kg) were individually fed a 50:50 sorghum silage-corncob base diet with one of five levels of the following supplements supplying 10.32% of the diet DM (Table 4): 1) MBM, 2) BM, 3) 90:10 combination (CP basis) of MBM and BM, 4) 80:20 MBM:BM, and 5) 70:30 MBM:BM. Each protein source was fed to supply 0 (urea supplement alone; n = 10), 25 (n = 2), 33 (n = 3), 41 (n = 3), or 49% (n = 2) of the supplemental CP (slope-ratio technique; Klopfenstein et al., 1985). The remainder of the supplemental CP was supplied by urea so that all calves received an 11.5% CP diet.

Charolais × Hereford heifers (230 ± 16 kg) were used in the second replication. To determine whether the type of tissue from which the MBM was derived influenced a possible complementary effect, a 43% CP MBM was used in the first replication and a 48% CP MBM was used in the second replication. All cattle were implanted with Compudose at trial initiation. Protein efficiency response to protein source was analyzed using the slope-ratio technique as outlined in Trial 2. The GLM procedure of SAS (1982) with ratio of BM to MBM protein in the model was used to analyze ADG as influenced by the BM content of the supplement.

Table 4. Supplements fed in Trial 4

Ingredient	Treatment[a] Urea control[b]	Blood meal[c]	Meat and bone meal[c]
Ground corn	63.10	39.74	.59
Urea	20.06	10.76	9.98
Ammonium sulfate	2.23	—	1.55
Salt	2.91	2.91	2.91
Limestone	2.33	2.71	—
Dicalcium phosphate	8.63	7.66	—
Trace minerals[d]	.48	.48	.48
Vitamins[d]	.10	.10	.10
Selenium[d]	.16	.16	.16
Blood meal	—	35.48	—
Meat and bone meal	—	—	84.23[e]

[a]Values expressed as percentage of DM.
[b]Urea supplement mixed with test supplements to allow 25, 33, 41, or 49% of supplemental protein to come from test proteins.
[c]Supplements combined to supply 90:10, 80:20, or 70:30 ratios of meat and bone meal to blood meal protein.
[d]See specifications in Table 2.
[e]64.65% for second replication; other ingredients adjusted accordingly.

Results and Discussion

Trial 1

There were no differences ($P > .20$) in apparent diet N or true supplemental N digestibility among the proteins (Table 5). Numerically, SBM had the

Table 5. Crude protein, nitrogen digestibility, and escape values of test proteins (Trial 1)

Protein	CP, %	Apparent diet N digestibility, %[a]	True supplement N digestibility, %[b]	Escape value,%[c]
Urea	287.0	61.0	—	—
Soybean meal	44.8	60.6	98.7	25.4
Meat and bone meal	40.4	59.9	96.7	53.6
Feather meal	82.8	57.9	89.8	60.6
SEM	—	1.5	4.4	—
Blood meal[d]	88.5	58.0	103.0	90.0

[a]Apparent N digestibility of total diet. No difference between diets ($P > .2$).
[b]Calculated by difference from apparent N digestibility of urea control diet. No significant difference between diets ($P < .20$).
[c]Percentage of protein remaining after 12-h incubation in situ.
[d]Values obtained by Goedeken et al. (1990b).

highest true N digestibility (98.7%) and FTH the lowest (89.8%), with MBM intermediate (96.7%). Although there have been reports of poor N digestibilities of FTH in swine (Knabe et al., 1989), there are few reports of low protein digestibilities for ruminants. Goedeken et al. (1990b) and Blasi et al. (1991) found that FTH protein, calculated by difference from urea, was digested more poorly ($P < .10$) than either BM or SBM protein, but both reports indicated a true N digestibility > 86%. Loerch et al. (1983) found true N digestibility of MBM, calculated from duodenal and ileal flow, to be 86.4%, which was 14 percentage units lower than that of BM. Results from the present trial indicate that all protein sources were highly digestible with minimal damage from processing.

Trial 2

Calves supplemented with Trp had plasma Trp levels of 1.50 μg/mL, which were higher ($P < .05$) than those of calves not supplemented with Trp (1.31 μg/mL), indicating that Promate T was being digested postruminally and that the Trp absorbed was available for protein synthesis. There was no plasma Trp × protein interaction ($P > .80$).

Tryptophan supplementation numerically increased protein efficiency (PE) for all proteins except the FTH:MBM combination (Table 6). There was, however, no interaction between protein source and Trp supplementation on daily gain ($P = .20$) and no main effect of Trp supplementation ($P > .35$). If the poor growth response to Trp addition to FTH:MBM was due to chance, the possibility of a Type II error increases. To avoid this, ADG was also analyzed using the GLM procedure of SAS (1982) excluding the FTH:MBM treatment. The model included protein source, level of supplementation, and Trp addition. No response ($P > .34$) in ADG to Trp addition was detected.

Fenderson and Bergen (1975) found that the Trp requirement had been met in steers receiving a 50% corn diet with a duodenal flow of 3.3 g/d of Trp. Using the equation of Burroughs et al. (1974) to estimate microbial production, the amino acid profile of microbial protein as determined by Goedeken et al. (1990a), and escape values as determined in Trial 1, the estimated daily flow of Trp would have been approximately 3.6 g/d for the basal diet alone. This assumes that digestibility of Trp is equal to that of other amino acids. At low levels of escape protein, the Trp addition may have improved PE for SBM, FTH, and MBM. Because there was no growth response ($P > .35$) to Trp supplementation, data were pooled for analysis of growth response.

Feather meal protein was utilized more efficiently for BW gain ($P < .05$) than was MBM, FTH:MBM, or SBM protein (Figure 1). The difference in escape protein (Table 5) likely accounts for a large part of this difference. The metabolizable protein

Table 6. Effect of tryptophan supplementation on efficiency of protein utilization (Trial 2)

Protein source	Protein efficiency[a] Without tryptophan	With tryptophan
Feather meal	$1.38^{b} \pm .12$	$1.49^{b} \pm .19$
Meat and bone meal	$.82^{c} \pm .20$	$1.16^{bc} \pm .31$
FTH:MBM[d]	$1.17^{bc} \pm .39$	$.38^{c} \pm .32$
Soybean meal	$.47^{c} \pm .26$	$.79^{c} \pm .19$

[a]Additional gain above urea controls per unit of protein fed above the urea controls. No protein × tryptophan interaction ($P > .20$).
[b,c]Values in the same column with different superscripts differ ($P < .05$).
[d]Feather meal and meat and bone meal mixed 50:50 on a CP basis.

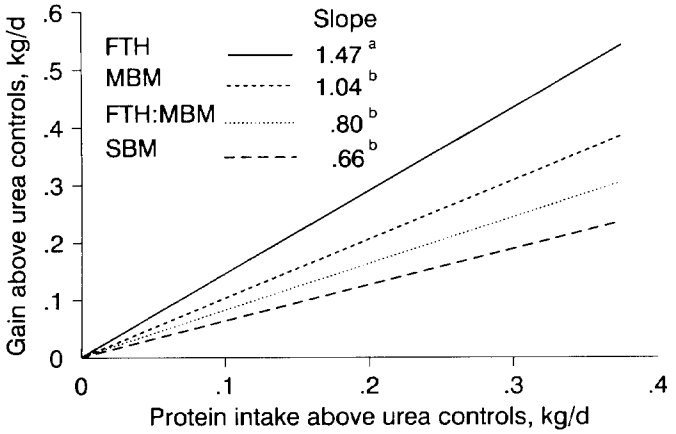

Figure 1. Regression of daily protein intake above urea controls against daily gain above urea controls. Resulting values (slopes) are the protein efficiencies from Trial 2. Standard errors of the slopes are .112, .192, .262, and .163 for feather meal, meat and bone meal, 50:50 (CP basis) combination of meat and bone meal and feather meal, and soybean meal, respectively. Values with different superscripts differ ($P < .06$).

supplied from the base diet would be almost entirely from microbial protein. It is possible that the limiting amino acid of microbial protein is still limiting at the low levels of escape protein supplementation. In this case, initial response to the proteins may reflect the supply of sulfur amino acids because these have been identified as limiting in microbial protein (Nimrick et al., 1970; Richardson and Hatfield, 1978; Titgemeyer and Merchen, 1990).

A complementary effect between FTH and MBM would have resulted in a PE greater than the average of the two (1.1). There seems to be little or no complementary effect between the two because the PE for the combination was 1.17. Blasi et al. (1991) and Goedeken et al. (1990b) theorized that the positive associative effect between BM and FTH was a result of the high lysine content of the BM complementing the high sulfur amino acids content of the FTH.

Feather meal is an excellent source of sulfur amino acids but it contributes primarily cystine rather than methionine. Although cystine may provide > 50% of the sulfur amino acids requirement (Ahmed and Bergen, 1983), there is also a requirement for methionine per se (Reis et al., 1973). Feather meal is also a very poor source of histidine (Table 7). Gibb et al. (unpublished data) found that histidine may become limiting with increasing FTH supplementation. Relative to beef muscle tissue, microbial protein is also low in histidine (Owens, 1986). Although MBM supplies nearly twice the histidine of FTH (Table 7), both are very poor sources relative to BM.

Microbial protein is considered to be of relatively high quality (Storm et al., 1983; Owens and Zinn, 1988) even though the amino acids mentioned previously may be slightly limiting. Because escape proteins mix with microbial protein, amino acid deficiencies may be minor. As a result, complementary responses may require an improved ratio of more than just the first- and second-limiting amino acids. Complementary responses observed with FTH and BM (Goedeken et al., 1990a,b; Blasi et al., 1991) may be the result of an improved ratio of lysine, sulfur amino acids, methionine, and possibly histidine and Trp. Meat and bone meal may not supply enough lysine, methionine, histidine, and Trp to complement the high sulfur amino acids content of FTH. Compared with BM, MBM and FTH are poor sources of these amino acids. This may explain why BM complements the high sulfur amino acids content of FTH, but MBM does not.

Trial 3

Calves that received FTH:MBM supplements had greater ($P < .10$) ADG than did calves that received the urea control (Table 8). Calves that received FTH:MBM-50 did not have better gains or feed efficiencies than calves that received FTH:MBM-30, suggesting that FTH:MBM-50 had supplied more metabolizable protein than required. This is possible considering the weight of the

Table 7. Metabolizable lysine, methionine, total sulfur amino acids, histidine, and tryptophan content of proteins, percentage of CP[a]

Protein	Lysine	Methionine	TSAA[b]	Histidine	Tryptophan
Soybean meal	1.3	.3	.7	.6	.3
Meat and bone meal	2.5	.8	1.5	.7	.2
Feather meal	1.1	.4	3.7	.4	.2
Blood meal	7.5	1.4	2.9	5.0	1.1

[a]Based on amino acid analysis (Table 10), escape values, and N digestibilities (Table 5). Assume uniform degradability (Goedeken et al., 1990b) and digestibility of amino acids.
[b]Total sulfur amino acids (methionine + cystine).

Table 8. Gain and feed efficiency of steers in Trial 3[a]

Item	MBM:FTH 30	MBM:FTH 30-9	MBM:FTH 30-18	MBM:FTH 50	Urea control	SEM
ADG, kg	.64[b]	.64[b]	.63[b]	.62[b]	.56[c]	.05
Gain:feed	.074[bc]	.082[b]	.084[b]	.083[b]	.073[c]	.003

[a]Treatments described in Table 3.
[b,c]Means in the same row with different superscripts differ ($P < .10$).

heifers used. A lack of a negative response to Trp addition suggests that the negative response observed in Trial 2 may have been spurious.

Trial 4

Results of the two replications were pooled because growth response was not influenced ($P > .80$) by the MBM used. Although increasing levels of BM in the supplement linearly increased ($P < .01$) ADG (Table 9), there was no complementary effect on PE between MBM and BM (Figure 2). Assuming an escape value of 54% for the MBM (Table 5) and 90% for the BM, the amount of MBM protein reaching the small intestine would have been only 60% that of BM. Averaged across all treatments containing MBM, MBM protein was utilized 59% as efficiently as BM, indicating that there is little difference between BM and MBM in quality of intestinally available protein for growing calves. Blood meal protein has a high escape value (Loerch et al., 1983; NRC, 1985), is highly digestible in both swine and ruminants (Knabe et al., 1989, Blasi et al., 1991), is high in essential amino acids (Goedeken et al., 1990a,b), and is usually the most efficiently utilized protein considered in calf growing trials (Stock and Klopfenstein, 1979; Goedeken et al., 1990a,b; Blasi et al., 1991). In Trial 4, the difference in PE between BM and MBM can be explained by the difference in escape value alone. In comparison, MBM had 88% the escape value of FTH (Table 5), but protein efficiency of MBM was only 71% that of FTH (Figure 1). This indicates that intestinally available protein from MBM was not utilized as efficiently as BM protein. Mantysaari et al. (1989) found that calves receiving MBM did not gain as well as calves receiving SBM. There have also been negative growth responses by nonruminants fed MBM (Atkinson and Carpenter, 1970b; Batterham et al., 1978; Leibholz, 1979). Considering that differences in escape value can explain most of the differences in protein efficiency, MBM compared favorably with BM in Trial 4.

Blood meal is a good source of essential amino acids, whereas MBM can contain large quantities of collagen (Eastoe and Long, 1960), resulting in a relatively low content of essential amino acids. Although there is a difference in quantities of total essential amino acids, both MBM and BM protein contain similar quantities of methionine and total sulfur amino acids (Table 10). If the amino acid profile of the protein does not change with ruminal degradation (Weakly et al., 1984; Varvikko, 1986;

Table 9. Average daily gain as influenced by meat and bone meal content of the supplement, Trial 4

MBM, %[a]	ADG, kg[b]
0	.60[c]
70	.54[d]
80	.50[d]
90	.50[d]
100	.54[d]
SEM	.05

[a]Percentage of protein from meat and bone meal, remainder from blood meal.
[b]Linear response to meat and bone meal ($P < .01$).
[c,d]Means in the same column with different superscripts differ ($P < .10$).

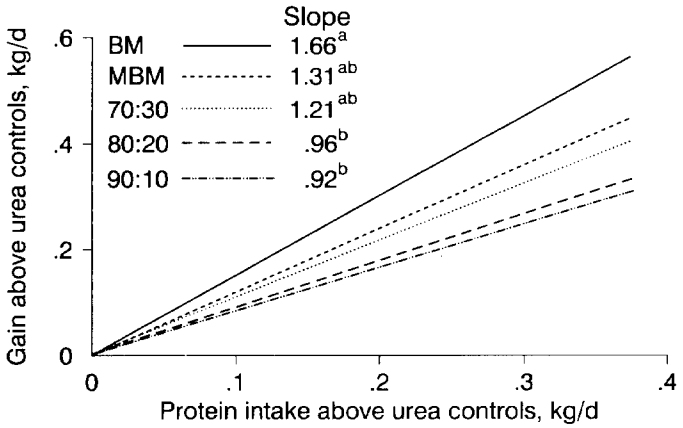

Figure 2. Regression of daily protein intake above urea controls against daily gain above urea controls. Resulting values (slopes) are the protein efficiencies from Trial 3. Standard errors of the slopes are .204, .234, .232, .209, and .282 for blood meal (BM), meat and bone meal (MBM), 70:30 combination (CP basis) of MBM and BM, 80:20 combination, and a 90:10 combination, respectively. Values with different superscripts differ ($P < .05$).

Table 10. Amino acid analysis of feeds[a]

Amino acid	Meat and bone meal	Feather meal	Soybean meal	Blood meal[b]
Arginine	7.6	6.8	7.7	5.7
Histidine	1.4	.7	2.4	5.5
Isolencine	2.2	4.1	3.7	2.5
Leucine	5.2	7.8	7.0	11.0
Lycine	4.9	2.0	5.4	8.3
Methionine	1.6	.7	1.3	1.6
Phenyalanine	3.0	4.9	4.4	6.1
Threonine	2.8	4.2	3.6	4.8
Tryphophan	.4	.4	1.1	1.2
Valine	3.4	6.2	3.8	6.2
Cystine	1.3	5.4	2.8	1.7
TSAA[c]	2.9	6.1	4.1	3.3

[a]Expressed as a percentage of CP.
[b]Determined by Goedeken et al. (1990a).
[c]Total sulfur amino acids (methionine + cystine).

Goedeken et al., 1990a,b), it is possible that the similar efficiency between escape proteins of MBM and BM is the result of a similar supply of methionine and total sulfur amino acids. This would also explain why a complementary effect was not detected. However, FTH, which is a good source of total sulfur amino acids, is rarely utilized as efficiently as BM (Goedeken et al., 1990a,b; Blasi et al., 1991). As discussed for Trial 2, the supply of other essential amino acids undoubtedly is a factor in protein efficiency. The high content of lysine, methionine, histidine, and Trp in blood meal compared to FTH may explain the difference in PE between these two proteins.

Implications

Protein digestibilities of meat and bone meal and feather meal are high when processing conditions are appropriate. Meat and bone meal and feather meal contain more metabolizable protein (as a percentage of crude protein) than soybean meal because of their lower ruminal degradabilities. Tryptophan was apparently not the first-limiting amino acid when meat and bone meal or combinations of meat and bone meal and feather meal were fed. There seems to be no advantage in combining meat and bone meal with feather meal or blood meal proteins. Most of the difference in protein efficiency between meat and bone meal and blood meal can be explained by escape values.

Literature Cited

Ahmed, B. M., and W. G. Bergen. 1983. Methionine-cyst(e)ine relationship in steers. J. Anim. Sci. 57(Suppl. 1):110 (Abstr.).

AOAC. 1975. Official Methods of Analysis (12th Ed.). Association of Official Analytical Chemists, Washington, DC.

Atkinson, J., and K. J. Carpenter. 1970a. Nutritive value of meat meals. I. Possible growth depressant factors. J. Sci. Food Agric. 21:360.

Atkinson, J., and K. J. Carpenter. 1970b. Nutritional value of meat meals. III. Value of meat meals as supplements to a cereal basal diet: Limiting amino acids in these diets. J. Sci. Food Agric. 21:370.

Batterham, E. S., R. D. Morison, and C. E. Lewis, 1978. An evaluation of total lysine as a predictor of lysine status in protein concentrates for growing pigs. Br. J. Nutr. 40:23.

Blasi, D. A., T. J. Klopfenstein, J. S. Drouillard, and M. H. Sindt. 1991. Hydrolysis time as a factor affecting the nutritive value of feather meal and feather meal-blood meal combinations for growing calves. J. Anim. Sci. 69:1272.

Burroughs, W., A. H. Trenkle, and R. L. Vetter. 1974. A system of protein evaluation for cattle and sheep involving metabolizable protein (amino acids) and urea fermentation potential of feedstuffs. Vet. Med. Small Anim. Clin. 69:713.

Eastoe, J. E., and J. E. Long. 1960. The amino acid composition of processed bones and meat. J. Sci. Food Agric. 11:87.

Fenderson, C. L., and W. G. Bergen. 1975. An assessment of essential amino acid requirements of growing steers. J. Anim. Sci. 41:1759.

Goedeken, F. K., T. J. Klopfenstein, R. A. Stock, and R. A. Britton. 1990a. Hydrolyzed feather meal as a protein source for growing calves. J. Anim. Sci. 68:2945.

Goedeken, F. K., T. J. Klopfenstein, R. A. Stock, R. A. Britton, and M. H. Sindt. 1990b. Protein value of feather meal for ruminants as affected by blood additions. J. Anim. Sci. 68: 2936.

Klopfenstein, T., R. Stock, and R. Britton. 1985. Relevance of bypass protein to cattle feeding. Prof. Anim. Scientist 1:27.

Knabe, D. A., D. C. LaRue, E. J. Gregg, G. M. Martinez, and T. D. Tanksley, Jr. 1989. Apparent digestibility of nitrogen and amino acids in protein feedstuffs by growing pigs. J. Anim. Sci. 67:441.

Leibholz, J. 1979. Meat meal in the diet of the early-weaned pig. III. Meat meal quality and the processing of meat meals. Anim. Feed Sci. Technol. 4:53.

Lewis, A. J., P. J. Holden, R. C. Ewan, and D. R. Zimmerman. 1976. An automated fluorometric method for the measurement of tryptophan in plasma. J. Agric. Food Chem. 24: 1081.

Loerch, S. C., L. L. Berger, S. D. Plegge, and G. C. Fahey, Jr. 1983. Digestibility and rumen escape of soybean meal, blood meal, meat and bone meal and dehydrated alfalfa nitrogen. J. Anim. Sci. 57:1037.

Mantysaari, P. E., C. J. Sniffen, T. V. Muscato, and M. L. Thonney. 1989. Performance of growing dairy heifers fed

diets containing soybean meal or animal by-product meals. J. Dairy Sci. 72:2107.

Nimrick, D., E. E. Hatfield, J. Kaminski, and F. N. Owens. 1970. Quantitative assessment of supplemental animo acid needs for growing lambs fed urea as the sole nitrogen source. J. Nutr. 100:1295.

NRC. 1984. Nutrient Requirements of Beef Cattle (6th Ed.). National Academy Press, Washington, DC.

NRC. 1985. Ruminant Nitrogen Usage. National Academy Press, Washington, DC.

Owens, F. N. 1986. Protein utilization in ruminants: Current concepts in formulating ruminant diets. pp 12–33. In: Proceedings from the American Feed Industry Association Nutrition Symposium. St. Louis, MO.

Owens, F. N., and R. Zinn. 1988. Protein metabolism of ruminant animals. In: D. C. Church (Ed.) The Ruminant Animal, Digestive Physiology and Nutrition. Prentice Hall, Englewood Cliffs, NJ.

Reis, P. J., D. A. Tunks, and L. F. Sharry. 1973. Plasma amino acid patterns in sheep receiving abomasal infusions of methionine and cystine. Aust. J. Biol. Sci. 26:635.

Richardson, C. R., and E. E. Hatfield. 1978. The limiting amino acids in growing cattle. J. Anim. Sci. 46:740.

SAS. 1982. SAS User's Guide: Statistics. SAS Inst. Inc., Cary, NC.

Steel, R.G.D., and J. H. Torrie. 1980. Principles and Procedures of Statistics: A Biometrical Approach (2nd Ed.). McGraw-Hill Book Co., New York.

Stock, R., and T. Klopfenstein. 1979. Feeding value of blood meal and meat meal as protein supplements for ruminants. J. Anim. Sci. 49(Suppl. 1):121 (Abstr.).

Stock, R., N. Merchen, T. Klopfenstein, and M. Poos. 1981. Feeding value of slowly degraded proteins. J. Anim. Sci. 53: 1109.

Storm, E., E. R. Ørskov, and R. Smart. 1983. The nutritive value of rumen microorganisms in ruminants. 2. The apparent digestibility and net utilization of microbial N for growing lambs. Br. J. Nutr. 50:471.

Titgemeyer, E. C., and N. R. Merchen. 1990. Sulfur-containing amino acid requirements of rapidly growing steers. J. Anim. Sci. 68:2075.

Varvikko, T. 1986. Microbially corrected amino acid composition of rumen-undegraded feed protein and amino acid degradability in the rumen of feeds enclosed in nylon bags. Br. J. Nutr. 56:131.

Weakley, D. C., F. N. Owens, and W. L. Stockland. 1984. Soybean meal digestion in the rumen: Amino acid changes. Oklahoma Agric. Exp. Sta. MP-116:179. Stillwater.

Williams, A. P., and R. H. Smith. 1974. Concentrations of amino acids and urea in the plasma of the ruminating calf and estimation of the amino acid requirements. Br. J. Nutr. 32: 421.