EFFECTS OF SUPPLEMENTAL PROTEIN SOURCE AND LEVEL OF UREA ON INTESTINAL AMINO ACID SUPPLY AND FEEDLOT PERFORMANCE OF LAMBS FED DIETS BASED ON ALKALINE HYDROGEN PEROXIDE-TREATED WHEAT STRAW[1]

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ABSTRACT

Two experiments were conducted to determine the effects of supplemental CP source and level of urea on intestinal amino acid (AA) supply and feedlot performance of lambs fed diets based on alkaline hydrogen peroxide-treated wheat straw (AHPWS). In Exp. 1, five cannulated (ruminal, duodenal, and ileal) crossbred wethers (61 kg) were used in a 5 × 5 Latin square design. Treatments consisted of different sources of CP and included soybean meal (SBM), a combination of urea, distillers dried grains (DDG), and fish meal, each provided an equal portion of supplemental CP (UDF), and three levels of urea (17, 33, and 50% of supplemental CP) fed in combination with DDG (U17, U33, and U50). Organic matter and N digestibilities decreased ($P < .05$) when lambs were fed U17 compared with those fed SBM. There were no differences ($P > .05$) in bacterial N or AA flows to the duodenum due to CP source despite large differences in ruminal NH_3 N concentrations and lower ruminal OM digestion when lambs were fed U17. Duodenal nonbacterial N and AA flows were highest ($P < .05$) in lambs fed U17 and UDF and lowest when lambs were fed U50 and SBM. Lysine concentration in duodenal digesta decreased with incremental increases in DDG. In Exp. 2, 30 individually penned ram lambs (33 kg) were allotted to five CP treatments in a randomized complete block design. Treatments were similar to those of Exp. 1, with the exception that U17 was replaced by a 14% CP diet with SBM as the supplemental CP source; all other diets were formulated to contain 12% CP. Lambs fed U50 had decreased ($P < .08$) ADG and gain/feed compared with all other treatments, and lambs fed UDF had greater ($P < .05$) ADG and gain/feed than lambs fed U33. It was concluded that 17% of the supplemental CP from urea seems adequate to maximize bacterial protein synthesis and that no more than 33% of the supplemental CP should be provided by urea in diets based on AHPWS. Feeding a combination of ruminally resistant protein sources with complementary AA profiles of lysine and methionine (UDF) may enhance quality of protein entering the duodenum and feedlot performance.

Key Words: Lambs, Amino Acids, Urea, Distillers' Grains, Fish Meal, Wheat Straw

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Introduction

Alkaline hydrogen peroxide-treated wheat straw (AHPWS) is a highly fermentable feedstuff for ruminants. Typical DM and NDF digestibilities of AHPWS-based diets are approximately 70 and 80%, respectively (Kerley et al., 1986; Cecava et al., 1990). To move AHPWS to commercial application, recommendations for optimal CP supplementation

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must be developed. Because AHPWS contains only 1 to 3% CP, essentially all dietary CP must be provided from supplemental CP sources. Urea is an economical CP source, and it would be beneficial to maximize its use. Burroughs et al. (1974) suggested that low CP, highly fermentable feedstuffs (> 75% TDN) have the greatest potential for being supplemented with urea. Cattle growth and protein efficiency ratio have been improved by feeding supplemental protein sources resistant to ruminal degradation in corn cob-based diets that contain little preformed protein (Waller et al., 1980; Stock et al., 1981). Cecava et al. (1990) demonstrated the complementary effects of supplementing diets based on AHPWS with corn gluten meal (high methionine content) and blood meal (high lysine content) vs soybean meal (SBM). Similar results may be achieved with distillers dried grains (DDG) and fish meal (FM). One approach to minimizing supplemental CP cost is to optimize combinations of nonprotein nitrogen and ruminally resistant protein sources, particularly those with complementary amino acid (AA) profiles.

The objectives of these experiments were to determine the effects of different supplemental CP sources and level of urea in diets based on AHPWS on intestinal N and AA supply (Exp. 1) and feedlot performance (Exp. 2) when fed to growing lambs.

Materials and Methods

Experiment 1

Animals and Diets. A 5 × 5 Latin square design was used to allot five cannulated Suffolk-cross lambs (mean initial BW = 61 kg) to five supplemental CP treatments. Lambs were fitted with permanent ruminal cannulas (i.d. 2.5 cm) and T-type cannulas in the proximal duodenum and terminal ileum 8 wk before the start of the experiment. Surgery was performed in a sterile environment under general anesthesia as described by Hsu et al. (1990) and followed a protocol approved by the University of Illinois Laboratory Animal Care Advisory Committee. Treatments consisted of different sources of supplemental CP and included SBM, a combination of urea, DDG plus corn, FM in which each protein source provided equal portions of supplemental protein (UDF), and three levels of urea fed in combination with DDG and corn. Levels of urea and DDG and corn (percentage of supplemental CP) were 17% urea:83% DDG and corn (U17), 33% urea:67% DDG and corn (U33), and 50% urea:50% DDG and corn (U50). Soybean meal is a protein source readily degraded in the rumen, whereas DDG and FM are more resistant to ruminal degradation. The U17, U33, and U50 treatments compared graded levels of urea, and the UDF treatment tested the complementary effects of protein sources from corn that are high in sulfur AA (DDG) and a high lysine source (FM). All diets were 65% AHPWS:35% concentrate and formulated to contain 12.5% CP (Table 1). However, due to differences in N content of FM compared with that analyzed before the trial and(or) sampling and mixing errors, the UDF diet was higher in CP than expected. Diets were balanced to contain .3% P, .45% Ca, .8% K, .2% S (maximum N:S ratio = 10:1), .3% trace mineralized salt, and 3,000 IU of vitamin A·lamb^{-1}·d^{-1}. These nutrient concentrations either meet or exceed NRC nutrient requirements (NRC, 1985). Calculations using NRC (1985) values for feedstuff composition showed that the K requirement was met by AHPWS and supplemental CP ingredients. However, because AHPWS contained high levels of Na, increased urinary excretion of Na and K was anticipated. To ensure against a K depletion, .3% supplemental KCl was provided. Alkaline hydrogen peroxide-treated wheat straw was prepared as described by Cecava et al. (1990). Fifteen kilograms of ground (.95-cm screen) wheat straw (90% DM) were weighed into a stainless steel mixer. Sodium hydroxide and hydrogen peroxide were added at 5 and 2%, respectively, to wheat straw DM. Final DM content of AHPWS was approximately 65%, and the pH was strictly monitored to ensure that the final product had a pH higher than 11.5. The AHPWS was stored in plastic-lined drums and frozen until 2 d before feeding. Because the diet containing FM was expected to be the least acceptable, a pretrial period was conducted to determine the ad libitum intake of the UDF diet. Dry matter intake was equalized for all lambs at 90% of the ad libitum intake of the lamb consuming the lowest quantity of DM. Daily DM intake averaged 1,743 g (2.87% of BW). Concentrate and AHPWS portions of the diet were weighed and manually mixed daily for each lamb and

fed in two equal portions at 0700 and 1900. At each feeding, lambs were dosed with a gelatin bolus containing 1.5 g of chromic oxide (2.01 g of Cr/d) via the ruminal cannula. Digesta flows were measured and digestibilities calculated in reference to this marker. Lambs were tethered in elevated pens with wire mesh flooring in an environmentally controlled (20°C) room with continuous lighting. Lambs were sheared and treated to eliminate internal and external parasites before the trial.

Sampling Procedures. Each 16-d period consisted of 10 d for diet adaptation and 6 d for sample collection. Feed samples were collected on d 10 through 15 and stored frozen until being dried at 55°C. Duodenal and ileal digesta samples were collected on d 11 through 16. On odd and even numbered days during the collection phase, duodenal (100 ml) and ileal (50 ml) samples were collected at 2, 6, and 10 h and 4, 8, and 12 h after the 0700 feeding, respectively. A total of 18 samples each of duodenal and ileal digesta was collected and frozen. Later, digesta samples were thawed, composited by lamb, and lyophilized. Lambs were fitted with canvas bags for total fecal collection from d 11 through 16. Feces were collected daily, weighed, and a 10% aliquot composited by lamb and frozen until subsequent drying at 55°C. All feed, digesta, and fecal samples were ground through a 1-mm screen. Ruminal contents (250 ml) were collected using a core sampler similar to that described by Firkins et al. (1986). Collection was once daily such that each 2-h interval after the 0700 feeding was represented. Ruminal contents were homogenized with an equal volume of saline for 30 s to dislodge bacteria adhering to feed particles. Homogenized contents were strained through four layers of cheesecloth and frozen. Subsequently, composited samples were thawed and a bacteria-rich fraction was isolated by differential centrifugation (Firkins et al., 1986). On

TABLE 1. DIETARY INGREDIENTS AND CHEMICAL COMPOSITION OF DIETS FED TO LAMBS IN EXP. 1

	CP source[a]				
Ingredient	SBM	U17	U33	U50	UDF
AHPWS[b]	63.8	64.3	64.3	64.3	64.1
Corn	18.6	3.0	10.8	18.6	18.1
Soybean meal	15.8	—	—	—	—
Distillers dried grains	—	30.5	21.9	13.3	10.2
Fish meal	—	—	—	—	5.5
Urea	—	.6	1.2	1.8	1.2
Dicalcium phosphate	.5	.2	.4	.6	—
Calcium sulfate[c]	—	—	+	+	.1
Calcium carbonate	.5	.6	.6	.6	—
Trace mineralized salt[d]	.3	.3	.3	.3	.3
Potassium chloride	.3	.3	.3	.3	.3
Vitamin premix[e]	.2	.2	.2	.2	.2
Chemical composition					
DM	66.9	66.4	66.4	66.4	66.6
OM	87.3	87.3	87.6	87.8	88.0
NDF	47.4	55.9	55.1	53.0	52.4
ADF	30.9	34.1	33.4	32.1	31.8
N	1.9	2.0	2.0	2.1	2.4

[a]Protein sources and levels (expressed as a percentage of supplemental CP) of each are as follows: SBM = soybean meal; U17 = 17% urea and 83% distillers dried grains (DDG) and corn; U33 = 33% urea and 67% DDG and corn; U50 = 50% urea and 50% DDG and corn; and UDF = 33% each of urea, DDG and corn, and fish meal.

[b]AHPWS = alkaline hydrogen peroxide-treated wheat straw.

[c]Calcium sulfate content was .02% and .05% in the U33 and U50 diets, respectively. Calcium sulfate was added to obtain a N:S ratio of 10:1.

[d]Composition: NaCl = 93 to 98%, Zn = .35%, Fe = .34%, Mn = .20%, Cu = .033%, I = .007%, Se = .0055%, and Co = .005%.

[e]Composition: vitamin A = 681,818 IU/kg; vitamin D = 68,182 IU/kg; vitamin E = 455 IU/kg; vitamin B_{12} = 3.6 mg/kg; riboflavin = 227 mg/kg; D-pantothenic acid = 1,250 mg/kg; niacin = 3,409 mg/kg; and choline chloride = 34,091 mg/kg.

the last day of each period, ruminal contents (50 ml) were collected at 3, 6, and 9 h after the 0700 feeding and pH was immediately determined. Ruminal samples were acidified with 2 ml of 6 *N* HCl, frozen, and subsequently analyzed for ruminal fluid NH_3 N and VFA concentrations.

Sample Analyses. Feed, duodenal, and ileal digesta and fecal samples were analyzed for DM, OM, and Kjeldahl N (AOAC, 1984). Chromium content of digesta samples and feces was analyzed by the technique of Williams et al. (1962). Digesta flows, fecal output, and digestion coefficients were calculated using the marker ratio technique. Chromium recovery in the feces averaged 87 ± 3.8%. Bacteria-rich samples isolated from the ruminal contents were analyzed for DM, OM, and Kjeldahl N (AOAC, 1984). Ruminal bacteria and duodenal digesta samples were analyzed for purines using the method of Zinn and Owens (1986). Because there were no differences in bacterial N:purine ratio due to supplemental CP treatment, the mean N:purine ratio (1.20, SE = .122) was used to calculate bacterial and nonbacterial N flow to the duodenum. To determine AA composition of protein supplements, AHPWS, bacteria, and duodenal and ileal digesta samples (ca. 150 mg) were hydrolyzed in 15 ml of 6 *N* HCl for 22 h at 110°C. Hydrolysis tubes and 6 *N* HCl were purged with N_2 gas before addition of HCl to minimize oxidation of sulfur AA during hydrolysis. A Beckman[3] AA Analyzer was used to determine AA composition of hydrolysates. Ruminal fluid samples were centrifuged at 20,000 × *g* and NH_3 N concentrations determined by a colorimetric procedure (Chaney and Marbach, 1962). Concentrations of individual and total VFA in ruminal fluid were determined with a Hewlett Packard[4] gas-liquid chromatograph as described by Merchen et al. (1986).

Statistical Analysis. Data were analyzed as a 5 × 5 Latin square design using the GLM procedure of SAS (1985). Terms in the model were period, animal, and protein source. Treatment means for effects of protein source were separated using the *F*-test-protected ($P < .05$) lsd method (Carmer and Walker, 1985). There was one missing observation due to the death of an animal for reasons unrelated to treatment. Data collected at various times postfeeding (ruminal pH, NH_3 N, and VFA concentrations) were analyzed as separate Latin squares for each time, and the average across time was analyzed as a separate square.

Experiment 2

Thirty ram lambs (mean initial BW = 33 kg) were blocked by weight and randomly allotted to one of five supplemental CP treatments in a 42-d growth trial. All lambs were of similar breed type (eight were straightbred Combination Six, and 22 were crossbred with various percentages of Targhee, Saint Croix, Dorset, and Combination Six breeding). Treatments were similar to those in Exp. 1 (designated in the same manner), with the exception that the U17 treatment was replaced with a 14% CP diet with supplemental protein provided by SBM (14-SBM; Table 2). In a previous experiment (Willms et al., 1991), N retention by growing lambs fed diets based on AHPWS supplemented with SBM was maximized at 12% CP when expressed as a percentage of N intake but at 14% CP when expressed as g/d. Therefore, 14-SBM was included as a positive control. Diets were formulated to the same vitamin and mineral specifications as in Exp. 1, except .5% KCl was added. Preparation of AHPWS was similar to that in Exp. 1 but on a larger scale. Large round bales of wheat straw were ground (.95-cm screen) in a tub grinder, conveyed to a horizontal stainless steel mixer, and treated as described by Cameron et al. (1991). Treated wheat straw was stored in an oxygen-limiting silo until complete diets were mixed. Complete diets were mixed approximately every 10 d and stored in plastic-lined, sealed drums in an air conditioned room until feeding. Lambs were allowed ad libitum access to feed (fresh feed was added once daily) and orts were collected and weighed as necessary and analyzed for DM.

Lambs were housed individually in an open-sided confinement facility with expanded metal flooring. All lambs were sheared and treated to control internal and external parasites before the trial. Lambs were managed according to procedures approved by the University Animal Care Committee. During the dietary adaptation period two lambs died, apparently from the stress of being shipped. During the 42-d feeding period, three lambs were removed from the experiment for causes

[3]Model 119CL, Beckman Instruments, Inc., Palo Alto, CA.

[4]Model 5890 A, Hewlett-Packard Co., Mt.View, CA.

TABLE 2. COMPOSITION OF DIETS FED TO RAM LAMBS IN EXP. 2

Ingredient	CP source[a]				
	14-SBM	SBM	U33	U50	UDF
AHPWS[b]	66.3	66.4	66.9	66.8	66.8
Corn	13.0	17.2	10.6	18.1	16.4
Soybean meal	18.9	14.6	—	—	—
Distillers dried grains	—	—	19.4	11.3	9.7
Fish meal	—	—	—	—	4.8
Urea	—	—	1.2	1.8	1.2
Dicalcium phosphate	.4	.5	.4	.6	—
Calcium sulfate[c]	—	—	+	+	.1
Calcium carbonate	.4	.4	.5	.4	—
Trace mineralized salt[d]	.3	.3	.3	.3	.3
Potassium chloride	.5	.5	.5	.5	.5
Vitamin premix[e]	.2	.2	.2	.2	.2
Crude protein, %	13.7	10.9	12.0	12.8	12.9

[a]14-SBM = 14% dietary CP with soybean meal as the supplemental protein source. Other diets were formulated to contain 12.0% CP. Levels (expressed as a percentage of supplemental CP) of protein sources in other treatments were as follows: SBM = soybean meal; U33 = 33% urea and 67% distillers dried grains (DDG) and corn; U50 = 50% urea and 50% DDG and corn; and UDF = 33% each of urea, DDG and corn, and fish meal.

[b]AHPWS = alkaline hydrogen peroxide-treated wheat straw.

[c]Calcium sulfate content was .02% and .05% in the U33 and U50 diets, respectively. Calcium sulfate was added to obtain a N:S ratio of 10:1.

[d]Composition: NaCl = 93 to 98%, Zn = .35%, Fe = .34%, Mn = .20%, Cu = .033%, I = .007%, Se = .0055%, and Co = .005%.

[e]Composition: vitamin A = 681,818 IU/kg; vitamin D = 68,182 IU/kg; vitamin E = 455 IU/kg; vitamin B_{12} = 3.6 mg/kg; riboflavin = 227 mg/kg; D-pantothenic acid = 1,250 mg/kg; niacin = 3,409 mg/kg; and choline chloride = 34,091 mg/kg.

not related to treatment. The lambs became ill after a period of extremely hot weather followed by an abrupt weather change.

After dietary adaptation, lambs were weighed on and off test after 2 d of equalized feeding to minimize gut fill differences. Dry matter intake, ADG, and efficiency of gain (G/F) were calculated. Statistical analysis of the data was performed by ANOVA for a completely randomized design using the GLM procedure of SAS (1985). Terms in the model were block and treatment. Treatment mean differences were separated using the lsd method only if there was a main effect ($P < .05$) for treatment (Carmer and Walker, 1985).

Results and Discussion

Experiment 1

Organic matter apparently and truly digested in the rumen was approximately 8 percentage units higher for lambs fed SBM than for those fed U17 (Table 3). True ruminal OM digestion by lambs when fed U17 tended ($P < .09$) to be lower than when lambs were fed U33 and UDF. Lambs when fed U50 tended ($P < .06$) to have lower true ruminal OM digestion than when they were fed SBM. Santos et al. (1984) reported numerically lower true ruminal OM digestibility by dairy cows supplemented with DDG than that of those supplemented with SBM. Small intestinal and hindgut digestion were unaffected by treatment. Small intestinal OM digestion ranged from 12.1 to 16.8% of OM intake for the U17 and SBM diets, respectively, whereas hindgut OM fermentation increased 6 percentage units for lambs fed U50 compared with lambs fed U33. Apparent total tract OM digestibility was lowest ($P < .05$) on the U17 diet (65.0%) compared with all other treatments. There were no differences in total tract OM digestibility among the remaining treatments (average = 72.7%). Santos et al. (1984) reported a nonsignificant decrease in total tract OM digestibility by cows supplemented with DDG (63.6%) compared with cows supplemented with SBM (68.0%). Similar OM digestibilities in each segment of the digestive tract have been reported previously for lambs fed diets based on AHPWS (Cecava et al., 1990; Willms et al., 1991).

TABLE 3. ORGANIC MATTER DIGESTION BY LAMBS FED DIFFERENT SOURCES OF SUPPLEMENTAL CRUDE PROTEIN IN EXP. 1

Item	CP source[a]					SE
	SBM	U17	U33	U50	UDF	
OM intake, g/d	1,533	1,533	1,530	1,513	1,525	12.5
OM digestion, % of OM intake						
$Stomach_A$[e]	50.4[d]	41.5[b]	47.5[cd]	46.1[bcd]	45.0[bc]	1.77
$Stomach_T$[e]	71.5[c]	63.6[b]	67.9[bc]	67.1[bc]	67.4[bc]	1.47
Small intestine	16.8	12.1	16.7	12.9	15.5	1.68
Hindgut	6.5	11.4	7.6	13.7	12.3	2.27
Total tract	73.7[c]	65.0[b]	71.7[c]	72.8[c]	72.7[c]	1.95

[a]Protein sources and levels (expressed as a percentage of supplemental CP) of each are as follows: SBM = soybean meal; U17 = 17% urea and 83% distillers dried grains (DDG) and corn; U33 = 33% urea and 67% DDG and corn; U50 = 50% urea and 50% DDG and corn; and UDF = 33% each of urea, DDG and corn, and fish meal.

[b,c,d]Means in the same row with different superscript letters differ ($P < .05$).

[e]$Stomach_A$ and $stomach_T$ = OM apparently and truly digested in the stomach, respectively.

Ruminal characteristics reflect differences in OM digestion. Total VFA (TVFA) concentrations (m*M*) were lower ($P < .05$) when lambs were fed U17 than that of all other treatments (Table 4). Lambs when fed SBM had higher ($P < .05$) TVFA concentrations (106.3 m*M*) than when they were fed U33 (94.8), whereas concentrations were intermediate when lambs were fed U50 and UDF. Similar TVFA concentrations have been reported in sheep fed diets based on AHPWS (Kerley et al., 1986; Cecava et al., 1990). Molar proportion of acetate was higher ($P < .05$) when lambs were fed SBM and UDF than when fed U17. Molar proportion of propionate was highest, and the acetate:propionate ratio lowest, when lambs were fed the U17 diet. When fed SBM, lambs had 43 and 35% higher valerate and isovalerate concentrations, respectively, than those of all other treatments. Cecava et al. (1990) reported a 30% increase in branched-chain VFA concentration when lambs fed diets based on AHPWS were supplemented with SBM vs corn gluten meal or blood meal. Small differences in pH are reflective of the differences in TVFA concentrations. Increases in OM digestion increased TVFA concentration and lowered pH. Kerley et al. (1986) reported lower ruminal pH values in sheep fed diets based on AHPWS. However, a different process was used to prepare AHPWS, which involved removing the sodium

TABLE 4. EFFECTS OF DIFFERENT SOURCES OF SUPPLEMENTAL CRUDE PROTEIN ON RUMINAL FLUID CHARACTERISTICS IN EXP. 1

Item	CP source[a]					SE
	SBM	U17	U33	U50	UDF	
Total VFA, m*M*[e]	106.3[d]	84.8[b]	94.8[c]	100.6[cd]	100.5[cd]	2.80
Acetate, mol/100 mol	68.3[c]	65.4[b]	67.6[bc]	66.3[bc]	68.2[c]	.83
Propionate, mol/100 mol	18.1[b]	21.7[d]	19.4[bc]	20.8[cd]	19.7[bc]	.62
Butyrate, mol/100 mol	10.7	10.6	10.7	10.9	9.9	.17
Isobutyrate, mol/100 mol	.8	.4	.8	.3	.5	.15
Isovalerate, mol/100 mol	1.4[c]	1.1[b]	1.0[b]	1.0[b]	1.1[b]	.09
Valerate, mol/100 mol	.8[d]	.7[cd]	.5[b]	.6[bc]	.6[bc]	.03
Acetate:propionate	3.8[c]	3.1[b]	3.5[bc]	3.2[b]	3.5[bc]	.14
pH	6.3[b]	6.6[d]	6.5[cd]	6.5[cd]	6.4[c]	.05

[a]Protein sources and levels (expressed as a percentage of supplemental CP) of each are as follows: SBM = soybean meal; U17 = 17% urea and 83% distillers dried grains (DDG) and corn; U33 = 33% urea and 67% DDG and corn; U50 = 50% urea and 50% DDG and corn; and UDF = 33% each or urea, DDG and corn, and fish meal.

[b,c,d]Means in the same row with different superscript letters differ ($P < .05$).

[e]Total VFA = sum of acetate, propionate, butyrate, isobutyrate, isovalerate, and valerate.

hydroxide. Ruminal pH was expected to remain high in this trial because of the alkalizing effect of sodium hydroxide remaining in the AHPWS.

The differences in OM digestion and ruminal characteristics can be related, in part, to differences in ruminal degradability between DDG and SBM. There was a difference of approximately 18 percentage units in ruminal escape of nonurea CP from the concentrate portion of the diets (nonbacterial N as a percentage of N intake, excluding N from urea and AHPWS) when lambs were fed U17 compared with SBM in this study (Table 5). The concentrates represent approximately 505 g of OM intake (1,530 g of OM intake × 33% concentrate, excluding minerals). Assuming a similar difference in OM digestion, this difference in ruminal degradability accounts for 90 g of undigested OM (505 g × 18%). Lambs supplemented with SBM digested 136 g more OM in the rumen than those fed U17.

Diets were formulated to be isonitrogenous, but variability in dietary ingredients from initial analysis, and(or) sampling and mixing errors, resulted in variations in N intake (Table 5). There were no differences due to treatment in bacterial N entering the duodenum. Other studies showed greater bacterial N flow at the duodenum when SBM was the supplemental CP source vs urea fed in combination with a ruminally resistant protein source (Merchen et al., 1979; Cecava et al., 1990). At 3 h after feeding, lambs fed U50 had a ruminal NH_3 N concentration two to eight times greater than lambs fed SBM, U33, and UDF (Table 6). At none of the sampling times did lambs have NH_3 N concentrations greater than 3.0 mg/dl when fed U17, yet bacterial N flow was similar to that for other treatments. Similar results have been reported previously (Kropp et al., 1977b). Lambs fed SBM had a higher ($P < .05$) ruminal NH_3 N concentration at 9 h after feeding than when they were fed the other treatments. Additionally, there were no differences ($P > .05$) in efficiency of bacterial CP synthesis expressed as g/100 g of OM either apparently or truly digested in the rumen (Table 5). However, a nonsignificant increase in efficiency of bacterial protein synthesis

TABLE 5. NITROGEN (N) DIGESTION BY LAMBS FED DIFFERENT SOURCES OF SUPPLEMENTAL CRUDE PROTEIN IN EXP. 1

Item	CP source[a]					SE
	SBM	U17	U33	U50	UDF	
	g/d					
N intake	33.2[b]	34.6[c]	35.6[c]	36.9[d]	41.5[e]	.30
Duodenal N flow						
Total	41.1[c]	43.4[cd]	42.0[c]	38.0[b]	45.6[d]	.89
Bacterial	32.5	31.4	30.8	30.8	33.7	1.02
Nonbacterial	8.6[bc]	12.0[d]	11.2[cd]	7.2[b]	11.9[d]	.90
Ileal N flow	14.1[b]	19.4[d]	16.7[c]	16.5[c]	19.0[cd]	.73
Fecal N excretion	12.1[b]	17.0[c]	14.5[bc]	12.8[b]	14.2[b]	.83
Bacterial N synthesis						
g/100 g of OMD_A[f]	4.26	5.13	4.30	4.48	4.95	.347
g/100 g of OMD_T[f]	2.98	3.25	2.96	3.04	3.38	.134
Nonbacterial N at duodenum, % of NUNWS-N intake[g]	29.8[b]	47.2[cd]	52.6[d]	39.9[bc]	43.4[cd]	3.72
N digestion, % of N entering						
Small intestine	65.6[c]	55.4[b]	60.2[bc]	56.5[b]	58.4[b]	1.71
Hindgut	13.5	10.4	11.7	21.2	24.6	6.16
Total tract	63.5[c]	51.0[b]	59.3[c]	65.3[c]	65.7[c]	2.24

[a]Protein sources and levels (expressed as a percentage of supplemental CP) of each are as follows: SBM = soybean meal; U17 = 17% urea and 83% distillers dried grains (DDG) and corn; U33 = 33% urea and 67% DDG and corn; U50 = 50% urea and 50% DDG and corn; and UDF = 33% each of urea, DDG and corn, and fish meal.

[b,c,d,e]Means in the same row with different superscript letters differ ($P < .05$).

[f]OMD_A = OM apparently digested in the rumen; OMD_T = OM truly digested in the rumen.

[g]NUNWS-N = nonurea, nonalkaline hydrogen peroxide-treated wheat straw-N.

TABLE 6. EFFECTS OF DIFFERENT SOURCES OF SUPPLEMENTAL CRUDE PROTEIN ON RUMINAL NH_3 N CONCENTRATIONS IN EXP. 1

Hours postfeeding	CP source[a]					SE
	SBM	U17	U33	U50	UDF	
	mg/dl					
3	5.2[bc]	2.9[b]	9.8[cd]	26.2[e]	11.9[d]	1.43
6	6.9	.5	2.7	5.3	5.1	1.40
9	12.4[c]	2.9[b]	4.3[b]	6.5[b]	4.8[b]	1.14
Avg	8.2[c]	2.1[b]	5.6[c]	12.7[d]	7.3[c]	.86

[a]Protein sources and levels (expressed as a percentage of supplemental CP) of each are as follows: SBM = soybean meal; U17 = 17% urea and 83% distillers dried grains (DDG) and corn; U33 = 33% urea and 67% DDG and corn; U50 = 50% urea and 50% DDG and corn; and UDF = 33% each of urea, DDG and corn, and fish meal.

[b,c,d,e]Means in the same row with different superscript letters differ ($P < .05$).

resulted in similar bacterial N flow to the duodenum despite lower ruminal OM digestion by lambs fed U17.

These data are interpreted to indicate that urea N was less effectively incorporated (in relation to amount fed) into microbial protein when it composed 50% of the supplemental protein than when fed at lower levels. Urea supplied sufficient ruminal NH_3 N to maximize postruminal supply of bacterial protein when fed at 17% of the supplemental CP. Several studies have been conducted with urea providing 33 to 40% of the supplemental CP to ensure adequate ruminal NH_3 N to maximize bacterial protein synthesis (Waller et al., 1980; Stock et al., 1981). In AHPWS-based diets fed to lambs, approximately one-half of this amount seems to be adequate. However, this may be due to the unique characteristics of AHPWS. Extremely divergent estimates of the quantity of urea that may be effectively utilized in AHPWS-based diets are derived from Burroughs et al. (1974) and Satter (1982). The calculated urea fermentation potential of AHPWS using the equation of Burroughs et al. (1974) is 18 g/kg of AHPWS DM. This is comparable to the amount of urea fed in the U50 treatment. This calculation assumes that all of the AHPWS N is degradable and that AHPWS is 70% TDN. However, using the equation of Satter (1982) for sheep, average ruminal NH_3 N reaches 5 mg/dl when dietary CP equals 9.9% in 70% TDN diets. In this system, predicted urea utilization would be zero above this level of CP. This system would predict urea to be of no value in diets based on AHPWS that contain 12.5% CP. Extrapolation of both the Burroughs et al. (1974) and Satter (1982) equations to predict urea utilization in AHPWS-based diets may be invalid because they were developed with traditional feed ingredients. Since the development of metabolizable protein systems, approaches to increasing the intestinal supply of N and AA have focused on various ruminally resistant protein sources with urea included in diets at a level believed to allow for maximal bacterial protein synthesis. Kropp et al. (1977a) substituted SBM with graded levels of urea (0, 25, 50, and 75% of supplemental N) in diets based on weathered bluestem grass hay. They found no differences in microbial protein production. This should be expected because urea replaced a degradable protein source (SBM) and NH_3 N levels were greater than 11 mg/dl for all diets.

Differences due to treatment in total N flow are due primarily to differences in nonbacterial N (NBN) flow (Table 5), although increased N intake could account for some of the increased NBN when lambs were fed UDF. Nevertheless, lambs fed U17 had similar amounts of NBN entering the duodenum as when they were fed UDF, even though lambs had higher N intake when fed UDF. Nonbacterial N flow was lowest when U50 and SBM diets were fed and highest when U17 and UDF diets were fed (Table 5). Low NBN flow when lambs were fed U50 and SBM was due to decreased intake of true protein and the high ruminal degradability of SBM protein, respectively. Nonbacterial N flow tended ($P < .10$) to be higher when U33 was fed and was increased ($P < .05$) when U17 and UDF diets were fed compared with SBM. Thus, decreased ruminal degradability of protein in DDG, corn, and FM vs SBM more than offset the decrease in proportion of true protein in the diet due to inclusion of urea. The proportion of N that escaped

TABLE 7. AMINO ACID (AA) COMPOSITION OF BACTERIA AND PROTEIN SUPPLEMENTS IN EXP. 1

Amino acid	Bacteria	CP supplement[a]				
		SBM	U17	U33	U50	UDF
	g/100 g of AA					
Threonine	5.5	4.1	4.0	3.9	3.9	4.1
Valine	6.0	5.3	5.6	5.3	5.5	5.5
Methionine	2.1	1.1	1.8	2.0	1.9	1.8
Isoleucine	5.9	4.7	4.1	4.0	4.0	4.0
Leucine	8.0	9.0	12.9	12.7	12.8	10.5
Phenylalanine	5.5	5.3	5.4	5.4	5.4	5.0
Histidine	1.8	2.8	2.5	2.6	2.6	2.4
Lysine	7.8	5.8	2.0	2.2	2.3	3.9
Arginine	4.8	7.0	4.2	4.5	4.6	5.8
Aspartic acid	12.0	11.5	7.5	7.6	7.6	8.4
Serine	4.5	5.3	5.2	5.1	5.2	5.6
Glutamic acid	13.2	19.6	19.9	19.7	19.8	17.4
Proline	3.9	6.1	8.9	8.8	8.9	8.2
Glycine	5.6	4.5	4.2	4.2	4.1	6.7
Alanine	7.3	5.3	8.1	8.0	8.0	7.6
Tyrosine	5.9	2.8	3.7	4.1	3.6	3.3

[a]Amino acid-containing ingredients (percentage of DM basis) in the supplements were as follows: SBM = 51.5% corn and 43.7% soybean meal; U17 = 85.5% distillers dried grains and 8.3% corn; U33 = 61.5% distillers dried grains and 30.2% corn; U50 = 37.5% distillers dried grains and 52.2% corn; UDF = 28.6% distillers dried grains, 15.3% fishmeal, and 50.4% corn.

ruminal degradation was lower ($P < .05$) when lambs were fed SBM (29.8%) than when they were fed U17 (47.2%), U33 (52.6%), and UDF (43.4%) and tended ($P < .10$) to be lower than when they were fed U50 (39.9%). In high roughage diets fed to sheep, Laughren and Young (1979) and Willms et al. (1991) reported estimates of SBM protein escaping ruminal degradation of 31.7 and 31.0%, respectively. Higher estimates of DDG protein escaping ruminal degradation (48.1 to 54.0%) have been reported in cattle (Firkins et al., 1984; Santos et al., 1984). Estimates of FM escaping ruminal degradation in sheep have been more variable, ranging from 43% in hay-based diets (Siddons et al., 1985) to 100% in barley-based diets (Miller, 1973). Inclusion of greater quantities of finely ground corn, which may be more susceptible to ruminal degradation, in the U50 and UDF diets may have contributed to the numerical decrease in escape N, not coming from urea or wheat straw, compared with the U17 and U33 diets.

Nitrogen digestion in the small intestine (Table 5) was similar when lambs were fed the urea-containing diets (average = 57.6% of N entering the duodenum). Lambs fed SBM had greater ($P < .05$) small intestinal N digestion than when they were fed U17, U50, and UDF and tended ($P < .10$) to have higher N digestion than when they were fed U33. There were no differences ($P > .05$) in digestion of N-containing compounds in the hindgut. Total tract N digestion was lower ($P < .05$) when lambs were fed U17 than that of all other treatments.

Amino acid compositions (g/100 g of total AA) of feed supplements and bacteria are presented in Table 7. The SBM supplement contained the least methionine and the greatest proportions of lysine and arginine. The DDG supplements (U17, U33, and U50) contained the most methionine and leucine and the least lysine and arginine. Differences in flows and profiles of AA entering the duodenum are reflective of the protein sources fed.

Flows of AA entering the duodenum are presented in Table 8. Lambs fed UDF had higher ($P < .05$) duodenal flows of threonine, histidine, and arginine than when they were fed other supplemental CP sources. Lambs fed U17 had more ($P < .05$) leucine entering the duodenum than when they were fed other treatments. Corn-derived protein is a rich source of leucine. Lysine flow was greatest ($P < .05$) when lambs were fed SBM and UDF compared with other diets. There were no differences ($P > .05$) in duodenal methionine flow, although lambs fed SBM and UDF numerically had the lowest and highest methi-

onine flows, respectively. Titgemeyer et al. (1989) reported that lysine was relatively more resistant and methionine more susceptible to ruminal degradation relative to other AA in SBM protein. Total flows of essential and nonessential AA to the duodenum were lowest when lambs were fed U50 and highest when they were fed UDF. Lambs fed SBM had total flows of AA similar to when they were fed U17, U33, and U50. In contrast, Cecava et al. (1990) reported that lambs fed diets based on AHPWS supplemented with SBM had lower total AA flows than those supplemented with corn gluten meal or blood meal. The variation in results among protein sources can be explained by differences in ruminal degradability. Titgemeyer et al. (1989) determined ruminal escape of corn gluten meal and blood meal protein to be 86 and 92%, respectively, whereas DDG escape was nearer 50% (Firkins et al., 1984; Santos et al., 1984). In general, as urea level increased, total, essential, and nonessential AA flows decreased (Table 8). There were no differences in flows of AA from bacterial origin. However, lambs fed SBM and UDF had numerically higher flows of bacterial AA to the duodenum than when they were fed U17, U33, and U50. Flows of essential and nonessential nonbacterial AA were numerically highest for lambs fed U17 and were decreased with additional urea. Lambs fed U17 and UDF had higher ($P < .05$) and when fed U33 had numerically higher nonbacterial AA flows than when they were fed SBM or U50. Nonbacterial essential and nonessential AA flows tended ($P < .10$) to be higher when lambs were fed U17 than when they were fed U33.

The proportion of each AA (g/100 g of total AA) entering the duodenum, except for methionine, was affected by supplemental protein source (Table 9). Duodenal threonine and isoleucine content in relation to other AA was

TABLE 8. DUODENAL FLOWS OF AMINO ACIDS (AA) IN LAMBS FED DIFFERENT SOURCES OF SUPPLEMENTAL CRUDE PROTEIN IN EXP. 1

	CP source[a]					
Amino acid	SBM	U17	U33	U50	UDF	SE
	g/d					
Total flows						
Threonine	10.7^{c}	10.3^{c}	10.0^{bc}	9.3^{b}	11.5^{d}	.27
Valine	11.8^{cd}	12.3^{de}	11.2^{bc}	10.4^{b}	13.3^{e}	.32
Methionine	2.3	2.7	2.8	2.9	3.2	.27
Isoleucine	10.4^{cd}	10.2^{cd}	9.7^{bc}	8.9^{b}	11.1^{d}	.32
Leucine	17.3^{b}	22.4^{d}	20.3^{c}	17.7^{b}	20.8^{cd}	.58
Phenylalanine	10.4^{bc}	11.2^{cd}	10.4^{bc}	9.5^{b}	11.5^{d}	.30
Histidine	4.3^{c}	4.6^{c}	4.3^{c}	3.8^{b}	4.7^{d}	.11
Lysine	13.4^{c}	10.2^{b}	10.6^{b}	10.6^{b}	13.6^{c}	.40
Arginine	9.6^{d}	8.9^{cd}	8.5^{bc}	7.7^{b}	10.8^{e}	.30
Total flows	193.3^{bc}	206.9^{cd}	195.4^{bc}	178.0^{b}	222.0^{d}	5.62
Essential AA[f]	90.1^{c}	92.7^{cd}	87.8^{bc}	80.8^{b}	100.5^{d}	2.69
Nonessential AA[g]	103.2^{bc}	114.2^{d}	107.6^{cd}	97.2^{b}	121.5^{d}	2.97
Bacterial						
Total AA	156.9	143.1	145.7	143.2	161.1	5.81
Essential AA	74.8	67.5	69.3	68.2	76.5	2.77
Nonessential AA	82.1	75.6	76.4	75.0	84.6	3.06
Nonbacterial[h]						
Total AA	36.4^{b}	63.8^{c}	49.7^{bc}	34.8^{b}	60.9^{c}	4.82
Essential AA	15.3^{b}	25.2^{c}	18.5^{bc}	12.6^{b}	24.0^{c}	2.22
Nonessential AA	21.1^{b}	38.6^{c}	31.2^{c}	22.2^{b}	36.9^{c}	2.62

[a]Protein sources and levels (expressed as a percentage of supplemental CP) of each are as follows: SBM = soybean meal; U17 = 17% urea and 83% distillers dried grains (DDG) and corn; U33 = 33% urea and 67% DDG and corn; U50 = 50% urea and 50% DDG and corn; and UDF = 33% each of urea, DDG and corn, and fish meal.

[b,c,d,e]Means in the same row with different superscript letters differ ($P < .05$).

[f]Essential AA = THR + VAL + MET + ILE + LEU + PHE + HIS + LYS + ARG.

[g]Nonessential AA = ASP + SER + GLU + PRO + GLY + ALA + TYR.

[h]This fraction contains dietary escape, endogenous, and possibly some protozoal AA.

highest ($P < .05$) when lambs were fed SBM. Lambs fed U17 had the highest ($P < .05$) proportions of leucine, glutamic acid, and proline. Lambs fed UDF had the lowest ($P < .05$) phenylalanine and highest ($P < .05$) glycine concentration in relation to other AA entering the duodenum. Lysine content in relation to other AA decreased ($P < .05$) and methionine content numerically increased with each incremental increase in DDG and corn (U50 to U33 to U17). Lambs fed SBM had the highest ($P < .05$) lysine and numerically the lowest methionine content compared with when they were fed other supplemental CP sources. Lambs fed UDF had a higher ($P < .05$) proportion of lysine than when they were fed U17 and U33 but a lower ($P < .05$) proportion than when they were fed SBM. Lambs fed UDF maintained relatively high proportions of lysine and methionine in duodenal digesta. Manipulating profiles of AA entering the small intestine by use of ruminal escape protein may enhance the biological value of protein to the host. Fish meal is a rich source of lysine and DDG is a rich source of methionine. Cecava et al. (1990) reported similar complementary effects of corn gluten meal and blood meal combinations on intestinal AA profile in sheep fed diets based on AHPWS.

Total, essential, and nonessential AA disappearance from the small intestine was numerically lowest when lambs were fed U50 and highest when they were fed UDF (Table 10). This is consistent with other reports where the quantity of AA disappearing increased as the quantity of AA entering increased (Santos et al., 1984; Cecava et al., 1990). However, net disappearance of total and nonessential AA expressed as a percentage of AA entering was lower ($P < .05$) when lambs were fed U17, U50, and UDF than when they were fed SBM. Santos et al. (1984) reported similar differences in AA disappearance (percentage of that entering) in cows fed SBM (70.3%) vs DDG (65.5%). This suggests that SBM protein escaping ruminal degradation is more available postruminally than the protein of DDG. In contrast, Titgemeyer et al. (1989) suggested that ruminally nondegraded AA originating from SBM were more resistant to small intestinal digestion than AA from other ruminally resistant protein sources (e.g., corn gluten meal, FM, and blood meal). They hypothesized that because SBM was highly degradable in the rumen, a highly refractory residue of SBM protein entered the intestine.

TABLE 9. PROFILE OF AMINO ACIDS (AA) ENTERING THE DUODENUM OF LAMBS FED DIFFERENT SOURCES OF SUPPLEMENTAL CRUDE PROTEIN IN EXP. 1

	CP source[a]					
Amino acid	SBM	U17	U33	U50	UDF	SE
	g/100 g of AA					
Threonine	5.5^{e}	5.0^{b}	5.1^{c}	5.2^{cd}	5.2^{cd}	.04
Valine	6.1^{d}	6.0^{cd}	5.7^{b}	5.9^{bc}	6.0^{cd}	.07
Methionine	1.2	1.3	1.4	1.6	1.5	.10
Isoleucine	5.4^{c}	4.9^{b}	5.0^{b}	5.0^{b}	5.0^{b}	.05
Leucine	8.9^{b}	10.8^{f}	10.4^{e}	9.9^{d}	9.4^{c}	.08
Phenylalanine	5.4^{c}	5.4^{c}	5.3^{c}	5.3^{c}	5.2^{b}	.03
Histidine	2.3^{d}	2.2^{cd}	2.2^{bc}	2.2^{b}	2.1^{b}	.02
Lysine	6.9^{e}	4.9^{b}	5.4^{c}	6.0^{d}	6.1^{d}	.09
Arginine	5.0^{c}	4.3^{b}	4.3^{b}	4.3^{b}	4.9^{c}	.03
Aspartic acid	11.6^{e}	9.9^{b}	10.2^{c}	10.5^{d}	10.6^{d}	.08
Serine	5.1^{b}	5.1^{b}	5.1^{b}	5.1^{b}	5.3^{c}	.05
Glutamic acid	14.8^{b}	16.7^{e}	16.2^{d}	15.7^{c}	15.1^{b}	.12
Proline	5.0^{b}	6.5^{e}	6.2^{d}	5.9^{c}	6.0^{cd}	.07
Glycine	5.2^{d}	4.8^{b}	4.9^{bc}	5.0^{c}	5.9^{e}	.04
Alanine	6.7^{b}	7.6^{d}	7.5^{d}	7.3^{c}	7.2^{c}	.05
Tyrosine	5.0^{bc}	4.7^{b}	5.0^{bc}	5.2^{c}	4.7^{b}	.11

[a]Protein sources and levels (expressed as a percentage of supplemental CP) of each are as follows: SBM = soybean meal; U17 = 17% urea and 83% distillers dried grains (DDG) and corn; U33 = 33% urea and 67% DDG and corn; U50 = 50% urea and 50% DDG and corn; and UDF = 33% each of urea, DDG and corn, and fish meal.

[b,c,d,e,f]Means in the same row with different superscript letters differ ($P < .05$).

TABLE 10. NET DISAPPEARANCE OF AMINO ACIDS (AA) FROM THE SMALL INTESTINE OF LAMBS FED DIFFERENT SOURCES OF SUPPLEMENTAL CRUDE PROTEIN IN EXP. 1

	CP source[a]					
Amino acid	SBM	U17	U33	U50	UDF	SE
	g/d					
Threonine	6.7[d]	5.5[bc]	5.8[bc]	5.0[b]	6.5[cd]	.35
Valine	7.7	6.9	6.6	6.1	7.7	.41
Methionine	2.0	2.1	2.3	2.4	2.6	.32
Isoleucine	7.5[c]	6.5[bc]	6.5[bc]	5.8[b]	7.4[c]	.36
Leucine	12.6[bc]	15.5[d]	14.4[cd]	12.2[b]	14.2[cd]	.62
Phenylalanine	7.4[c]	7.3[c]	7.1[bc]	6.1[b]	7.6[c]	.32
Histidine	3.1[d]	2.6[bc]	2.6[bc]	2.3[b]	2.9[cd]	.14
Lysine	9.9[c]	6.1[b]	7.0[b]	6.9[b]	9.0[c]	.46
Arginine	7.5[c]	6.1[b]	6.1[b]	5.2[b]	7.8[c]	.33
Total AA	132.9	124.6	126.0	109.2	138.2	6.50
Essential AA[e]	64.3	58.6	58.5	51.8	65.7	3.14
Nonessential AA[f]	68.6	66.0	67.5	57.4	72.5	3.38
Disappearance, % of AA entering duodenum						
Total AA	68.7[c]	60.5[b]	64.4[bc]	61.0[b]	62.0[b]	1.90
Essential AA	71.4	63.4	66.5	63.8	65.0	1.91
Nonessential AA	66.4[c]	58.0[b]	62.7[bc]	58.8[b]	59.4[b]	1.90

[a]Protein sources and levels (expressed as a percentage of supplemental CP) of each are as follows: SBM = soybean meal; U17 = 17% urea and 83% distillers dried grains (DDG) and corn; U33 = 33% urea and 67% DDG and corn; U50 = 50% urea and 50% DDG and corn; and UDF = 33% each of urea, DDG and corn, and fish meal.

[b,c,d]Means in the same row with different superscript letters differ ($P < .05$).

[e]Essential AA = THR + VAL + MET + ILE + LEU + PHE + HIS + LYS + ARG.

[f]Nonessential AA = ASP + SER + GLU + PRO + GLY + ALA + TYR.

Experiment 2

There were no differences ($P > .05$) in ADG among lambs fed 14-SBM, SBM, and UDF treatments (Table 11). These results are interpreted to indicate that AHPWS-based diets supplemented with SBM to contain 12% CP maximizes lamb performance as suggested by a previous N balance trial (Willms et al., 1991). Lambs fed U33 gained at a rate similar to lambs fed 14-SBM and SBM but slower ($P < .05$) than those fed UDF. Providing 33% of the supplemental CP as urea was not detrimental to performance. The improvement in performance of lambs fed UDF vs U33 can be attributed to changes in the profile of AA

TABLE 11. EFFECTS OF SUPPLEMENTAL CRUDE PROTEIN SOURCE ON DM INTAKE AND FEEDLOT PERFORMANCE OF GROWING RAM LAMBS IN EXP. 2

	CP source[a]					
Item	14-SBM	SBM	U33	U50	UDF	SE
Replications	5	5	6	4	5	—
Initial weight, kg	33.5	35.1	32.5	32.4	31.6	—
Final weight, kg	44.7	45.7	41.2	39.1	43.9	—
Daily gain, kg/d	.26[bc]	.25[bc]	.21[cd]	.15[d]	.29[b]	.022
DMI, kg/d	1.49[bc]	1.51[bc]	1.43[bc]	1.26[c]	1.63[b]	.095
Gain/feed	.18[b]	.16[bc]	.14[cd]	.12[d]	.18[b]	.010

[a]14-SBM = 14% dietary CP with soybean meal as the supplemental protein source. Other diets were formulated to contain 12.0% CP. Levels (expressed as a percentage of supplemental CP) of protein sources in other treatments were: SBM = soybean meal; U33 = 33% urea and 67% distillers dried grains (DDG) and corn; U50 = 50% urea and 50% DDG and corn; and UDF = 33% each of urea, DDG and corn, and fish meal.

[b,c,d]Means in the same row with different superscript letters differ ($P < .05$).

entering the duodenum as discussed in Exp. 1. Daily gain of lambs fed U50 tended to be lower ($P < .08$) than for lambs fed U33 and was decreased ($P < .05$) compared with all other treatments. This reduction in ADG is reflective of reduced essential AA flow to and disappearance from the small intestine reported in Exp. 1.

Dry matter intake of lambs fed U50 was lower ($P < .05$) than that of lambs fed UDF and tended ($P < .13$) to be lower than that of lambs fed 14-SBM and SBM diets. Dry matter intake was similar among lambs fed the remaining diets. There were no differences ($P > .05$) in G/F among lambs fed the 14-SBM, SBM, and UDF treatments. The G/F of lambs fed U33 (.14) was lower ($P < .05$) than of lambs fed SBM (.18) or UDF (.18) but tended to be higher ($P < .11$) than that of lambs fed U50 (.12).

In conclusion, the data from these two experiments are interpreted to indicate that no more than 33% of supplemental CP should be derived from urea (when fed in combination with protein sources that are 40 to 50% ruminally degradable) in diets based on AHPWS. Feeding higher levels of urea decreased total and nonbacterial AA flow to the duodenum and lamb performance. As little as 17% of supplemental CP from urea was adequate to maximize bacterial protein synthesis. Feeding a high level of DDG (e.g., the U17 diet) can lead to decreased OM, N, and AA digestion. Supplementing diets with a combination of ruminally resistant protein sources with complementary AA profiles of lysine and methionine improved the quality of protein entering the small intestine and, thereby, increased lamb ADG and G/F compared with lambs fed U33. In particular, lambs fed UDF had a higher proportion of lysine in relation to total AA entering the duodenum than when they were fed urea in combination with DDG and a nonsignificant increase in proportion of methionine in duodenal digesta compared with when they were fed SBM.

Implications

Diets with basal ingredients that are low in preformed protein such as alkaline hydrogen peroxide-treated wheat straw are ideally suited for supplementation with ruminally resistant protein sources that have complementary amino acid profiles. Because supplemental protein sources account for a larger portion of total dietary protein with alkaline hydrogen peroxide-treated wheat straw, it is possible to shift the profile of amino acids entering the duodenum to increase the biological value. Optimal levels of urea and degradable protein to maximize bacterial protein synthesis in the rumen of animals fed these diets may be different from diets based on more typical feedstuffs.

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