Effects of Fish Meal and Sodium Bentonite on Daily Gain, Wool Growth, Carcass Characteristics, and Ruminal and Blood Characteristics of Lambs Fed Concentrate Diets[1,2]

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ABSTRACT: We evaluated the effects of replacing some soybean meal (SBM) protein with fish meal (FM) protein in diets adequate and slightly deficient in CP, with or without .75% sodium bentonite (NaB) on performance and ruminal and blood metabolites of individually fed Suffolk lambs. Diets were based on corn, SBM, and cottonseed hulls. In Exp. 1, five lambs were assigned to each of the three dietary treatments (11% CP with 3% FM, 13% CP with 0 or 3% FM). Lambs fed diets that contained 11% CP with 3% FM or 13% CP with 0% FM had similar DMI and ADG. Gain and feed efficiency were slightly improved (P = .18) by the 13% CP diet with 3% FM. In Exp. 2, 32 lambs were assigned to four dietary treatments (13.5% CP of DM) in a 2 × 2 factorial arrangement (0 or 3% FM, and 0 or .75% NaB on an as-fed basis). The DMI and ADG were increased (P < .05) by FM and NaB supplementation. Interactions (P < .05) revealed that NaB increased DMI, ADG, gain per feed (g/kg of DMI), and plasma urea N concentration in the absence of FM but not in the presence of FM in the diet. Neither FM nor NaB influenced (P = .25) wool growth. Total ruminal VFA were increased (P < .06) by FM and NaB. Differences in mineral content of phalanx bone, liver, and kidney were small and may be related to the mineral content of diets and the effect of NaB on mineral solubilities. Similar DMI and ADG of lambs fed FM and NaB separately and in combination suggest that their beneficial effect is not additive.

Key Words: Lambs, Growth, Fish Meal, Sodium Bentonite

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Introduction

Lambs require undegradable feed protein to support high rates of growth and wool production (NRC, 1985). Fish meal (**FM**) is an excellent source of high-quality protein that is slowly degraded in the rumen (Amos et al., 1972; Adam et al., 1982; Zerbini and Polan, 1985), but the response in growth rate has been variable (Pond, 1984; Beerman et al., 1986; Hassan and Bryant, 1986; Hussein and Jordan, 1991a). The inconsistent response to feeding ruminally undegradable protein has been reviewed with emphasis on FM (Hussein and Jordan, 1991b). Ruminal protein degradability differs among fish meals (Sticker et al., 1990), which may explain differences in the observed growth response. Fish meal with low ruminal protein degradation improved ADG of steers fed diets slightly deficient in CP (White et al., 1991), of finishing steers under high ambient temperatures (White et al., 1992), and of beef calves that grazed mature forage (White et al., 1995).

Sodium bentonite (**NaB**) is an expanded lattice clay of the montmorillonite group of minerals (Bates and Jackson, 1980) with high ion exchange capacity that binds a wide range of cations (Fenn and Leng, 1989). It has improved wool growth (Fenn and Leng, 1989, 1990; Cobon et al., 1992), decreased ruminal ammonia concentration, and improved feed and bacterial protein flow to the small intestine (Ivan et al., 1992b).

The objectives of this study were to examine the effects of using FM to increase the percentage of ruminally undegradable protein in lamb diets containing 13% CP and to compare diets containing 11 and 13% CP with similar percentages of undegradable protein. Another objective was to determine whether the effects of FM and NaB in growing and finishing lamb diets are additive.

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Table 1. Ingredient and chemical composition of diets fed to lambs in Exp. 1 and 2

Composition	0% Fish meal 13% CP[a]	3% Fish meal 13% CP[a]	3% Fish meal 11% CP
Ingredient		% as is	
Cottonseed hulls	20.0	20.0	20.0
Ground corn	68.0	69.0	74.0
Soybean meal	10.0	6.0	1.0
Fish meal	—	3.0	3.0
Urea	.5	.5	.5
Oystershell flour	1.1	1.1	1.1
Salt[b]	.4	.4	.4
Vitamins, mg/kg[c]	88	88	88
Chemical		% of DM	
Crude protein	13.4	13.6	11.4
DIP[d]	8.0	7.5	6.0
UIP[d]	5.4	6.1	5.4
NDF	35.3	34.4	36.4
ADF	16.1	15.4	16.4
Ash	3.3	3.9	2.8
Ca	.54	.70	.68
P[d]	.34	.40	.38
Mg	.16	.15	.14
K	.68	.57	.50
		ppm	
Cu	10.2	9	8.4
Zn	31	36	34
Mn	46	46	45
Fe	101	112	107

[a]Sodium bentonite (.75% of diet) replaced .75% of ground corn in appropriate diets of Exp. 2.
[b]Trace mineralized salt supplied 4.9 g of NaCl, 7 mg of Zn, 14 mg of Mn, 8.7 mg of Fe, 1.7 mg of Cu, .35 mg of I, and .35 mg of Co per kilogram of diet.
[c]Supplied 1,358 IU of vitamin A, 136 IU of vitamin D_2, and 3.9 IU of vitamin E per kilogram of diet.
[d]Values were calculated for degradable intake protein (DIP), undegradable intake protein (UIP), and phosphorus.

Experimental Procedure

These experiments were approved by the Animal Care and Use Committee of the Louisiana State University Agricultural Center. Before initiating each experiment, Suffolk lambs were treated according to manufacturer recommendations with an anthelmintic (Valbazen; Smith, Kline and Beecham, Philadelphia, PA) and a coccidiostat (Amprolin; Aguet, Rahway, NJ). Lambs were individually housed in 1.5- × 1.5-m elevated pens in an open-sided building and were allowed ad libitum access to feed and water. Diets (Table 1) for both experiments were based on corn and soybean meal (**SBM**) and 20% cottonseed hulls was included as a roughage. When FM (Sea-lac™, Zapata Protein, Hammond, LA) was included in the diet, it replaced an equal amount of SBM protein.

In Exp. 1, nine wether (mean BW = 25 kg) and six ewe (mean BW = 26 kg) lambs were blocked by weight and sex, and lambs in each block were randomly assigned to three dietary treatments (three wethers and two ewes per treatment). The three diets (13% CP with or without 3% FM, and 11% CP with 3% FM) were fed for 92 d.

The lambs were slaughtered, and the carcasses were chilled (2°C) for 24 h. Carcasses were evaluated for hot carcass weight, quality grade, yield grade, flank streaking, body wall thickness, and the longissimus muscle area (USDA, 1992). Liver, kidney, and kidney fat were removed and weighed immediately after slaughter.

Jugular blood samples were obtained from lambs at 0 and 3 h after feeding on d 35 and 70 following 16 h of feed and water deprivation. Blood samples were collected via venipuncture in vacuum blood-collecting tubes (Becton Dickinson Vacutainer System, Rutherford, NJ) that contained NaF plus potassium-oxalate, placed on ice, transported to the laboratory, and centrifuged at 1,500 × *g* at 4°C for 15 min. Plasma was harvested and stored at –20°C until it was analyzed (in duplicate) for urea N and total protein (Laborde et al., 1995).

Feed samples were ground in a Wiley mill to pass a 1-mm screen and analyzed for DM, ash, and N (AOAC, 1990) and for NDF and ADF (Goering and Van Soest, 1970).

In Exp. 2, 20 wether (mean BW = 24 kg) and 12 ewe (mean BW = 25 kg) lambs were blocked by

weight and sex, and lambs in each block were randomly assigned to four dietary treatments (five wethers and three ewes per treatment) in a 2 × 2 factorial arrangement. The following four isonitrogenous (13.5% CP, DM basis) diets were fed for 83 d: 0% FM and 0% NaB, 0% FM and .75% NaB (Prince Agri Products, Quincy IL), 3% FM and 0% NaB, and 3% FM and .75% NaB (on an as-fed basis).

Lambs were shorn on d 0 and 84 for wool growth measurements. Samples of the 84-d wool growth were analyzed for yield (ASTM, 1996a), and clean wool production was calculated. Wool samples were analyzed for staple length (ASTM, 1996b) and for fiber diameter by using the Optical Fibre Diameter Analyser (IWTO, 1995). Five wethers from each treatment were slaughtered, and their carcasses were chilled (2°C) for 24 h. Specific gravity of carcasses was determined with the procedure of Wilson et al. (1970). Carcasses were evaluated as described in Exp. 1. Liver, kidney, and kidney fat were removed and weighed immediately after slaughter. Liver, kidney, and phalanx bone were dried and ashed, and their mineral content (Ca, Mg, Mn, K, Cu, Zn, and Fe) was determined by using atomic absorption spectrophotometry (Perkin-Elmer 5000; Norwalk, CT). Jugular blood samples were obtained from all lambs 0 and 3 h after feeding on d 21, 42, and 63 as described in Exp 1.

Ruminal fluid samples were collected via stomach tube from wether lambs 0, 2, 4, and 8 h after feeding on d 84. Samples were frozen in acetone and Dry Ice immediately after determining pH. The frozen samples were stored at –20°C. Samples were thawed, and 5 mL of each sample was treated with 1 mL of 25% meta-phosphoric acid and centrifuged (10,000 × *g* for 15 min at 4°C). The supernatant was analyzed for VFA with gas chromatography (Erwin et al., 1961). A portion of each sample was centrifuged (10,000 × *g* for 15 min at 4°C) and analyzed for ammonia N with the phenol-hypochlorite colorimetric procedure (Chaney and Marbach, 1962). Feed samples were prepared and nutrient content determined as described for Exp. 1. The mineral content of feed was determined as described for the organs.

Data for both experiments were analyzed using the GLM procedure of SAS (1988). Performance data in Exp. 1 were analyzed as a randomized block with weight and sex as blocks and diets as main effects. The model for analysis included weight, sex, diet, and their interaction, with residual as the error term. A repeated measures analysis of variance was performed on the blood data with blocks × diet as the error term for diets. Blocks × diet × period was the error term for period and period × diet effects, and residual was the error term for hour and the hour × period × diet interaction.

A complete randomized design was used in Exp. 2 to analyze ADG, DMI, feed efficiency, and wool data. Weight and sex were blocks and FM, NaB, and FM × NaB were main effects; the error term was block × FM × NaB. Carcass characteristics and mineral content of organs were analyzed as described for performance data except that sex was deleted from the model. A repeated measures analysis of variance with three dates (d 21, 42, and 63) and two times per date was used to analyze the blood data. Lambs within blocks × FM × NaB combinations were used as the error term for block and diet effects. Lambs within block × FM × NaB × date was used as the error term for date, date × FM, and date × NaB effects, and residual was the error term for all effects including time. Ruminal fluid data collected on d 84 from wethers were analyzed with blocks, FM, NaB, and FM × NaB as main effects, and block × FM × NaB was the error term. A repeated measures analysis of variance was performed using the residual as the error term for all hour effects. Mean separation was achieved using F-protected least significant differences ($P < .05$).

Results and Discussion

In Exp. 1, lambs consumed similar ($P = .96$) amounts of DM (1.16 ± .053 kg·lamb^{-1}·d^{-1}) on each treatment. Undegradable intake protein (**UIP**) (63 ± 3 g/d), growth rates (171 ± 18 g/d), and gain per feed (g/kg of DMI) (146 ± 13 g) were similar for lambs fed the diet that contained 13% CP without FM and the diet that contained 11% CP with 3% FM. A slight numerical improvement in ADG (206 ± 18 g/d) and gain per feed (g/kg of DMI) (176 ± 13 g) was detected ($P = .18$) when the diet that contained 13% CP with 3% FM was fed, which resulted in an UIP of 72 ± 3 g/d ($P = .10$). Carcass characteristics were not influenced ($P > .30$) by treatments.

In Exp. 2, DMI and ADG were improved ($P < .05$) by FM and NaB supplementation (Table 2). Lambs fed diets that contained FM had more ($P < .01$) UIP than lamb fed diets without FM (80 vs 69 ± 1.3 g/d). This was the result of more UIP in the diet and higher DMI. Because NaB increased DMI, there was a tendency ($P = .10$) for NaB to increase UIP. There was a FM × NaB interaction ($P < .05$) for DMI, ADG, and gain:feed, wherein NaB increased DMI, ADG, and feed efficiency in the absence of FM but not in the presence of FM in the diet. Carcasses were heavier with greater ($P < .05$) body wall thickness when FM was included in the lamb diets. There was a FM × NaB interaction ($P < .01$) for specific gravity of chilled carcasses. Specific gravity was increased by FM in the absence of NaB but reduced in the presence of NaB. Wool growth and quality were not influenced by FM or NaB ($P = .25$).

Performance of lambs in Exp. 1 and 2 demonstrates the beneficial effect of including ruminally undegradable FM in lamb diets. This is consistent with results of others (Beerman et al., 1986; Hasson and Bryant, 1986; Tan and Bryant, 1991), who reported increased

Table 2. Influence of fish meal (FM) and sodium bentonite (NaB) on DMI and body and wool growth of lambs

	Fish meal, %		Sodium bentonite, %		
Item	0	3	0	.75	SEM
Intake and growth performance[a]					
DMI, g/d[b]	1,271	1,314	1,265	1,320	15.5
ADG, g[c]	261	285	260	285	5.8
Gain, g/kg DMI[d]	204	218	207	216	4.6
Clean wool, g	420	445	415	448	15.8
Staple length, mm	23	23	23	23	.79
Fiber diameter, μm	30	31	30	31	.52
Carcass characteristics[a]					
Carcass weight, kg[e]	25.5	27.9	26.4	27.0	.56
Longissimus muscle area, cm^2	14.2	15.2	14.9	14.5	.49
Specific gravity[f]	1.046	1.048	1.050	1.044	.002
Body wall thickness, mm[g]	11.9	14.0	12.4	13.4	.71
Rib fat thickness, mm	4.2	5.0	4.4	4.7	.46
Flank streaking[h]	283	253	266	270	20.18
Quality grade[i]	11.5	10.9	11.2	11.2	.26
Yield grade	2.0	2.4	2.1	2.2	.18
Liver weight, g	685	708	705	687	25
Kidney weight, g	112	110	112	110	4.5
Kidney fat weight, g	450	537	440	547	57

[a]Each intake and growth value is the mean of 10 wether and 6 ewe lambs. Each carcass characteristic value is the mean of 10 wether lambs.
[b]FM effect ($P < .05$), NaB effect ($P < .01$), FM × NaB effect ($P <. 05$).
[c]FM, NaB, and FM × NaB effects ($P < .01$).
[d]FM and FM × NaB effects ($P < .05$).
[e]FM effect ($P < .01$).
[f]NaB and FM × NaB effects ($P < .01$).
[g]FM effect ($P < .05$).
[h]Slight minus = 200 to 233, slight = 234 to 266, and slight plus = 267 to 299.
[i]Choice minus = 10, Choice = 11, and Choice plus = 12.

ADG of lambs when FM replaced plant protein sources in the diet. In contrast, growth rate of lambs was not improved by including FM in the diet in the experiments of Pond (1984) or Hussein and Jordan (1991a). These differences may be explained by the high CP level (16%) of the diets used by Pond (1984) or the high degradability (52.5%) of FM used by Hussein and Jordan (1991a). Our diets were lower in CP (11 or 13%), and the protein in the FM was higher (70%) in ruminally undegradable protein (White et al., 1995), which resulted in greater UIP. Furthermore, Exp. 2 was conducted during June, July, and August, when the average maximum temperature was 36°C, and it has been demonstrated with lambs (Bunting et al., 1992) and finishing steers (White et al., 1992) that the beneficial response to FM is greater at high ambient temperature (30 to 33°C average daily maximum). Feeding FM did not result in muscle hypertrophy, as reported by Beerman et al. (1986) with crossbred ram lambs.

Improvements in DMI and ADG when diets contained FM and NaB separately were similar to improvements when diets contained FM and NaB. This can be explained by assuming that the improvements associated with feeding NaB are due to increased feed and bacterial protein supply to the small intestine (Ivan et al., 1992b). Therefore, the modes of improvement by FM and NaB are similar and not additive at the levels fed in these diets. Specific gravity and feed efficiency data suggest that carcasses were leaner when lambs were fed FM alone but not when fed with NaB, in which case carcasses were fatter.

Wool growth seems to be stimulated by bentonite when sheep are fed low-energy diets (Fenn and Leng, 1989, 1990; Cobon et al., 1992). In our experiment, FM and NaB improved growth rate but had no effect on wool production. One explanation is that nutrient demand for body growth is greater than for wool growth in lambs bred primarily for growth (Black and Reis, 1979). Also, these young lambs may partition nutrients toward body growth rather than wool growth to a greater extent than do adult sheep.

In Exp. 1, plasma urea N (**PUN**) levels were similar when lambs were fed 11 and 13% CP diets with 3% FM but lower ($P < .06$) than when lambs were fed a 13% CP diet without FM (12.3 vs 14.7 ± .68 m*M*). Plasma urea N levels were higher ($P < .01$) on d 70 than on d 35 (15.9 vs 10.4 ± 1.90 m*M*). On d 35, plasma total protein was lower than on d 70 when 3% FM was included in the 13% CP diet (54.2 vs 58.2 ± 1.2 g/L) and reversed (56.9 vs 54.3 ± 1.2 g/L) when

Table 3. Influence of fish meal (FM) and sodium bentonite (NaB) on ruminal fluid characteristics in lambs

	Fish meal, %		Sodium bentonite, %		
Item[a]	0	3	0	.75	SEM
pH[b]	6.69	6.52	6.62	6.59	.04
Ammonia N, m*M*	4.5	5.9	5.2	5.2	.6
Total VFA, m*M*[c]	57.2	69.3	59.5	67.0	2.5
Individual VFA, mol/100 mol					
Acetate	57.5	55.9	57.0	56.4	1.6
Propionate	27.8	30.4	29.7	28.5	2.3
Isobutyrate[d]	.5	.6	.6	.6	.02
Butyrate	11.4	10.7	10.1	12.0	.1
Isovalerate	.8	.7	.8	.7	.05
Valerate	2.0	1.7	1.8	1.9	.2

[a]Each value is the mean of samples from 10 wether lambs at 0, 2, 4, and 8 h after feeding.
[b]FM effect ($P < .01$).
[c]FM effect ($P < .01$), NaB effect ($P < .06$).
[d]FM effect ($P < .05$), FM × NaB effect ($P < .01$).

the 13% CP diet did not contain FM (treatment × sampling day interaction, $P < .05$). This suggests a more favorable protein status late in the experiment in lambs fed diets containing FM (Sykes, 1978). The higher PUN on d 70 than on d 35 may suggest greater protein deposition early in the experiment (Sykes, 1978; Carter et al., 1989). The treatment × sampling day interaction on plasma total protein and the slight improvement in gain would also suggest that protein deposition continued longer when FM was in the 13% CP diet.

Across the three sampling days (d 21, 42, and 63) in Exp. 2, FM increased PUN compared with no FM (14.0 vs 12.9 ± .41 m*M*, $P < .05$). Sodium bentonite increased PUN in the absence of FM (13.6 vs 12.2 ± .59 m*M*) but not in the presence of FM (13.8 vs 14.3 ± .59 m*M*; FM × NaB, $P < .05$). A FM × sampling day interaction ($P < .05$) existed for PUN and plasma total protein. Plasma total protein and PUN concentrations reached maximum levels faster when lambs were fed FM. Fish meal has been reported to decrease (Pond, 1984) and to increase (Bunting et al., 1992) PUN in lambs, slightly reduce PUN in finishing steers (White et al., 1992), and reduce serum urea N in two of four growth experiments with beef calves (White et al., 1995).

Ruminal fluid data for d 84 of Exp. 2 are presented in Table 3. Ruminal pH was decreased and total VFA were increased ($P = .01$) by feeding diets containing 3% FM. Ruminal isobutyrate was increased by NaB in the absence of FM and decreased by NaB in the presence of FM in the diet (FM × NaB, $P = .01$). There was a trend ($P = .12$) for FM to increase ruminal ammonia N. That FM decreased ruminal pH is consistent with data from finishing steers in one experiment (White et al., 1992) but not in another experiment (White et al., 1991) or with dairy cows (Zerbini et al., 1988). In each of these reports, ruminal pH seems to be related to total VFA concentrations. Even though NaB is expected to change ruminal microbial populations, this was reflected only in increased total VFA ($P < .06$) levels and a FM × NaB interaction ($P < .01$) for isobutyrate proportions. The increase in VFA concentration may be related to DMI, which was increased by FM and NaB. Acetate and butyrate levels were increased and propionate levels decreased by NaB (Colling et al., 1979). Others have reported little or no influence of NaB on ruminal fermentation (Galyean and Chabot, 1981; Jacques et al., 1986; Ivan et al., 1992b).

The influence of FM and NaB on mineral composition of phalanx bone, liver, and kidney is shown in Table 4. Including FM in lamb diets increased ($P < .05$) phalanx bone Mn with a corresponding decrease ($P < .05$) in liver Mn. The increased ADG associated with feeding FM may have shifted Mn from the liver to the bone. That kidney Cu was lower ($P < .01$) in lambs fed FM may be explained by the lower Cu content of the diets containing FM. It seems likely that the mineral content of body organs would be affected by dietary NaB, given its binding qualities (Fenn and Leng, 1989), but this effect was minimal at the low level fed in Exp. 2. Phalanx bone Mn content was decreased ($P < .05$) and kidney K content was increased ($P < .01$) in lambs fed diets that contained NaB. The concentration of kidney Fe was increased by NaB in the absence of FM and decreased by NaB in the presence of FM (FM × NaB, $P < .01$). Ivan et al. (1992a) reported that NaB reduces ruminal protozoa and reduced the solubilities of some cations, but not Fe and Mn. The mineral transport process by mucosal cells is improved by chelation (Helbock and Saltman, 1967; Forth and Rummel, 1973) that may result from complexes of amino acids (Martinez-Torres et al. (1981) supplied by FM.

Table 4. Influence of fish meal (FM) and sodium bentonite (NaB) on phalanx bone, liver, and kidney mineral content of lambs

	Fish meal, %		Sodium bentonite, %		
Item[a]	0	3	0	.75	SEM
	Phalanx bone ash				
Weight, g	2.73	3.05	2.92	2.86	.12
Ca, %	17.58	17.81	17.47	17.92	.29
Mg, %	.62	.67	.64	.65	.02
K, %	.10	.11	.10	.11	.006
Cu, ppm	4.10	4.00	3.70	4.40	.54
Zn, ppm	155.2	148.3	155.7	147.8	5.8
Mn, ppm[b]	2.10	2.60	2.60	2.10	.15
Fe, ppm	27.80	29.40	26.70	30.50	4.02
	Liver DM				
Weight, g	210.0	218.8	216.7	212.1	7.8
Ca, ppm	159.6	181.5	179.9	161.2	29.5
Mg, ppm	580	558	583	555	22
K, %[c]	.35	.40	.36	.38	.01
Cu, ppm	257	240	274	223	20
Zn, ppm	137.1	122.0	132.6	124.5	12.0
Mn, ppm[c]	11.6	9.7	11.4	9.9	.57
Fe, ppm	131.1	155.9	146.5	140.5	10.8
	Kidney DM				
Weight, g	23.5	22.6	23.4	22.7	.85
Ca, ppm	442	650	524	567	101
Mg, ppm	738	679	721	695	45
K, %[d]	.57	.53	.51	.59	.02
Cu, ppm[e]	13.4	7.0	10.5	9.9	.92
Zn, ppm	84.6	92.0	88.3	88.2	3.7
Mn, ppm	4.8	4.6	4.8	4.6	.39
Fe, ppm[f]	140.2	157.7	156.6	141.4	11.9

[a]Each value is the mean from 10 wether lambs.
[b]FM and NaB effects ($P < .05$).
[c]FM effect ($P < .05$).
[d]NaB effect ($P < .01$).
[e]FM effect ($P < .01$).
[f]FM × NaB effect ($P < .01$).

Implications

Fish meal with low ruminal degradability and sodium bentonite have the potential to increase dry matter intake and growth rate of lambs fed high-concentrate diets. However, they should not be fed in combination because their modes of improvement seem to be similar. Based on our results, supplementation of high-concentrate diets with 3% fish meal or .75% sodium bentonite has no beneficial effect on wool growth of growing lambs. Fish meal and sodium bentonite at the levels fed in this study had only a slight influence on bone, liver, or kidney mineral content.

Literature Cited

Adam, A. I., D. E. Hogue, and B. H. Magee. 1982. Protein sources in diets of rapidly growing lambs. J. Anim. Sci. 55(Suppl. 1):401 (Abstr.).

Amos, H. E., G. E. Mitchell, Jr., C. O. Little, and D. G. Ely. 1972. Abomasal and blood plasma nitrogen constituents of wethers fed corn gluten and fish meal supplemented semipurified diets. J. Anim. Sci. 35:1020–1024.

AOAC. 1990. Official Methods of Analysis (15th Ed.) Association of Official Analytical Chemists, Arlington, VA.

ASTM. 1996a. Standard test method for wool content of raw wool: Laboratory scale. Designation D584-94. Annual Book of ASTM Standards. Section 7, Vol. 07.01:206–210. American Society for Testing and Materials, West Conshohocken, PA.

ASTM. 1996b. Standard test method of sampling and testing staple length of grease wool. Designation D1234-85. Annual Book of ASTM Standards. Section 7, Vol. 07.01:329–332. American Society for Testing and Materials, West Conshohocken, PA.

Bates, R. L., and J. A. Jackson. 1980. Glossary of Geology. American Geological Institute, Alexandria, VA 22302.

Beerman, D. H., D. E. Hogue, V. K. Fishell, R. H. Dalrymple, and C. A. Ricks. 1986. Effects of cimaterol and fishmeal on performance, carcass characteristics and skeletal muscle growth in lambs. J. Anim. Sci. 62:370–380.

Black, J. L., and P. J. Reis. 1979. Speculation on the control of nutrient partition between wool growth and other body functions. In: J. L. Black and P. J. Reis (Ed.) Physiological and Environmental Limitations to Wool Growth. p 269. Univ. New England Publishing Unit, Armidale, N.S.W., Australia.

Bunting, L. D., L. S. Sticker, and P. J. Wozniak. 1992. Effect of ruminal escape protein and fat on nitrogen utilization in lambs exposed to elevated ambient temperatures. J. Anim. Sci. 70: 1518–1525.

Carter, M. L., S. N. McCutcheon, and R. W. Purchas. 1989. Plasma metabolite and hormone concentrations as predictors of genetic merit for lean meat production in sheep: Effects of metabolic challenges and fasting. N.Z. J. Agric. Res. 32:343–353.

Chaney, A. L., and E. P. Marbach. 1962. Modified reagents for determination of urea and ammonia. Clin. Chem. 8:130–132.

Cobon, D. H., R.G.A. Stephenson, and P. S. Hopkins. 1992. The effect of oral administration of methionine, bentonite, methionine/bentonite and methionine/oil homogenates on wool production of grazing and penned sheep in a semi-arid tropical environment. Aust. J. Exp. Agric. 32:435–441.

Colling, D. P., R. A. Britton, S. D. Farlin, and M. K. Nielsen. 1979. Effects of adding sodium bentonite to high grain diets for ruminants. J. Anim. Sci. 48:641–648.

Erwin, E. S., G. J. Marco, and E. Emery. 1961. Volatile fatty acid analysis of blood and rumen fluid by gas chromatography. J. Dairy Sci. 44:1768–1771.

Fenn, P. D., and R. A. Leng. 1989. Wool growth and sulfur amino acid entry rate in sheep fed roughage based diets supplemented with bentonite and sulfur amino acids. Aust. J. Agric. Res. 40: 889–896.

Fenn, P. D., and R. A. Leng. 1990. The effect of bentonite supplementation on ruminal protozoa density and wool growth in sheep either fed roughage based diets or grazing. Aust. J. Agric. Res. 41:167–174.

Forth, W., and W. Rummel. 1973. Iron absorption. Physiol. Rev. 53: 724–792.

Galyean, M. L., and R. C. Chabot. 1981. Effects of sodium bentonite, buffer salts, cement kiln dust and clinoptilolite on rumen characteristics of beef steers fed a high roughage diet. J. Anim. Sci. 52:1197–1204.

Goering, H. K., and P. J. Van Soest. 1970. Forage fiber analyses (apparatus, reagents, procedures, and some applications). Agric. Handbook 379. ARS, USDA, Washington, DC.

Hassan, S. A., and M. J. Bryant. 1986. The response of store lambs to dietary supplements of fish meal. Anim. Prod. 42:233–240.

Helbock, H. J., and P. Saltman. 1967. The transport of iron by rat intestine. Biochim. Biophys. Acta 135:979–990.

Hussein, H. S., and R. M. Jordon. 1991a. Fish meal as a protein supplement in finishing lamb diets. J. Anim. Sci. 69:2115–2122.

Hussein, H. S., and R. M. Jordon. 1991b. Fish meal as a protein supplement in ruminant diets: A review. J. Anim. Sci. 69: 2147–2156.

Ivan, M., M. de S. Dayrell, and M. Hidiroglou. 1992a. Effects of bentonite and monensin on selected elements in stomach and liver of fauna-free and faunated sheep. J. Dairy Sci. 75: 201–208.

Ivan, M., M. de S. Dayrell, S. Mahadevan, and M. Hidiroglou. 1992b. Effects of bentonite on wool growth and nitrogen metabolism in fauna-free and faunated sheep. J. Anim. Sci. 70:3194–3202.

IWTO. 1995. Measurement of the mean and distribution of fiber diameter of wool using an Optical Fibre Diameter Analyser (OFDA). Test method 47-95. International Wool Secretariat, Ilkley, U.K.

Jacques, K. A., D. E. Axe, T. R. Harris, D. L. Harmon, K. K. Bolsen, and D. E. Johnson. 1986. Effect of sodium bicarbonate and sodium bentonite on digestion, solid and liquid flow, and ruminal fermentation characteristics of forage sorghum silage-based diets fed to steers. J. Anim. Sci. 63:923–932.

Laborde, C. J., A. M. Chapa, D. W. Burleigh, D. J. Salgado, and J. M. Fernandez. 1995. Effects of processing and storage on the measurement of nitrogenous compounds in ovine blood. Small Ruminant Res. 17:159–166.

Martinez-Torres, C., E. Romano, and M. Layrisse. 1981. Effect of cysteine on iron absorption in man. Am. J. Clin. Nutr. 34: 322–327.

NRC. 1985. Nutrient Requirements of Sheep (6th Ed.) National Academy Press, Washington, DC.

Pond, W. G. 1984. Response of growing lambs to clinoptilolite or zeolite NaA added to corn, corn-fish meal and corn-soybean meal diets. J. Anim. Sci. 59:1320–1328.

SAS. 1988. SAS/STAT® User's Guide. SAS Inst. Inc., Cary, NC.

Sticker, L. S., F. G. Hembry, and T. W. White. 1990. In situ nitrogen and dry matter disappearance of soybean meal, Mexican anchovy, Maine herring and 14 Menhaden fish meals. Prof. Anim. Sci. 6:1–4.

Sykes, A. R. 1978. An assessment of the value of plasma urea nitrogen and albumin concentrations as monitors of the protein status of sheep. In: D. Lister (Ed.) Blood Profiles in Animal Production. p 143. British Soc. Anim. Prod., U.K.

Tan, P. V., and M. J. Bryant. 1991. A note on the response of store lambs to isonitrogenous diets containing rapeseed meal or fish meal. Anim. Prod. 52:395–399.

USDA. 1992. Official U.S. standards for grades of lamb, yearling mutton, and mutton carcasses. AMS, USDA, Washington, DC.

White, T. W., L. D. Bunting, L. S. Sticker, F. G. Hembry, and A. M. Saxton. 1992. Influence of fish meal and supplemental fat on performance of finishing steers exposed to moderate or high ambient temperatures. J. Anim. Sci. 70:3286–3292.

White, T. W., J. M. Fernandez, P. T. DeRouen, and L. S. Sticker. 1995. Growth and metabolic responses to calves grazing dormant forages and fed soybean meal, fishmeal, and urea in corn-based supplements. Prof. Anim. Sci. 1:110–115.

White, T. W., L. S. Sticker, F. G. Hembry, and A. M. Saxton. 1992. Influence of fish meal level in rice- or corn-based diets for finishing steers. Prof. Anim. Sci. 7:42–46.

Wilson, L. L., J. H. Ziegler, M. C. Rugh, J. L. Watkins, T. L. Merritt, M. J. Simpson, and F. L. Kreuzberger. 1970. Comparison of live, slaughter and carcass characteristics of rams, induced cryptorchids and wethers. J. Anim. Sci. 31:455–458.

Zerbini, E., and C. E. Polan. 1985. Protein sources evaluated for ruminating Holstein calves. J. Dairy Sci. 68:1416–1424.

Zerbini, E., C. E. Polan, and J. H. Herbein. 1988. Effect of dietary soybean meal and fish meal on protein digesta flow in Holstein cows during early and midlactation. J. Dairy Sci. 71:1248–1258.