

Source and level of supplemental protein for growing lambs¹

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ABSTRACT: Two 3 × 2 factorial growth trials and a companion metabolism trial with 13, 15, or 17% dietary CP (DM basis), with or without 3% of the DM replaced with slowly degraded menhaden fish meal, were conducted to determine if level of dietary protein influences whether slowly degraded protein improves lamb growth and protein use. The growth trials included 32 and 34 pens of two weanling lambs initially weighing 23 to 26 kg and fed for 42 d. The metabolism trial included 12 additional lambs fed in metabolism cages with a 2-wk adjustment period, a 1-wk preliminary period, and a 7-d collection period. Plasma urea N (PUN) was measured in all lambs at the conclusion of the second growth trial and at the end of the metabolism trial. There was a protein level × protein source interaction ($P = 0.05$) for

PUN of the 12 lambs in the metabolism trial but not for the 68 lambs in the second growth trial. Replacement of part of the soybean meal protein with protein from fish meal did not affect ADG or G:F at any protein level, but it lowered ($P = 0.08$) PUN in the second growth trial. Plasma urea N values were higher ($P = 0.002$) in lambs fed diets with 15 or 17% CP; however, ADG ($P = 0.037$ in Exp. 1 and $P = 0.055$ in Exp. 2), and G:F ($P = 0.094$ in Exp. 1 and $P = 0.003$ in Exp. 2) were lower for lambs fed the diets with 13% CP. There was little difference in ADG or G:F between lambs fed the diets with 15 or 17% CP, suggesting that a CP level of 15% with supplemental protein from soybean meal would be optimal for 25- to 40-kg growing Finnsheep × Dorset lambs.

Key Words: Fish Meal, Metabolism, Protein, Sheep, Soybean Meal

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Introduction

Soybean meal and fish meal are two important sources of high-quality protein used extensively to feed ruminants. Soybean meal usually is rapidly degraded and fish meal usually is slowly degraded in the rumen (AFRC, 1993). However, the extent of degradability is influenced by animal variation, other dietary ingredients, and feed processing. These may be some of the reasons that replacing soybean meal with fish meal has not given consistent results (Pond, 1984; Hassan and Bryant, 1986; Walz et al., 1998).

Level of dietary protein may influence whether including slowly degradable protein in the diet improves animal growth. Higher protein could compensate for a poorer distribution of absorbed amino acids and might be more economical than paying for expensive slowly

degraded protein. Surprisingly, the authors could find no references to test this hypothesis. For example, the early experiments at the Rowett Research Institute (Andrews and Orskov, 1970a; Orskov et al., 1971, 1976) compared diets with low to high protein levels, but the source of supplemental protein was only white fish meal. Tan and Bryant (1991) noted that previous experiments on the effect of slowly degraded protein on lamb growth were confounded with protein level, so that it was unclear that growth responses were due to the addition of slowly degraded protein. They found that lambs grew faster and more efficiently when rapeseed meal was replaced with fish meal in diets that contained 15% CP, but fish meal was not compared with rapeseed meal at the lower level of 11.2% CP. The objective of the experiments reported herein was to determine, across a range of dietary CP encompassing standard recommendations for early weaned lambs (NRC, 1985), whether level of dietary protein influences the effects of slowly degraded protein on lamb growth and protein use.

Materials and Methods

Three experiments were conducted using 156 Finnsheep × Dorset lambs to evaluate diets containing 13, 15, or 17% CP (DM basis) with or without 3% of the dietary DM as fish meal replacing an equivalent

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Table 1. Ingredient composition of diets for Exp. 1

Ingredient	CP, % of DM:	Source of supplemental protein					
		Soybean meal			Soybean meal + fish meal		
		13	15	17	13	15	17
		— % DM —					
Barley		70.73	65.98	61.23	72.13	67.33	62.53
Soybean hulls		20.00	20.00	20.00	20.00	20.00	20.00
Soybean meal		4.00	8.75	13.50	0.20	5.00	9.80
Sea-Lac fish meal ^a		—	—	—	3.00	3.00	3.00
Vegetable oil		2.20	2.20	2.20	2.20	2.20	2.20
Limestone		1.65	1.65	1.65	1.40	1.40	1.40
Agway sheep mineral mix ^b		0.70	0.70	0.70	0.70	0.70	0.70
CoPhos ^c		0.35	0.35	0.35	—	—	—
Ammonium chloride		0.25	0.25	0.25	0.25	0.25	0.25
Vitamin premix ^d		0.13	0.13	0.13	0.13	0.13	0.13
Bovatec premix ^e		0.02	0.02	0.02	0.02	0.02	0.02

^aOmega Protein, Inc., Hammond, LA.

^bMinimum of 18% Ca, 36.5% salt, 90 ppm Se, 1.6% Zn, 8,000 ppm Mn, 4,600 ppm Fe, 70 ppm I, 60 ppm Co. (Agway, Inc., Syracuse, NY).

^cContained 15% Ca, 21% P; Farmland Industries, Inc., Kansas City, MO.

^dContained 1,763,680 IU of vitamin A and 881,840 IU of vitamin D per kilogram.

^eContained 150 g of lasalocid sodium/kg (Alpharma, Fort Lee, NJ).

amount of soybean meal protein (Tables 1 and 2). Sea-Lac menhaden fish meal (Omega Protein Inc., Hammond, LA) was chosen for these experiments due to high protein quality and a slow ruminal degradation of less than 30% in 12 h (reported by Omega Protein) compared with the degradability of solvent-extracted soybean meal of approximately 65% in 12 h (AFRC, 1993). Nutrients in the major ingredients were chemically measured before formulating the diet for the second and third experiments. All diets were coarsely ground and mixed before the start of the experiments.

Feeding Trials (Exp. 1 and 2)

Lambs were given access to a barley-based diet similar to the diets in Tables 1 and 2 beginning at approximately 10 d of age through weaning at 40 to 70 d old and continuing until the start of the experiments. Lambs were 60 to 90 d old and started the experiments with average initial BW of 23 ± 2 kg in Exp. 1, and 26 ± 2.9 kg in Exp. 2. Experiment 1 began in early summer, with 36 elevated, expanded metal floor pens, each with two ram lambs, for a total of 72 lambs. Experiment 2

Table 2. Ingredient composition of diet for Exp. 2 and 3

Ingredient	CP, % of DM:	Source of supplemental protein					
		Soybean meal			Soybean meal + fish meal		
		13	15	17	13	15	17
		— % DM —					
Barley		72.60	68.30	63.90	73.90	69.60	65.40
Soybean hulls		15.00	15.00	15.00	15.00	15.00	15.00
Soybean meal		5.30	10.00	14.70	1.50	6.20	10.70
Sea-Lac fish meal ^a		—	—	—	3.00	3.00	3.00
Limestone		3.20	3.10	3.02	2.82	2.70	2.60
Vegetable oil		2.20	2.20	2.20	2.20	2.20	2.20
Agway sheep mineral mix ^b		0.50	0.50	0.50	0.50	0.50	0.50
Monosodium phosphate		0.44	0.33	0.23	0.23	0.10	—
Potassium chloride		0.26	0.12	—	0.36	0.23	0.10
Ammonium chloride		0.25	0.25	0.25	0.25	0.25	0.25
Vitamin premix ^c		0.13	0.13	0.13	0.13	0.13	0.13
Decoquinatate premix, 6% ^d		0.11	0.11	0.11	0.11	0.11	0.11

^aOmega Protein, Inc., Hammond, LA.

^bMinimum of 18% Ca, 36.5% salt, 90 ppm Se, 1.6% Zn, 8,000 ppm Mn, 4,600 ppm Fe, 70 ppm I, 60 ppm Co. (Agway, Inc., Syracuse, NY).

^cContained 1,763,680 IU of vitamin A and 881,840 IU of vitamin D per kilogram.

^dAlpharma, Fort Lee, NJ.

Table 3. Chemically determined nutrient composition of diet for Exp. 2 and 3^a

Nutrient	Source of supplemental protein						
	CP, % of DM:	Soybean meal			Soybean meal + fish meal		
		13	15	17	13	15	17
DM, % diet	86.70	86.71	86.70	87.13	87.03	87.42	
CP, %	12.10	14.20	16.61	12.81	14.52	17.34	
NDF, %	27.24	23.66	24.67	25.86	25.73	25.97	
ADF, %	13.09	11.77	11.62	14.12	14.44	18.15	
Lignin, %	1.35	2.87	1.48	3.24	2.20	2.84	
Ca, %	1.14	1.57	1.71	1.20	1.61	1.72	
P, %	0.48	0.51	0.51	0.56	0.55	0.52	
Mg, %	0.18	0.19	0.21	0.17	0.19	0.20	
K, %	0.65	0.69	0.75	0.60	0.67	0.77	
Na, %	0.15	0.19	0.19	0.16	0.17	0.16	
Fe, ppm	244	295	326	263	295	337	
Zn, ppm	85	96	112	85	99	101	
Cu, ppm	9	10	10	9	9	10	
Mn, ppm	49	53	73	44	49	58	
Mo, ppm	1.1	1.2	1.5	1.0	1.4	1.9	

^aWet chemistry methods by Dairy One, Ithaca, NY. All values except DM, %, are expressed on a DM basis.

began in midwinter with two gender-location blocks of 18 pens of two lambs each for a total of 72 lambs. Both experiments were carried out in the same unheated barn. To minimize pen-to-pen variation, each pen of lambs contained a heavy and a light lamb. Thus, the 36 pens were to be the experimental units in Exp. 1, and the 18 pens of ram lambs on one side of the barn and the 18 pens of ewe lambs on the other side of the barn were to be the experimental units in Exp. 2. Water buckets were emptied and refilled and the feed supply in each feeder was replenished in the morning each day of the 42-d experiments to ensure that the lambs had access to feed at all times.

One ram lamb in each of four pens in Exp. 1 became sick (a pen with and a pen without fish meal at 13% CP, and pens without fish meal at 15 and 17% CP), so the eight lambs in those four pens were removed from the experiment, leaving 32 observations. In Exp. 2, one ram in each of two pens receiving the diet containing 17% protein without fish meal became sick, so the four lambs in those two pens were removed from the experiment, leaving one pen of ram lambs and three pens of ewe lambs assigned to that diet, for a total of 34 observations.

To minimize variation due to drinking, feeding, and defecation, lambs were weighed full on the morning of the first day of the experiment and weekly before morning replenishment of feed. Initial and final BW were determined from linear growth equations (regression of BW on experimental day) computed for each lamb. Lambs were removed from pens after the final weighing and the residual feed was weighed.

In Exp. 2, a 1-kg sample of each diet was collected each week. At the end of the experiment, the six samples of each diet were pooled, mixed, and a 1-kg subsample was saved for analysis (wet chemistry methods by Dairy

One, Ithaca, NY). Table 3 shows the analytical composition of the diet for Exp. 2 and 3.

On the morning of d 41 of Exp. 2 (1 d before the final BW measurement) after feed replenishment, a jugular blood sample from each lamb was collected into heparinized tubes. Blood samples were immediately placed on ice, transported to the laboratory, and centrifuged at $1,000 \times g$ at 4°C for 20 min. Plasma from each lamb was harvested and stored at -20°C until it was analyzed in duplicate by gender-location blocks for urea N using a kit procedure (No. 640; Sigma Chemical Co., St. Louis, MO).

Weight gains for the lambs in each pen were averaged and total pen feed intake was halved so that the experimental observations were the data for pens expressed on a per lamb basis. In Exp. 2, the plasma urea nitrogen (PUN) was averaged for the two lambs in each pen. The experiments were analyzed as a 3 (protein level) \times 2 (protein sources) factorial with interaction. Gender-location was included as a block effect in Exp. 2. The factors in the statistical models were fixed. The 2 df for protein level were separated into linear and quadratic orthogonal polynomials (Steel and Torrie, 1960).

Nitrogen Metabolism Trial (Exp. 3)

Nitrogen balance was determined using 12 Finn-sheep \times Dorset ram lambs from the same cohort as those used in Exp. 2. Each lamb was placed in a separate metabolism cage designed to collect feces and urine separately. Two lambs were randomly assigned to each of the same diets as in Exp. 2. Feed was offered once daily at 0900 and water was refreshed at 1000 and 1600. Before starting the collection of feces and urine, animals were fed their respective diets for a 2-wk adjustment period and a 1-wk preliminary period. During

Table 4. The effect of source and level of protein supplement on lamb growth in Exp. 1

Item	Initial wt, kg	Final wt, kg	ADG, g/d	DMI, g/d	G:F, g/kg DM
Source of supplemental protein					
Soybean meal (n = 15 pens)	22.9	35.2	291	1,079	269
Soybean meal + fish meal (n = 17 pens)	23.6	35.8	292	1,099	266
SE ^a	0.52	0.69	12.2	28.0	8.8
P-value	0.361	0.457	0.947	0.606	0.849
Level of protein, % of dietary DM					
13 (n = 10 pens)	22.9	34.1	267	1,059	252
15 (n = 11 pens)	23.1	35.5	296	1,086	273
17 (n = 11 pens)	23.8	36.9	312	1,123	278
SE ^a	0.64	0.84	14.9	34.2	10.8
P-value (linear)	0.341	0.026	0.037	0.185	0.094
P-value (quadratic)	0.711	0.983	0.726	0.893	0.511

^aSE sometimes varied for means; the highest value is reported.

the adjustment period, the quantity of feed offered and refused was weighed daily to determine ad libitum feed intake. Feed levels were adjusted so that animals refused only 10 to 15% of feed offered. The feed offered to each lamb during the preliminary and collection period was set to 90% of average feed intake during the second week of the adjustment period. There were no feed refusals during the 7-d collection period.

Feed was sampled daily during the collection period and subsequently composited into 1-kg samples and preserved in sealed plastic bags kept at room temperature until analyzed. Feces were collected at 0700, weighed, and a 10% subsample frozen for later analysis. Urine was collected twice daily at 0700 and 1600. The collected urine was weighed and a 10% subsample was stored in plastic containers and frozen for later analysis. Thirty milliliters of 6 N HCl was added daily to urine collection buckets to prevent ammonia volatilization. On the last day of the collection period, a jugular blood sample was obtained from each lamb as described for Exp. 2. At the end of the experiment, a subsample of pooled daily fecal samples for each lamb was obtained for measurement of N before drying the remainder at 55°C. Feed and oven-dried feces were ground to pass a 2-mm screen in a Wiley mill. Samples were analyzed for DM and Kjeldahl N (AOAC, 1990). Pooled urine samples from each lamb were analyzed for Kjeldahl N. The urine and blood samples were analyzed for urea N concentration using the same kit as in Exp. 2. Nitrogen balance was calculated as the difference between N consumed and the sum of fecal N plus urinary N. Apparent biological value of N was calculated by dividing N balance by the apparent N digested.

The experiment was analyzed as a 3 (protein level) × 2 (protein sources) factorial with interaction, and both factors in the model were fixed. The 2 df for protein level were separated into linear and quadratic orthogonal polynomials (Steel and Torrie, 1960).

Results and Discussion

Replacement of part of the supplemental protein from soybean meal with fish meal did not affect rate or effi-

ciency of growth in Exp. 1 (Table 4). Based on results from previous experiments with lambs (Hogue and Adam, 1982; Beermann et al., 1986), this was unexpected, and Exp. 2 (Table 5) and 3 (Table 6) were carried out to confirm this result.

It was expected that the effect of fish meal on growth, feed efficiency, and N metabolism would be greater at lower protein levels than at higher protein levels. Surprisingly, except for PUN in the 12 lambs in the N metabolism experiment (Exp. 3; Table 6), there were no significant protein source × protein level interactions and there was no interaction for PUN in the second feeding trial (Exp. 2), where there were two to three times more observations and four to six times more lambs per diet. Therefore, the effect of protein source will be presented and discussed followed by the effect of protein level.

Source of Protein Supplements

As in Exp. 1, replacement of some of the soybean meal with fish meal in Exp. 2 had no effect on ADG, feed intake, or efficiency of growth, although PUN values were lower ($P = 0.078$) in lambs fed diets that contained fish meal in Exp. 2 (Table 5). Similarly, no effect of fish meal on rate or efficiency of growth was reported by several researchers (Batchelder, 1987; Hussein and Jordan, 1991a; Villalba and Provenza, 2000). In contrast, rate and efficiency of lamb growth were improved by including fish meal in the diets in other experiments (Hassan and Bryant, 1986; Tan and Bryant, 1991; Walz et al., 1998). Stock et al. (1983) also found that lambs gained faster and more efficiently when fed 14% CP corn-based diets with supplemental protein from blood meal rather than soybean meal. Similar inconsistent results were found for cattle (Thonney and Hogue, 1986; Thonney et al., 1987). Hussein and Jordan (1991b) suggested that variable responses to fish meal might be explained by variation in the degradability of both soybean meal and fish meal. Other environmental conditions, such as lamb breed, age, and gender, might also be important. Some of these possible effects are discussed below.

Table 5. The effect of source and level of protein supplement on lamb growth and plasma urea nitrogen (PUN) values in Exp. 2

Item	Initial wt, kg	Final wt, kg	ADG, g/d	DMI, g/d	G:F, g/kg DM	PUN, mg/dL
Source of supplemental protein						
Soybean meal (n = 16 pens)	25.7	38.6	308	1,247	244	22.8
Soybean meal + fish meal (n = 18 pens)	26.3	38.7	297	1,219	244	19.8
SE ^a	0.58	0.87	11.1	34.7	6.5	1.20
P-value	0.460	0.906	0.480	0.567	0.801	0.078
Level of protein, % of dietary DM						
13 (n = 12 pens)	27.0	38.7	279	1,240	223	15.0
15 (n = 12 pens)	25.2	38.2	310	1,216	255	23.6
17 (n = 10 pens)	25.7	39.0	317	1,242	254	25.4
SE ^a	0.74	1.10	14.1	44.1	8.2	1.52
P-value (linear)	0.201	0.848	0.055	0.971	0.003	<0.001
P-value (quadratic)	0.172	0.598	0.450	0.607	0.091	0.057

^aSE sometimes varied for means; the highest value is reported.

Feeding a high level of grain to growing ruminants, like the diets fed to lambs in the current study, is associated with a decrease in ruminal pH. A depression in pH has been shown to markedly decrease CP degradation of soybean meal to levels similar to those observed for meat and bone meal (Loerch et al., 1983). Furthermore, it was reported (Devant et al., 2001) that, despite relatively high ruminal pH above 6 for diets containing soybean meal, the degradability of soybean meal was lower than values reported by the AFRC (1993) and the NRC (1996). This was attributed to the low ruminal cellulolytic activity in animals fed high-concentrate diets (Hoover, 1986). Thus, lower than expected degradability of soybean meal could explain the lack of response for growth and efficiency of steers and lambs when soybean meal was compared with slowly degradable protein supplements in high-corn diets (Loerch and Berger, 1981). There was no effect of protein source when Merchen et al. (1987) compared the growth of cattle and N metabolism of lambs fed diets that con-

tained supplemental protein from corn gluten meal, another slowly degraded protein source, with soybean meal or urea. When Ludden et al. (1995) fed cattle 12.4% CP diets that contained one of four sources of supplemental protein at 20, 30, or 40% of the dietary CP, neither rate nor efficiency of growth was improved. Their Dacron bag ruminal escape protein data supported the hypothesis of Loerch and Berger (1981) that the ruminal degradability of SBM was decreased for cattle fed high-concentrate diets. They also showed that the microbial protein flow from the rumen was decreased for diets with high rumen-escape protein sources so that total duodenal supply of AA was unchanged (Ludden and Cecava, 1995). Nonetheless, most of the data in support of these hypotheses regarding the lack of effect of slowly degraded protein were obtained from cattle feeding experiments and the slowly degraded protein sources did not include fish meal, which often is higher quality. In addition, they contradict the results of previous experiments with lambs

Table 6. The effect of source and level of protein supplement on nitrogen metabolism values in Exp. 3

Item	DMI, g/d	Digestibility, %		N intake, g/d	Fecal N, g/d	Urine, N, g/d	N balance, g/d	Urine urea N, mg/dL	PUN, mg/dL ^a	N biological value, % ^b
		DM	CP ^a							
Source of supplemental protein										
Soybean meal (n = 6)	867	81.0	75.3	19.95	4.87	11.97	3.11	521	15.0	17.5
Soybean meal + fish meal (n = 6)	838	80.2	74.2	19.86	5.08	10.91	3.87	567	14.2	26.8
SE	35.6	0.75	1.20	0.919	0.395	0.748	1.131	151.9	0.83	6.39
P-value	0.583	0.514	0.536	0.944	0.730	0.353	0.649	0.839	0.498	0.343
Level of protein, % of dietary DM										
13 (n = 4)	869	81.7	72.4	17.32	4.79	10.10	2.43	204	10.5	19.2
15 (n = 4)	818	78.6	72.8	18.81	5.16	10.42	3.22	593	15.6	22.8
17 (n = 4)	870	81.5	79.0	23.58	4.97	13.80	4.82	836	17.7	24.6
SE	43.6	0.92	1.47	1.125	0.484	0.916	1.385	186.1	1.02	7.83
P-value (linear)	0.988	0.868	0.019	0.008	0.799	0.029	0.269	0.053	0.002	0.640
P-value (quadratic)	0.374	0.035	0.159	0.278	0.655	0.223	0.821	0.761	0.276	0.928

^aInteraction between source and level of protein ($P = 0.05$) for plasma urea nitrogen (PUN). Means for soybean meal were 13.2, 16.0, 15.9 mg/dL, and means for soybean meal plus fish meal were 7.8, 15.2, 19.6 mg/dL for 13, 15, and 17% CP, respectively, all with SE = 1.43 mg/dL.

^bCalculated as N balance \times 100 divided by difference between N intake and fecal N.

(Hogue and Adam, 1982; Beermann et al., 1986) in which fish meal improved rate and efficiency of growth.

The length of the feeding period and environmental temperature also may have contributed to these results. The lack of improvement in ADG when some of the soybean meal was replaced with fish meal in the present 6-wk feeding trials is consistent with the first period of 35 d in one of the previous lamb growing experiments at Cornell (Beermann et al., 1986). Increased long-term ADG was observed in studies conducted by several researchers (Beermann et al., 1986; Goedecken et al., 1990; Titgemeyer and Merchen, 1990).

The second experiment was carried out in cold weather during the late winter and early spring when the average maximum temperature was less than 5°C. It has been demonstrated with lambs (Bunting et al., 1992; Walz et al., 1998) and finishing steers (White et al., 1992) that the beneficial response to fish meal is greater at higher ambient temperatures of 30 to 36°C (average daily maximum). However, the first experiment was carried out in summer with maximal daily temperatures near 30°C, so it is unlikely that environmental temperature was the cause of the lack of advantage for fish meal in the feeding trials reported here.

As Walz et al. (1998) explained, the lower degradability of fish meal (30%) in the diets of lambs in their experiment compared with the higher degradability of fish meal (52.5%) in diets in the experiment of Hussein and Jordan (1991a) could have caused the contrasting differences between those two studies. However, the fish meal and soybean meal in the present experiments represented practical extremes in supplemental protein ruminal degradability, and it seems unlikely that the diets used in the present experiments would have resulted in higher degradability of fish meal than in previous experiments with lambs (Hogue and Adam, 1982; Beermann et al., 1986), in which fish meal improved rate and efficiency of growth.

In general, the responses to fish meal have been more significant in faster-growing lambs and cattle (Hussein and Jordan, 1991b). The positive responses to fish meal in one of the previous Cornell experiments (Beermann et al., 1986) could be the influence of Suffolk-sired lambs compared with the Finnsheep × Dorset lambs in present study. An exception to this conclusion was reported by Tan and Bryant (1991), who found a response to fish meal compared with a combination of rapeseed meal and urea in 35- to 43-kg Suffolk-sired lambs growing at less than 160 g/d.

Thus, as suggested by Devant et al. (2000) for high-concentrate diets with relatively high protein levels (13 to 17%), as used in the current study, there are many reasons why the source of protein supplements may not affect the ADG or G:F of growing lambs, and not all of them are known.

Except for PUN, there was no significant interaction between protein source and protein level in the N metabolism trial; therefore, main effects of protein source ($n = 6$) and protein level ($n = 4$) are reported in Table

6. Dry matter intake, digestibility, and N metabolism values shown in Table 6 echoed the lack of effect for source of supplemental protein that was found in the growth trials. The numerically higher biological value for N in diets containing fish meal (Table 6), along with the significantly lower PUN values from Exp. 2 (Table 5), imply that absorbed protein from fish meal may have been used more efficiently and lambs fed diets with fish meal might have gained more protein. The lack of an effect of fish meal on rate or efficiency of growth (Tables 4 and 5), however, does not support this possibility.

Level of Protein

The effect of protein level on ADG, DMI, and efficiency is shown in Tables 4 and 5. There was a linear increase in ADG in Exp. 1 ($P = 0.037$) and in Exp. 2 ($P = 0.055$). Although the quadratic effect was not significant, the increase in ADG was much greater from 13 to 15% CP than from 15 to 17% CP. Daily DMI was not affected by level of protein, but lambs fed diets with 15 or 17% CP were more efficient than lambs fed a diet with 13% CP in Exp. 1 ($P = 0.094$ for linear effect) and in Exp. 2 ($P = 0.003$ for linear effect; $P = 0.094$ for quadratic effect). The diet with 17% CP offered no advantage for G:F over the diet with 15% CP.

The NRC (1985) listed sheep CP requirements based on a formula that divided the sum of protein deposited, metabolic fecal protein, endogenous urinary protein, and dermal loss by net protein value. This resulted in CP requirements of 16.9, 15.1, and 14.5% for moderate to rapid growth of early-weaned lambs weighing 20, 30, and 40 to 60 kg, respectively.

A requirement of 15% based upon lambs growing from 23 to 39 kg in the current study supports the recommendations in the last edition of (NRC, 1985) and is consistent with earlier reports from the Rowett Research Institute for lambs fed barley-based diets. Andrews and Orskov (1970b) found that the optimal dietary protein concentration for Suffolk-sired lambs fed barley-based diets decreased from 17% at 20 kg live weight to 12.5% at 35 kg live weight and that the protein requirement declined as the digestible energy concentration declined. Using 50 Suffolk × North Country Cheviot lambs fed barley-based diets from 15 to 30 or to 50 kg live weight, Orskov et al. (1971) observed a consistent improvement in rate and efficiency of lamb growth as dietary CP increased from 11 to 15.7 to 19.4% of the dietary DM.

In this study with high-concentrate diets, ADG started to plateau above a CP level of 15%, which is in general agreement with results published for lambs since the last edition of Nutrient Requirements of Sheep (NRC, 1985) was published. Willms et al. (1991) fed their St. Croix and Barbados lambs diets with 6, 8, 10, 12, 14, or 16% CP based on alkaline hydrogen peroxide-treated wheat straw with soybean meal supplements. They reported maximal N retention at levels of 12 to 14% CP for these low energy diets. The Suffolk-sired

lambs of Tan et al. (1991) fed a NaOH-treated straw and barley-based diet containing 15% CP grew faster and more efficiently than those fed a similar diet but with only 11.2% CP. In contrast with the present experiment, however, the higher protein level was beneficial only if fish meal, and not a combination of rapeseed meal and urea, was the added protein source.

Results of the N metabolism trial (Exp. 3) are presented in Table 6. Given the quadratic effect ($P = 0.035$) of protein level, DM digestibility was less for lambs fed the diet containing 15% CP than for lambs fed diets with CP levels of 13 or 17%. Willms et al. (1991) found maximal digestibility at 12% CP when comparing dietary protein levels ranging from 6 to 16% in growing lambs. The lower apparent DM digestibility by lambs fed diets containing 15% CP in the present experiment was unexpected, especially given that they had the lowest DMI. Protein digestibility was higher ($P = 0.019$ for linear effect) for lambs fed the diet with 17% CP than for lambs fed diets containing 13 or 15% CP. Willms et al. (1991) also found an improvement in CP digestibility by growing lambs as CP levels increased. Although N intake ($P = 0.008$) and urinary N output ($P = 0.029$) increased linearly with increasing dietary CP, because DMI in Exp. 3 was numerically less for lambs fed diets with 15% CP, differences between lambs fed diets with 13 or 15% CP were small. Fecal N, N balance, and apparent biological value of N were not significantly affected by level of dietary CP.

Concentrations of PUN are presented in Tables 5 and 6 for Exp. 2 and 3, respectively. There was a protein source \times level interaction ($P = 0.05$) for PUN in Exp. 3 (Table 6). Lambs fed diets containing fish meal had a larger spread of PUN values across protein levels than lambs fed diets without fish meal (Footnote a of Table 6). In Exp. 2, with two to four times as many observations, however, the protein source \times level interaction for PUN was not significant. The higher concentrations of PUN in Exp. 2 compared with Exp. 3 reflect higher DMI by the lambs. There were linear ($P < 0.001$) and quadratic ($P = 0.057$) effects of protein level on PUN values in Exp. 2 (Table 5) and a linear effect ($P = 0.002$) in Exp. 3 (Table 6). Lambs fed the diet containing 13% CP had lower levels of PUN than lambs fed the higher protein diets. Although the higher PUN values for lambs fed the 15 and 17% CP diets could have reflected protein wastage, the values were within the range reported by others (Cole et al., 1988; Karnezos et al., 1994) for lambs fed high-concentrate diets. Adding protein supplements to diets or infusion of casein into the abomasum of growing ruminants has been found to increase PUN (Beermann et al., 1991). Urine urea N increased linearly ($P = 0.053$) as dietary protein increased. A close relationship between PUN and urine urea N was found when dietary protein was increased in cattle (Huntington et al., 2001).

Increased urinary N excretion by lambs fed the diets containing 15 or 17% CP could have been the result of intestinal absorption of amino acids in excess of tissue

requirements and/or ammonia absorbed across the ruminal wall or intestine (Willms et al., 1991). Zinn and Owens (1993) suggested that feeding excess protein would place an additional demand on energy or arginine to run the urea cycle, diverting nutrients away from growth. However, the lambs in Exp. 1 and 2 grew faster and more efficiently when fed the diet with 15% CP compared with the diet with 13% CP. Willms et al. (1991) found that the maximal quantity of N was retained at 14% CP for lambs fed diets based upon alkaline hydrogen peroxide-treated wheat straw from 6 to 16% CP.

Implications

In contrast to the hypothesis that a higher protein level could compensate for lack of slowly rumen-degraded protein in lamb diets based on barley, replacement of protein from soybean meal with protein from high-quality fish meal did not affect rate or efficiency of growth for early-weaned, rapidly growing lambs fed diets containing 13, 15, or 17% crude protein in the dietary dry matter. Although plasma urea nitrogen values were higher in lambs fed diets with 15 or 17% crude protein, the apparent biological values of nitrogen, average daily gain, and feed efficiency were lower for lambs fed the diet with 13% crude protein. There was little difference in average daily gain or feed efficiency between lambs fed the diets with 15 or 17% CP, suggesting that a crude protein level near 15% based on supplemental soybean meal would be optimal for 25- to 40-kg growing Finnsheep \times Dorset lambs.

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