The Influence of Dietary Nitrogen Source and Drinking Water pH on Growth, Digestibility, and Nitrogen Metabolism in Lambs Fed a High Roughage Diet

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Abstract

The influence of drinking water pH and dietary nitrogen source on the growth and metabolism of young lambs fed a high roughage diet was examined in a series of trials. Two phases of a drylot feeding trial involved a comparison of diets in which all crude protein was derived from natural sources (NATURAL) or 25% of the crude protein equivalent was derived from urea (NPN). The third phase involved a comparison of NATURAL and NPN diets and drinking water of pH 5.5 to 6.0 or pH 9.0 to 9.5. Lambs tended to perform better on the NATURAL diet, largely due to increased feed consumption. Drinking water pH had no significant effects on performance. Twelve lambs were used in 3 successive metabolism trials. In trial 1 (NATURAL vs. NPN), no significant differences were observed in dry matter, organic matter, acid detergent fiber or cellulose digestibility. Nitrogen retention was similar for NPN-fed NATURAL- or NPN-fed lambs. Trials 2 and 3 compared NATURAL and NPN diets with pH 5.5 to 6.0 or pH 9.0 to 9.5 drinking water. Small but significant (P<.05) increases in dry matter, organic matter and cellulose digestion were observed with pH 9.0 to 9.5 drinking water in trial 2, and a similar effect was noted in NATURAL-fed lambs in trial 3. Nitrogen retention was not influenced by drinking water pH. These studies with high roughage diets indicate that drinking water pH would not appear to be a major concern in the management of rangeland ruminants.

Alkaline waters are common throughout much of the western United States. In New Mexico, most municipal water supplies have a pH of 8.0 or greater (Anonymous 1974). With regard to stock water, Stephenson (1973) reported pH's of 7.4 to 8.3 in spring water and 7.4 to 8.2 in well water in southwest Idaho. In addition, Darling and Coltharp (1973) found pH varied from 7.6 to 8.3 in mountain streams of Utah. Yet, little is known about the effect of alkaline drinking water on the performance of grazing ruminants.

The rumen has a greater buffering capacity for acid conditions than for alkaline (Bloomfield et al. 1966). Consumption of alkaline water might temporarily elevate rumen pH above neutrality and increase the concentration of NH_3 relative to NH_4+. Coombe et al. (1960) found that NH_3 was readily absorbed from the rumen, whereas NH_4+ was either poorly absorbed or not absorbed at all. Increased ruminal and perhaps post-ruminal absorption of NH_3 and subsequent excretion of urea might decrease overall nitrogen utilization. Smith and McAllan (1973) suggested that rumen bacteria can effectively utilize high rumen ammonia levels over time as long as the ammonia is in the ionic (NH_4+) form.

Thus, water pH may influence the utilization of nitrogen by grazing ruminants, particularly when rumen ammonia levels are transiently high, as may be the case with nonprotein nitrogen supplementation. This study was conducted to evaluate the effect of drinking water pH and dietary nitrogen source on the growth, intake, and metabolism of growing lambs. Because of the difficulty of controlling experimental conditions in a grazing situation, a high roughage diet was fed in a dry-lot in an effort to simulate the dietary conditions encountered by ruminants grazing range grasses.

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Journal article 889, Agricultural Experiment Station, New Mexico State University, Las Cruces, 88003.

Experimental Procedure

Drylot Feeding Trial

Forty-eight New Mexico fine wool lambs (average initial weight of 19.5 kg) were used in a 64-day feeding trial. Before the trial began, all lambs were sheared, vaccinated[1] for blackleg, malignant edema, and overeating disease and wormed.[2] The trial was divided into 3 phases and lambs were held off feed and water for 12 to 14 hours and weighed at the beginning and end of each phase. Phase 1 of the trial was 22 days in length. The 48 lambs were randomly allotted to 12 covered shed pens (3.1 × 3.1 m) with 4 lambs per pen. Treatments consisted of 2 completely mixed, pelleted diets (Table 1), one in which all of the dietary crude protein was derived from natural sources (NATURAL) and another in which approximately (NATURAL) 25% of the crude protein equivalent was derived from urea (NPN). The two dietary treatments were randomly assigned to the 12 pens so that each treatment was replicated with 6 pens of 4 lambs each. Lambs were offered fresh feed daily in quantities sufficient to allow free choice consumption. Tap water (pH 7.0 to 8.0) was available to all lambs *ad libitum*.

Phase 2 of the feeding trial was 14 days in length. Procedures and treatments were the same as described for phase 1, except that 1 lamb was removed from each pen at the start of the phase to be used in a series of metabolism trials. Thus, each treatment was replicated with 6 pens of 3 lambs per pen.

Phase 3 was 28 days in length. Diets were the same as described for phases 1 and 2; however, 3 pens per dietary treatment were randomly chosen to receive drinking water of either pH 5.5 to 6.0 or pH 9.0 to 9.5. Thus, each of 4 treatments (NATURAL 6.0, NPN 6.0, NATURAL 9.0 and NPN 9.0) was replicated with 3 pens of 3 lambs per pen. Drinking water of pH 5.5 to 6.0 (referred to as pH 6.0 in tables) was prepared by adding HCl to tap water in quantities sufficient to lower the pH to the desired range. Water of pH 9.0 to 9.5 (referred to as pH 9.0 in tables) was prepared by adding granular CaOH to tap water and mixing until the pH reached the desired range. Fresh water supplies were mixed and stored in 120 liter plastic containers every 2 days during the period. Water pH was determined with a combination electrode pH meter.[3]

Pen feed intake, average daily gain, and feed efficiency were measured in all three phases of the trial. Pen water consumption was measured during period 3. Over the 64 days, 3 lambs were

[1]Bar-Vac 7. Anchor Laboratories, Inc., St. Joseph. Mo.
[2]Tramisol drench. Cyanamid Agr. de Puerto Rico, Manati, Puerto Rico.
[3]pH Master. Van Waters and Rogers, Inc., Denver, Colo.

Table 1. Composition of experimental diets.[1]

Ingredient	NATURAL	NPN
Sorghum hay	28.50	29.85
Cotton gin by-products	28.60	29.95
Cottonseed hulls	14.24	14.27
Sorghum grain, ground	—	10.22
Cottonseed meal	17.67	2.19
Cane molasses	10.34	10.37
Urea, Min 45% N	—	1.9
Salt	.5	.5
Trace mineral mix[2]	.1	.1
Vitamin A[3]	.05	.05
Sodium sulfate	—	.3
Biofos[4]	—	.3

[1]Percentage of dry matter
[2]Contained 4.40% Mn, .30 I, .20% Co, 6.60% Fe, 1.30% Cu, 12.0% Zn, and 20% Mg.
[3]Supplied 30 IU of vit A per gram.
[4]Mixture of mono-and dicalcium phosphates, min 21% P, Max 18% Ca. International Minerals and Chemical Corp., Mundelein, Ill.

removed from the experiment for health reasons apparently unrelated to treatments. Feed samples were obtained on a weekly basis and analyzed for dry matter, ash, crude protein, acid detergent fiber, and acid detergent lignin by standard procedures (AOAC 1980). Phases 1 and 2 were analyzed as a completely randomized design and phase 3 was analyzed as a completely randomized design with a factorial arrangement of treatments. Treatment means were separated by the predicted difference (*t* test) method of the Statistical Analysis System (Barr et al. 1979). Pens were assumed to represent experimental units, and all analyses were done on a pen basis. Feed efficiency values shown in Tables 3 and 4 were calculated as the average of pens on a given treatment, and as such, will not equal the value of average feed intake divided by average daily gain. This is true since the average of ratios does not equal the ratio of averages.

Metabolism Trials

At the end of phase 1 of the feeding trial, 1 lamb from each pen was randomly selected and moved to a metabolism crate in a continuously lighted, closed building. This provided 6 lambs for both NATURAL NPN treatments and an initial adaptation period to the diets of 22 days. Lambs were fitted with fecal collection bags and allowed to adjust to the stalls for 9 days. Feed was offered at a constant rate of 1000 g (as fed basis) throughout the metabolism trials.

Trial 1 was a 5-day total collection of feces and urine following the 9-day adaptation period. Daily samples of feces and urine (acidified with HCl) were collected, weight of feces and volume of urine recorded, and a 10% subsample saved. Daily subsamples were composited over the 5-day period and frozen for later analysis.

Table 2. Chemical composition (%) of experimental diets used in the feeding trial and metabolism trials.

Item	NATURAL	NPN
Feeding trial[1]		
Dry matter	93.8	93.9
Ash	12.5	12.0
Crude protein	17.8	21.2
Acid detergent fiber	38.8	36.1
Acid detergent lignin	12.2	11.2
Metabolism trials[1]		
Dry matter	93.3	93.4
Ash	12.1	12.0
Crude protein	21.6	23.4
Acid detergent fiber	36.5	35.9
Acid detergent lignin	11.3	10.4

[1]Values are reported on a dry matter basis.

Table 3. Performance of lambs in phases 1 and 2 of the feeding trial as influenced by dietary nitrogen source.

Item	NATURAL	NPN	SEM[4]
		Phase 1	
Initial weight, kg	19.8	19.2	
Days on feed	22	22	
Average daily gain, kg	.21	.17	.01
Daily feed intake, kg[1]	1.48[2]	1.37[3]	.03
Kg feed/kg gain	7.44	8.27	.54
		Phase 2	
Initial weight, kg	24.9	23.8	
Days on feed	14	14	
Average daily gain, kg	.18	.20	.02
Daily feed intake, kg[1]	1.72	1.67	.04
Kg feed/kg gain	9.63	9.33	.89

[1]Dry matter basis
[2,3]Values in the same row with different superscripts differ ($P<.05$).
[4]Standard error of treatment means; 6 observations per mean.

Trial 2 was a 5-day collection period which began immediately after trial 1. Diets (NATURAL vs. NPN) were the same as in trial 1, but 3 randomly selected lambs within a dietary treatment received pH 5.5 to 6.0 or pH 9.0 to 9.5 drinking water. Water was prepared in the same manner as described for the feeding trial. Fecal and urine collection methods were as described for trial 1.

Trial 3 was another 5-day collection period immediately following trial 2 and was designed to determine if lambs might alter their response to variations in drinking water pH over time. Procedures and treatments were the same as in trial 2.

Fecal samples from all 3 trials were dried at 55° C in a forced air oven for 48 hours, ground through a 2-mm screen in a Wiley mill, and analyzed for dry matter, ash, crude protein, and acid detergent fiber and lignin by standard procedures (AOAC, 1980). Urine was analyzed for nitrogen by the kjeldahl method and feed samples were analyzed as described for fecal samples.

Digestibility and nitrogen balance data from the metabolism trials were analyzed as a completely randomized design. Tests for significant differences were accomplished as described previously for the feeding trial.

Results and Discussion

Chemical composition of the experimental diets is shown in Table 2. Diets were formulated to be isocaloric and isonitrogenous based on published feed composition figures (NRC 1975). However, some variation was noted in chemical composition, especially in the case of crude protein content. The NPN diet had a higher crude protein content than the NATURAL diet in both the feeding and metabolism trials, the difference being less in the batch of feed used in the metabolism trials. Diets were similar in the content of other constituents.

Feeding trial results are shown in Tables 3 and 4. In phase 1 (Table 3), lambs fed the NATURAL diet gained faster and were more efficient than those fed the NPN diet, although differences

Table 4. Influence of dietary nitrogen source and drinking water pH on performance of lambs in phase 3 of the feeding trial.

Item	NATURAL	NPN	pH 6.0	pH 9.0	SEM[3]
Initial weight, kg	27.5	26.5	26.9	27.0	
Days on feed	28	28	28	28	
Average daily gain, kg	.17	.14	.15	.16	.01
Daily feed intake, kg[4]	1.92	1.82	1.85	1.89	.05
Kg feed/kg gain	11.30	13.92	13.06	12.17	1.02
Water intake, liters	6.80[1]	5.82[2]	6.20	6.43	.23

[1,2]Means in a row within a main effect (NATURAL *vs* NPN or pH 6.0 *vs* pH 9.0) with different superscripts differ ($P<.05$).
[3]Standard error of treatment means; 6 observations per mean.
[4]Dry matter basis.

Table 5. The influence of dietary nitrogen source on digestibility and nitrogen balance in metabolism trial 1.

Item	NATURAL	NPN	SEM[1]
Dry matter intake, g/day	932.7	934.2	
Organic matter intake, g/day	820.1	822.4	
Nitrogen intake, g/day	32.2	34.9	
Dry matter digested, %	54.3	51.7	1.9
Organic matter digested, %	55.4	52.9	2.0
Acid detergent fiber digested, %	28.8	23.8	3.4
Cellulose digested, %[2]	47.1	42.7	2.6
Nitrogen digested, %	71.0	71.9	1.1
Nitrogen retained, g/day	11.3	11.6	.8
N retained, % of intake	35.2	33.1	2.4
N retained, % of absorbed	49.6	46.0	3.3

[1]Standard error of treatment means; 6 observations per mean.
[2]Cellulose was calculated from the acid detergent fiber/acid detergent lignin analysis.

were not significant. NATURAL-fed lambs consumed more ($P<.05$) feed than NPN-fed lambs, which would largely account for differences in gain and efficiency. Similar results have been observed in lambs fed 87% milo stover diets with either supplemental soybean meal or urea (Bolsen et al. 1975).

In phase 2 (Table 3), lambs fed NATURAL and NPN diets had similar gains, intakes, and feed efficiencies. Repp et al. (1955) found that lambs fed urea as 50% of the total ration nitrogen gained as well as those fed soybean meal based rations after 21 days on feed. Moreover, lambs fed urea as 30% of the total ration nitrogen gained equal to those supplemented with soybean meal.

The water pH × nitrogen source interaction was not significant in phase 3; therefore, main effect means are reported in Table 4. No differences were observed in gain, intake, or efficiency due to nitrogen source (NATURAL vs. NPN); however, NPN-fed lambs tended to have poorer feed efficiencies than lambs fed the NATURAL diet. Daily water intake per lamb was greater ($P<.05$) for lambs fed the NATURAL diet, with a difference of about 1 liter between the two dietary treatments. No differences in performance or water intake were observed due to drinking water pH. It would appear that lambs can tolerate wide variations in pH of drinking water without adverse effects on performance. Similar results were reported by Johnson et al. (1959), who found no difference in rumen pH, cellulose digestion, and health of steers or heifers given drinking water of pH 9.76 versus control water of pH 8.54.

Results of the metabolism trials are shown in tables 5 through 8. In trial 1 (NATURAL vs. NPN), no differences were observed in dry matter, oranic matter, nitrogen, acid detergent fiber or cellulose digestion (Table 5), although lambs fed the NPN diet tended to have lower digestibilities for all of these constituents except nitrogen. Bolsen et al. (1975) observed similar digestibility responses in lambs fed all-natural or urea-supplemented milo stover diets. Nitrogen retention was similar with both NATURAL and NPN diets.

Table 6. The influence of dietary nitrogen source and drinking water pH on digestibility and nitrogen balance in metabolism trial 2.

Item	NATURAL	NPN	pH 6.0	pH 9.0	SEM[3]
Dry matter intake, g/day	932.7	934.2	933.5	933.5	
Organic matter intake, g/day	820.1	822.4	821.3	821.3	
Nitrogen intake, g/day	32.2	34.9	33.6	33.6	
Dry matter digested, %	53.0	52.0	51.3[1]	53.7[2]	.70
Organic matter digested, %	54.3	53.1	52.6	54.7[2]	.60
Acid detergent fiber digested, %	23.2	19.5	19.6	23.1	1.3
Cellulose digested, %	44.3[1]	39.0[2]	38.3[1]	45.1[2]	1.5
Nitrogen digested, %	68.4[1]	75.3[2]	71.1	72.6	.60
Nitrogen retained, g/day	10.8[1]	15.4[2]	13.5	12.7	.90
N retained, % of intake	33.6	44.1[2]	40.0	37.7	2.6
N retained, % of absorbed	49.1	58.5	56.0	51.6	3.5

[1,2]Means in a row within a main effect (NATURAL vs NPN or pH 6.0 vs pH 9.0) with different superscripts differ ($P<.05$).
[3]Standard error of treatment mean;s 6 observations per mean.

Table 7. Digestibility data in metabolism trial 3 as influenced by dietary nitrogen source and drinking water pH.

Item	NATURAL 6.0	NPN 6.0	NATURAL 9.0	NPN 9.0	SEM[3]
Dry matter intake, g/day	932.7	934.2	932.7	934.2	
Organic matter intake, g/day	820.1	822.4	810.1	822.4	
Dry matter digested, %	50.6[1]	52.5[1,2]	55.2[2]	52.5[1,2]	1.0
Organic matter digested, %	52.1[1]	54.4[1,2]	56.4[2]	53.3[1,2]	1.1
Acid detergent fiber digested, %	18.8[1]	22.8[1]	30.2[2]	23.7[1]	2.2
Cellulose digested, %	42.2[1]	41.4[1]	51.2[2]	42.9[1,2]	1.6

[1,2]Means in a row with different superscripts differ ($P<.05$)
[3]Standard error of treatment means; 3 observations per mean.

In trial 2, the water pH × nitrogen source interaction was not significant, and main effect means are reported in Table 6. Results were similar to those of trial 1, as far as the comparison of NATURAL and NPN diets; however, NPN-fed lambs had lower ($P<.05$) digestion coefficients for cellulose and retained more ($P<.05$) nitrogen per day and as a percent of intake than NATURAL-fed lambs. When NPN supplies all of dietary nitrogen in ruminant diets, nitrogen retention is usually poorer than with natural protein sources (Oltjen 1969). However, urea supplied only 25% of the crude protein equivalent in the present study.

Drinking water with a pH of 9.0 to 9.5 resulted in higher ($P<.05$) digestion coefficients for dry matter, organic matter, and cellulose than pH 5.5 to 6.0 water (Table 6). These results are not in agreement with those of Johnson et al. (1959), who reported no effect of pH 9.76 drinking water on in vitro cellulose digestion. However, the control water in their study had a pH of 8.54, which limits comparison with our study. It is not clear why alkaline drinking water would improve dry matter or cellulose digestion. Perhaps an elevation in rumen pH might improve conditions for cellulose digestion or the added Ca^{++} ions in the alkaline water may have enchanced cellulose digestion. Hubbert et al. (1958) have shown that calcium may stimulate cellulose digestion by rumen microorganisms in vitro.

Since the water pH × nitrogen source interaction was significant ($P<.05$) for dry matter, organic matter, acid detergent fiber and cellulose digestion in metabolism trial 3, the simple effect means for those variables are presented in Table 7. Within pH 5.5 to 6.0 water, digestibilities were similar for NATURAL and NPN diets. However, with pH 9.0 to 9.5 drinking water, lambs fed the NPN diet had lower ($P<.05$) acid detergent fiber digestibilities and tended to have lower coefficients for dry matter, organic matter and cellulose digestion than did NATURAL-fed lambs. Water pH appeared to have a greater effect on the NATURAL-fed lambs than on those fed the NPN diet, with the NATURAL 6.0 lambs having lower ($P<.05$) digestion coefficients for dry matter, organic matter, acid detergent fiber and cellulose than NATURAL 9.0 lambs. The reason for the effect of water pH on digestion in lambs fed the NATURAL diet is not clear, and not in agreement with results of the feeding trial. However, lambs in the metabolism trials were limit fed and cannot be directly compared with the ad libitum

Table 8. Nitrogen balance data in metabolism trial 3 as influenced by dietary nitrogen source and drinking water pH.

Item	NATURAL	NPN	pH 6.0	pH 9.0	SEM[3]
Nitrogen intake, g/day	32.2	34.9	33.6	33.6	
Nitrogen digested, %	72.1[1]	76.3[2]	73.3[1]	75.1[2]	.50
Nitrogen retained, g/day	13.3	14.4	13.2	14.5	.90
N retained, % of intake	41.3	41.2	39.2	43.4	2.7
N retained, % of absorbed	57.1	54.0	53.5	57.7	3.4

[1,2]Means in a row within a main effect (NATURAL *vs* NPN or pH 6.0 *vs* pH 9.0) with different superscripts differ ($P<.05$).
[3]Standard error of treatment means; 6 observations per mean.

fed lambs of the feeding trial.

Unlike the dry matter and fiber digestibility data of trial 3, the water pH × nitrogen source interaction was not significant for nitrogen digestion and balance data (Table 8),. Lambs fed the NPN diet had higher ($P<.05$) nitrogen digestion coefficients and tended to retain more nitrogen than lambs fed the NATURAL diet. Drinking water pH had little effect on nitrogen metabolism, except that lambs with pH 9.0 to 9.5 water digested more ($P<.05$) nitrogen than lambs with pH 5.5 to 6.0 water. It should be pointed out that nitrogen retention values were high in all 3 trials with values greater than 10 g per day in all cases. These values seem rather high for the diets used in the studies; but, when one considers the fact that the lambs were lightweight and eating the diets in excess of 4% of body weight, such values are plausible. In addition, the diets were high in crude protein and of fairly good quality, as evidenced by dry matter and organic matter digestion coefficients.

In summary, these data suggest that drinking water pH has little effect on the performance of sheep fed diets containing 70 to 75% roughage. Moreover, the metabolism trial data suggest little effect of drinking water pH on digestion or nitrogen metabolism, except that higher digestion coefficients were observed with pH 9.0 to 9.5 water, especially in lambs fed the NATURAL diet. Water pH did not influence nitrogen retention. We conclude that drinking water pH would appear to be of minimal concern in the management of grazing ruminants consuming diets similar in composition to those used in this study.

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