THE EFFECT OF WATER TEMPERATURE ON RUMEN TEMPERATURE, DIGESTION, AND RUMEN FERMENTATION IN SHEEP

by

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INTRODUCTION

Water is the single most abundant nutrient in the body and comprises some 60% of total body mass in mature sheep. Its role in metabolism at both the cellular and extracellular levels has been well documented. The only true variation that can exist among pure, clean water is temperature and its effect on the ruminant animal's metabolism is not conclusive. The main scope of this research was to measure the effect of water temperature on rumen temperature, digestion, rumen pH and volatile fatty acids, and free ammonia nitrogen concentrations in mature wether sheep.

LITERATURE REVIEW

Water Requirement

From the state of being an embryo with a composition of near 95% water to the adult ram with a total body composition of about 65% water, water is the major constituent of the living organism. If the individual's water requirement is not met, and the deficit in a hot, dry environment is about 12%, death will most likely occur (Maynard and Loosli, 1969). Water's physical and chemical properties make it ideal for the physiological functions it performs. So many different factors affect total body water that establishing a water requirement for an animal of a specified sex, breed, weight, age, or state of production, and then having that requirement be representative of all like animals is impossible. Approximations or ranges must be used for the present though, until accurate requirements can be defined. Most researchers agree, though, that the water requirement of an animal is that amount which he will freely consume.

Water intake is affected by ambient temperature, physical form of feed, nutrient composition of feed, digestive tract fill and exercise, to mention only a few.

Bailey et al. (1962) reported a decrease in environmental temperature from 15 to -12 C resulted in reduced water intake by 50% in sheep. Range sheep in mountain areas frequently have snow as their only source

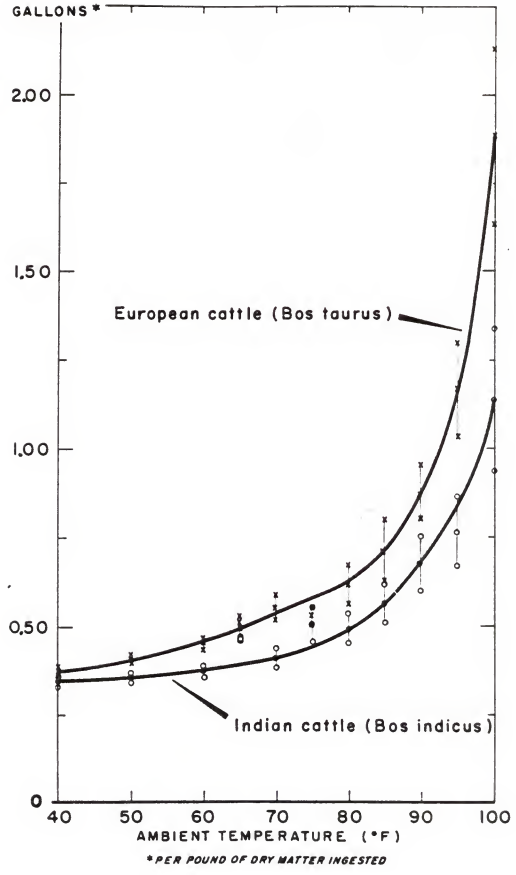
for drinking water. Butcher (1966) fed two sheep identical diets, with one group receiving snow and the other drinking water. There were no significant differences in feed consumed or weight gain but daily water intake was 4.2 kg for the drinking water group compared to 3.0 kg for the snow group. This agrees with results with dairy cattle in which consumption of 1.1 C water was significantly lower, and the consumption of 39.3 C water was significantly higher than consumption of 13.9 C and 26.7 C water (Cunningham et al., 1964).

The effect of ambient temperature on the relationship between water and DM intake of cattle was investigated by Winchester and Morris (1956). They found that at temperatures from about -12.2 to 4.4 C, the rate of water intake/unit of DM consumed was fairly stable. From 4.4 to 37.8 C, however, the ratio increased markedly (Figure 1).

Water consumption of lactating cows fed different rations was reported by Castle et al. (1975). They found that with silage, average dry matter (DM) of 35%, water intake varied from 17.2 to 35.4 kg/cow/day and that drinking occasions/cow/day were 2.6 to 4.6. When cows were fed dried grass, 74 kg of water/cow/day was consumed in 7.0 drinking occasions/cow/day. In earlier reports by Waldo et al. (1965), Holstein heifers fed an ad libitum ration of alfalfa-grass silage (45% DM) consumed 4.93 kg of water per kg of silage DM compared to 3.79 kg of water per kg of alfalfa hay DM. A formula for predicting free water consumption was developed by Winchester and Morris (1956):

$$\text{free water consumption (kg)} = \frac{\%\ \text{water in feed}}{\%\ \text{DM in feed}} \times \text{daily DM intake (kg)}$$

Figure 1. Water intake expressed as a function of dry matter consumption and ambient temperature. Winchester and Morris (1956).


GALLONS*
2.00
1.50
1.00
0.50
0
European cattle (Bos taurus)
Indian cattle (Bos indicus)
40
50
60
70
80
90
100
AMBIENT TEMPERATURE (°F)
*PER POUND OF DRY MATTER INGESTED

Castle et al. (1975) reported that if the dry matter content of the ration is known and the maximum daily yield of milk can be predicted, the intake of drinking water can be calculated from the equation:

$$Y = 2.53x_1 + 0.45x_2 - 15.30$$

where x_1 is the daily milk yield per cow and x_2 is the ration dry matter.

The intake of water by ewes, pregnant and non-pregnant with single and multiple births, was recorded by Forbes (1968). His data showed a significant relationship between total water intake and DM intake of non-pregnant ewes fed on a ration of either wilted grass silage or cubed dried grass. The mean results were expressed by the equation:

$$TWI = 3.86\ (\pm 0.75)\ DMI - 0.99$$

where TWI was the total water intake and DMI was the dry matter intake, each expressed as kg/ewe/day.

The importance of lactating animals having free access to drinking water has been established by many researchers. Sykes (1955) noted that cows producing 36.32 kg of milk/day would drink as much as 86.26 kg of water/day and that lactating ewes needed 30 to 50% more water than non-lactating ewes. Maynard and Loosli (1969) reported that 4 to 5 kg of water is required for each kg of milk produced. When lactating cattle have free access to water, more milk is produced and more water consumed than if water is offered once or twice a day.

Total water intake/unit of feed DM between the 14th and 20th week of pregnancy for ewes fed silage increased according to the number of fetus present but the differences were not significant according to Forbes (1968). As the term of pregnancy proceeds, TWI (kg)/DMI (kg) increased as shown in Figure 2. From the 19th week of pregnancy to parturition, ewes carrying single or twin fetuses drank significantly more water/unit of feed DM than did the non-pregnant ewes.

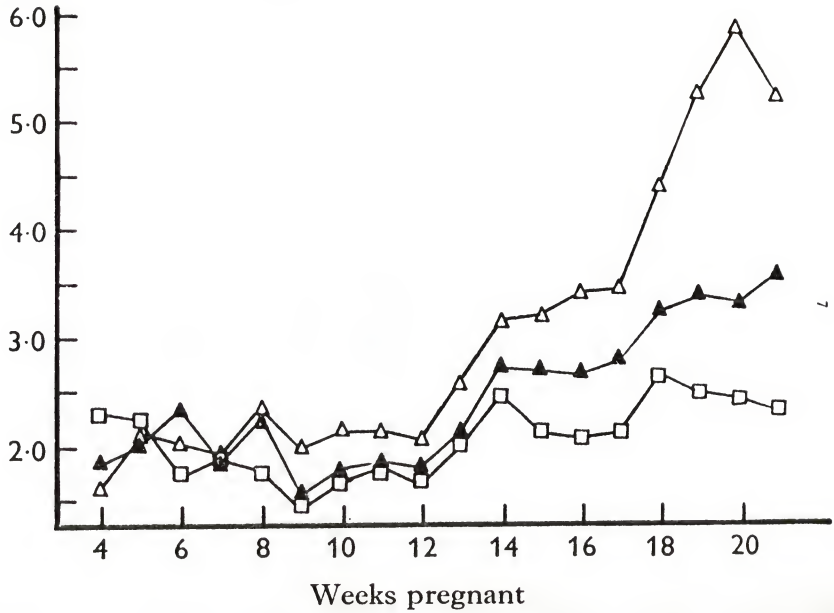
When Forbes compared milk yield, DMI or TWI between ewes that reared singles to those that reared twins, he found no significant differences. During the first 4 weeks of lactation water intake for lactating ewes, corrected to account for the water in the milk, was greater than water intake of non-lactating ewes. From the 5th to the 7th week of lactation, however, non-lactating ewes had the highest water consumption.

Water Metabolism

Body Water Pool

Reid et al. (1955) reported the total body water of the fat-free adult body averaged 71 to 73% among many species. Total body water was estimated by Argenzio et al. (1968) as 69.8± 3.5% of body weight in lactating cows with a half life (as determined by use of tritiated water) of 5.5 days. Factors which influence the turnover rate of body water are: the size of the total body water pool; the amount of water gained/unit time by drinking, eating, or metabolism of food; and the amount of water lost/unit time by breathing, sweating, and excretion (urine, feces, and, in the case of lactating cows, milk). When a

Figure 2. Total water intake (kg/kg dry matter intake) of pregnant ewes; Δ , six ewes carrying twins; ▲ , nine ewes carrying singles; ▢ , six non-pregnant ewes. Forbes (1968).


6·0
5·0
4·0
3·0
2·0
4
6
8
10
12
14
16
18
20
Weeks pregnant

group of Holstein cows were restricted to 50% of their ad libitum water consumption at an ambient temperature of 18 C, a 50% reduction in water loss occurred along with a decline in total body fluid volume (Seif et al., 1973). At 32 C and the same water restriction, however, Seif reported a marked reduction in water loss through feces and urine thus rendering the water to be metabolized for heat loss by vaporization. This observation has been supported by several other researchers. Weeth et al. (1967) deprived Hereford heifers of water for 4 days and recorded a 16% loss of body weight, a 72% reduction in urine weight, a 53% increase in urine osmolarity (from 780 mOsmol/kg for the control to 1196 mOsmol/kg for the water restricted), and fecal weight and water reductions of 91% and 16%, respectively.

Water Turnover

Average rumen water volume of 11.1% of body weight in cattle and goats with a half life of 10 hrs for cattle and 17 hrs for goats were reported by Argenzio et al. (1968). In an experiment relating body mass to rumen volume, Purser and Moir (1966) showed that sheep whose weights varied from 61.8 to 75.5 kg, had rumen volumes between 2.5 and 7.6 l. Warner and Stacy (1968) reported an average rumen volume constituting about 10% of the body water or about 3.9 l in sheep averaging 39 kg body weight. Rumen fluid volumes of wethers weighing 44 to 58 kg were expressed by Kennedy et al. (1976) as 6.88 l in an ambient temperature of 18 to 21 C and 5.28 l at -1 to 1 C. Engelhardt (1970) expressed the rumen fluid volume as about 15% of the total body water with 30% of the total body water flowing into the rumen as saliva in a 24 hr period.

When Black et al. (1964) injected cattle varying in weight from 177 to 783 kg with tritium labeled compounds, they recorded values for half lives of the labeled water as 3.54± .105 days for dairy cows and 3.4± .179 days for dairy bulls. They estimated the size of the body water pool as about 74% of body weight. The effect of lactation appeared to be nominal. MacFarlane and Howard (1966) measured the water turnover of six pairs of identical twin cattle. Three pairs were stall fed and three pairs grazed pasture. One twin of each stall-fed pair received water daily, the other twin every four days. Stall-fed twins that received water daily had an average water turnover of 14.2 1/24 hrs compared to an average turnover of 12.4 1/24 hrs for the twin receiving water each 4th day. The grazing cattle had a water turnover rate of 261 to 364 ml/kg $^{0.82}$/24 hrs and the stall-fed cattle had a 74 to 132 ml/kg $^{0.82}$/24 hrs turnover rate. The youngest cattle (17 months) had the highest water turnover rate. Rumen turnover rate in sheep as determined by Kennedy et al. (1976) using ^{103}Ru was reported to be 17.6 hrs at an ambient temperature of 18 to 21 C and 10.9 hrs at -1 to 1 C.

Cattle have a much quicker rate of body water turnover compared to other mammals. Hungate (1966) attempts to explain the comparatively rapid turnover of water in cattle by the exchange of water with hydrogen during rumen fermentation. By the production of 330 l of methane, 540 g of water/day is lost; hardly enough, though, to account for the elevated water turnover of cattle.

Transepithelial Water Flow

The net flux of water across the rumen epithelium has produced many contradictory reviews. Most researchers agree that the net flux through

the healthy rumen wall is not large, thus the epithelium appears to be an effective barrier against large rates of transepithelial net flux of water. Warner and Stacy (1968) reported that in sheep, with an average resting rumen volume of 3.9 l, there was a net average inflow of .29 l/hr with an overall average rate of absorption of about .05 l/hr. During periods of feed consumption, the rumen contents became hypertonic with osmolalities to 500 mOsmoles/kg, but no substantial water flow through the epithelium into the rumen was recorded. Ternouth (1967) also recorded a hypertonicity of the rumen following feeding but noted an increased volume of 5.8 l of which he accounted for 77.6% of the increase from saliva and the remaining 22.4% from transruminal flow. Willes et al. (1970) reported a rapid exchange of water between the rumen contents and blood. Mean water absorption from the rumen ranged from 37.1 to 70.8 ml/min while water insorption ranged from 30.5 to 65.0 ml/min. The mean net water transfer from the rumen was observed as 5.1 to 13.4 ml/min. The water exchange from the rumen increased 2 to 3 hrs post-feeding and declined after 17 hrs. When they reduced the pH of the rumen to 5.5 to 5.8 by the addition of HCl, a significant increase in the rate of water exchange occurred at 3 to 17 hrs post-feeding. In a review, Engelhardt (1970) reported a wide range of exchange of water between rumen contents and blood in goats (6.7 to 50 ml/min). There was, however, little net difference in total influx into the rumen and no net movement was observed within a certain osmotic range (265 to 325 mOsmol/kg) above and below isotonicity.

Water Temperature

Little is known about the effect of water temperature on rumen metabolism. Bailey et al. (1962) reported that when sheep received water of 0, 10, 20, and 30 C, rumen temperature would decline then return to normal. Cunningham et al. (1964) used similar temperature treatments with Holstein cows and reported no significant differences in digestible dry matter, digestible energy, or digestible crude protein.

Butcher et al. (1966) recorded an average maximum depression in rumen temperature of 6.6 C for 20 C water, 4.6 C for snow, and 15.3 C for 1 C water. The average rate of recovery was 17.2, 26.8 and 9.6 min per degree of temperature depression for water at 20 C, snow and 1 C water, respectively. Bailey et al. (1962) reported a significant increase at -12 C in average rectal temperature in sheep when receiving water at 0 and 10 C compared with receiving water at 30 C. Although not significant, there was a trend for the temperature of the rumen to be higher when receiving 0 C water (39.6 C) than when receiving 30 C (39.4 C) and for the reticulum (0 C, 39.0 C; 30 C, 38.7 C).

EXPERIMENTAL PROCEDURES

Four 2½ year old Hampshire wethers, average weight 66 kg, were housed in individual metabolism crates (Figure 3). All four wethers were previously fitted with permanent rumen fistulas at one year of age. The crates were 48.3 cm wide, 77.5 cm high and 121.9 cm long. Crate floors were made of steel mesh and directly below were removable stainless steel pans for collecting urine. The front of the crates were fitted with a removable divided feed trough; one side for feed, the other for water.

The room was thermatically controlled with a range of 15.56 C to 21.00 C and equipped with ceiling ventilation.

In all three studies, the same water temperature treatments were used: 0, 10, 20 and 30 C. The design of the experiments assigned each wether to a treatment for a specified time until all wethers received each treatment.

The ration fed in the rumen temperature and digestion studies were pelleted dehydrated alfalfa (Table 1). In the temperature study, the pellets were fed at 3.5% of body weight once in the morning. The feeding level for the digestion study was determined by recording maximum voluntary intake for each wether then reducing feed by 10% to insure total consumption. The ration fed in the metabolism study was chopped alfalfa hay (Table 1). The feed level was determined by the same method as in the digestion study.

Figure 3. Experimental wether.

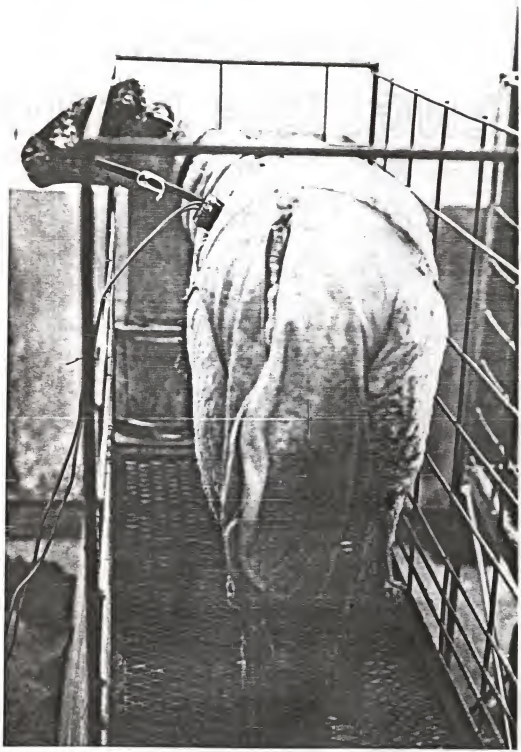


TABLE 1. ANALYSIS OF ALFALFA

Item	Dehydrated Alfalfa Pellets	Chopped Alfalfa Hay
Dry Matter, %	90.41	89.96
Ether Extract, %[1]	2.83	2.47
Crude Fiber, %[1]	24.39	26.50
Crude Protein, %[1]	20.09	19.15
Ash, %[1]	13.60	10.94

[1]Expressed on 100% dry matter basis.

Rumen Temperature Study

The objective was to determine the effects of water temperature on rumen liquid temperature over time.

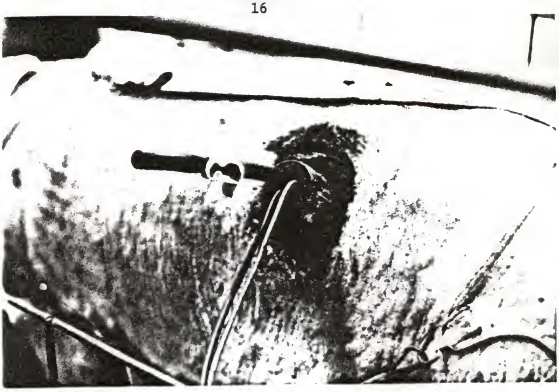
A three hole #7 rubber stopper was secured in the fistula opening. Two .95 cm diameter copper tubes were placed in the ventral rumen sac; one extending 17.78 cm horizontally and 20.32 cm vertically down and the second tube extending 27.78 cm horizontally and 10.16 cm vertically down into the rumen. A third .95 cm diameter copper tube of 7.62 cm length was likewise fit through the rubber stopper. Exterior to the animal, a rubber tube was fitted over the third copper tubing and a hose clamp was attached (Figure 4).

A flexible general purpose thermistor probe (Yellow Spring Instrument Co., Model #LN 5737, 401) was pushed through the first two copper tubes of each animal until the probe extended the length of the tubing (Figure 5). Temperatures were monitored on a scanning tele-thermometer (YSI Model 47) (Figure 6). Room temperature was also monitored.

Water was withheld for 24 hrs. Within 5 min of feeding dehydrated alfalfa pellets, 2 l of water was injected intraruminaly through the short copper tubing for each animal (Figure 7). The tele-thermometer would read a probe for 20 sec then move to read the next. Because room temperature was being recorded, there were 9 input channels and 180 sec for a complete cycle. Temperatures were monitored from pre-dosage until the rumen temperature reached at least .5 C of the initial rumen temperature.

Figure 4. Rumen fistula with thermistor probe wires.

Figure 5. Interruminal temperature monitoring apparatus.



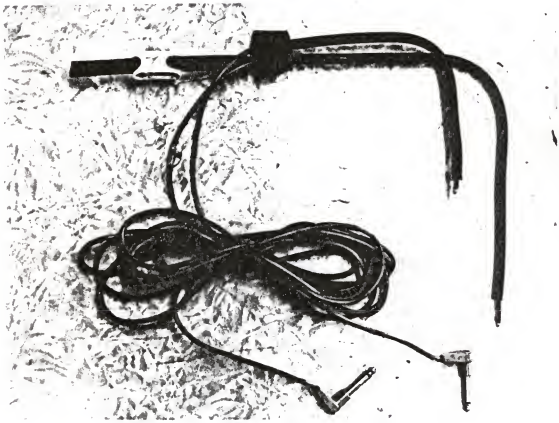
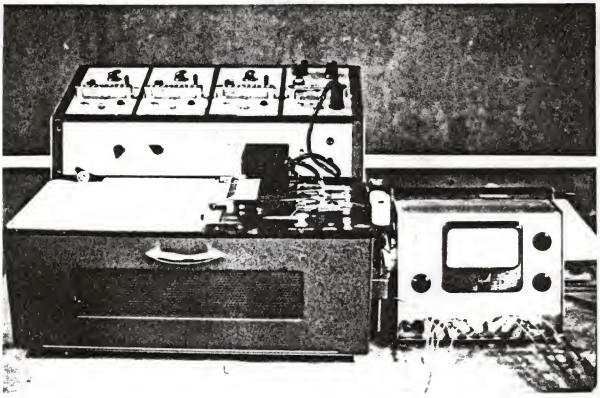
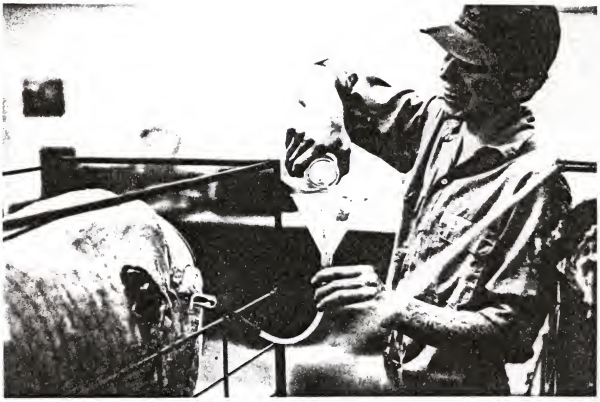


Figure 6. Tele-thermometer with recorder.

Figure 7. Experiment water infussion.





Digestion Study

The objective was to measure the effect of water temperature on ration digestibility and nitrogen balance.

Dehydrated alfalfa pellets were fed at 90% of ad libitum intake in the morning. Within 5 min after feeding 2 l of water was injected through the rumen port and 8 hrs later an additional 2 l of water was injected.

Each wether received each water temperature for 10 days. This consisted of a 5-day temperature adjustment period followed immediately by a 5-day fecal and urine collection period.

A canvas fecal collection bag was fitted to each wether and a plastic bucket was set below the urine collection tray to which urine would empty. Daily total collections of feces were made and 10% of total recorded weight was frozen in polyethelene bags. A 5-day composite sample was dried for 48 hrs at 15.6 C then analyzed by proximate analyses (A.O.A.C., 1975). Fifty ml of 6N HCl was added to each urine collection bucket the evening before each daily collection to inhibit bacterial action and fix free ammonia in the urine. On collection, each sample was diluted to the nearest liter and 10% of the recorded volume was then transferred to a composite glass vessel. After the 5-day collection period, 500 ml of the urine composite was bottled and 2 ml aliquots were analyzed for nitrogen by the kjeldhal procedure (A.O.A.C., 1975).

Rumen Fermentation Study

The purpose was to determine the effect of water temperature on concentrations of rumen ammonia-N, rumen volatile fatty acids and rumen pH.

A single hole #4 rubber stopper was permanently fixed to the opening of the fistula. A .95 cm diameter copper tube was fit through the hole extending 10.16 cm horizontally into the rumen and descending 10.16 cm vertically down into the ventral rumen sac. At this end of the tubing a stainless steel rumen suction strainer (Precision Machines, Inc.) was secured and to the end exterior to the animal, a #0 cork was used as a plug and as easy access to the tube.

Free choice water was removed 24 hrs before trial began. Two l of water was infused through the copper tube of each animal and a sample of rumen fluid was taken immediately. A 240 ml stainless steel dose syringe with a 5 cm piece of plastic tubing on the end was fit over the extended copper tubing for taking subsequent samples.

After the first sample, each animal was fed at a rate of 90% of ad libitum intake of chopped alfalfa hay and a second sample was taken immediately after the feeding. Subsequent samples were taken at 1, 2, 3, 4 and 5 hours. The four water temperature treatments were given to each wether on four consecutive days and the study was replicated (thus, each wether received each treatment twice).

Each sample was immediately monitored for pH (Beckman, #9600; Glass electrode: silver chloride internals, Beckman #41263). Eighteen ml of the strained rumen fluid was transferred to a 20 ml vial to which

1.2 ml of a saturated solution (.07 g/ml) of HgCl was added to prevent artifact ammonia-N (Davidovich, 1977). The vials were capped and frozen for later analysis.

After thawing, samples were analyzed for ammonia-N and volatile fatty acids (VTA). Ammonia-N determinations were made by the micro-diffusion analysis (Conway, 1963). A 1 ml sample was placed on one side of the sampling ring in an O'Brink modified Conway dish. On the other side of the sampling ring, 1 ml of saturated potassium carbonate was placed as well as 1.5 ml in the sealing ring. One ml of boric acid was placed in the center well, the dish was sealed and the alkali and acid were mixed by slight rotation. Ammonia was measured by titrating the center well to a pink end point with standard titration acid, using a glass syringe microburet (Micro-Metric Instrument Co., #5B2) and a magnetic stirrer. All samples were analyzed in duplicate.

The remainder of the sample was acidified by an addition of 2 ml of 6N HCl, and centrifuged 15 min at 42,000 and 10 C. An aliquot was placed in a 1 ml serum vial for volatile fatty acid analysis.

VFA's were separated on a 182.9 x .61 cm x 2 mm IU glass column containing 100-120 mesh Chromosorb 101 (Supelco, Inc.). Conditions employed on a Hewlett-Packard (Model 5730 A) gas chromatograph were as follows:

-flash vaporization injector, without lines, 250 C

-carrier gas (nitrogen) flow, 15 ml/min

-column temperature, 192 C, isothermal

-flame ionization detector

-temperature, 250 C

-H_2 flow, 45 ml/min

-air flow, 200 ml/min

An automatic injector system was used (Hewlett-Packard, Model 7671A) and programmed as follows:

-injection size (Hamilton syringe, model 701N), 1 ml

-flush cycles, 5

-de-bubbling cycles, 5

-analysis cycle time, 30 min

The signal from the electrometer (10*2 attenuation) was fed to a Spectra-Physics Minigrator (Model #23000-010) using the following conditions:

-5 PW

-15 SS

-10 BL

-100 T1

-340 T2

-850 T4

-1 PL

Performance of the integrator was monitored using a strip chart recorder (Sargent, model SR).

For quantitation, a standard containing the following authentic volatile fatty acids was injected:

-Acetic acid, 40 µm/ml

-Propionic acid, 40 µm/ml

-Isobutyric acid, 10 μm/ml

-Butyric acid, 20 μm/ml

-Isovaleric acid, 10 μm/ml

-Valeric acid, 10 μm/ml

Calibration constants were computed by dividing the standard concentration by the standard's integration units and then multiplying by the unknowns integration units. All analyses were run in duplicate, and standards were run every four samples to account for instrumental drift. Results were expressed both as μm/ml and molar percent.

RESULTS AND DISCUSSION

Rumen Temperature Study

Results obtained from the study are shown in Figure 8 and Table 2. Temperatures given are the means obtained from the average readings of both locations in the rumen for the four wethers at each water temperature. Maximum depression from initial temperature, as shown in Table 2, was greatest for the 0 C treatment (6.44 C) followed by the 10 C (4.62 C), 20 C (4.01 C), and 30 C (2.36 C) treatments. The rate of incline (Figure 8) was greatest for the 0 C treatment followed in order by the 10, 20, and 30 C treatments. The rumen of the 30 C treatment reached initial temperature (39.24 C) at 72 min. Rumens of the 20 and 10 C water treatments reached initial temperatures (39.55 and 39.36 C, respectively) at 96 min. It took 108 min for the rumen of the 0 C water treatment to reach the initial temperature (39.28 C). Bailey et al. (1962) and Cunningham et al. (1964) reported similar results showing that with cold water, rumen temperature decreased and the return to normal rumen temperature took longer with cold water.

Digestion Study

Animal number 3 was removed in the study due to a non-experimental related illness.

Figure 8. Rumen temperature over time in rumen temperature study.

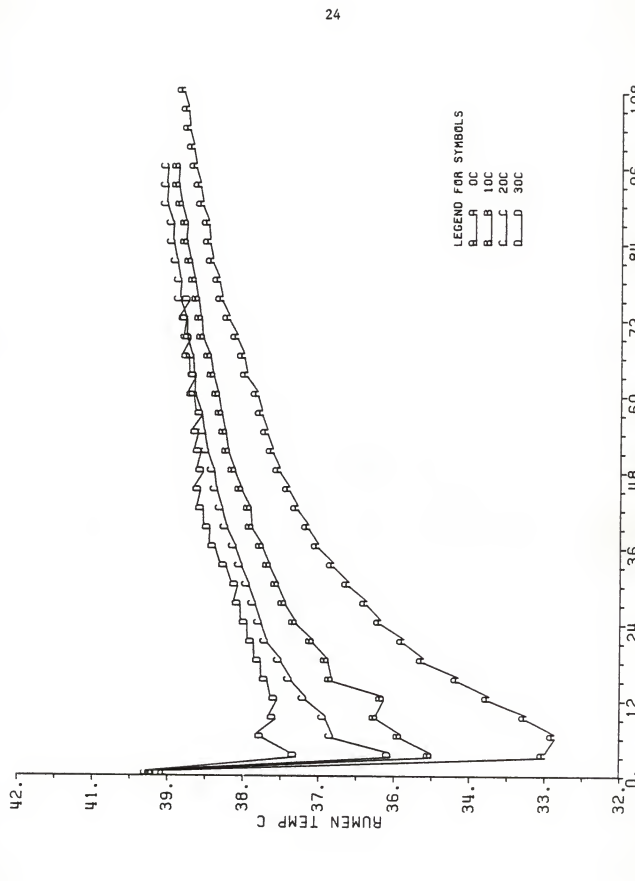

RUMEN TEMP C
42.
41.
39.
38.
37.
36.
34.
33.
32.
0.
12.
24.
36.
48.
60.
72.
84.
96.
108.
TIME (MIN)
LEGEND FOR SYMBOLS
A 0C
B 10C
C 20C
D 30C

TABLE 2. MEAN VALUES FOR RUMEN TEMPERATURE OVER TIME

Time (min)	Temperature			
	0	10	20	30
0	39.52	39.74	39.81	39.72
3	33.24	35.12	35.80	37.36
6	33.08	35.63	36.76	37.92
15	34.68	36.77	37.45	37.85
30	36.51	37.68	38.16	38.36
45	37.50	38.29	38.70	38.98
60	38.03	36.68	39.07	39.10
75	38.63	39.03	39.32	39.19
96	39.08	39.36	39.55	-
108	39.28	-	-	-

Nitrogen balance for the means of the four wethers is shown in Table 3. Temperature of the water had no significant effect on nitrogen intake, nitrogen retained, nitrogen retained as a percent of intake, or on nitrogen retained as a percent of absorption. There was, however, a significant effect ($P<.03$) within animals for nitrogen intake but the effect was not seen within animals for the other nitrogen factors.

Dry matter digestibility (Table 4), crude protein digestibility (Table 5), or crude fiber digestibility (Table 6) were not significantly effected by water temperature. There was a trend for the digestion coefficients to be lowest for the 0 C water treatment although the means were not significantly different as indicated by Duncan's Multiple Range Test (alpha = .05). Tests for significance were by the ANOVA program of SAS (Barr et al., 1976).

Cunningham et al. (1964) used a Latin-square design with dairy cows and reported similar results for the digestibility factors. As in this experiment, the temperature of the water did not significantly effect the digestion coefficients in Cunningham and co-worker's research.

Rumen Fermentation Study

Results for rumen pH are shown in Table 7 and Figure 9. From feeding to 2 hrs post-feeding, there was a sharp decline in pH for all water temperatures. The 0 C treatment reached a maximum pH depression (6.29) at 2 hrs then gradually increased. The pH for the 10 C treatment decreased until 3 hrs (6.19) then increased. The 20 C temperature resulted in maximum pH depression (6.17) at 4 hrs post-feeding while the lowest pH for the 30 C treatment (6.18) occurred at 3 and 4 hrs post-feeding.

TABLE 3. NITROGEN BALANCE

Item	Temperature, °C			
	0	10	20	30
N intake, g/day	50.61	50.64	52.13	49.70
Fecal N, g	19.83	18.84	18.99	18.37
Urinary N, g	20.91	20.65	21.81	21.82
N retained, g	9.85	9.10	11.51	9.49
N retained, % of I	20.20	17.42	20.55	18.72
N retained, % of A	32.85	27.56	33.26	29.35

TABLE 4. DRY MATTER DIGESTIBILITY[1]

Temperature	Animal				
	1	2	3	4	AVG
0	56.34	54.27	57.72	57.25	56.39
10	64.26	55.91	54.76	58.29	58.30
20	61.29	56.39	59.05	57.97	58.67
30	61.35	54.80	-	58.67	58.27

[1]Expressed as a %.

TABLE 5. CRUDE PROTEIN DIGESTIBILITY[1]

Temperature	Animal 1	2	3	4	AVG
0	62.32	55.89	59.08	62.01	59.82
10	69.49	62.82	60.35	60.17	63.20
20	65.22	61.39	64.87	62.20	63.42
30	66.48	60.44	-	62.08	63.00

[1]Expressed as a %.

TABLE 6. CRUDE FIBER DIGESTIBILITY[1]

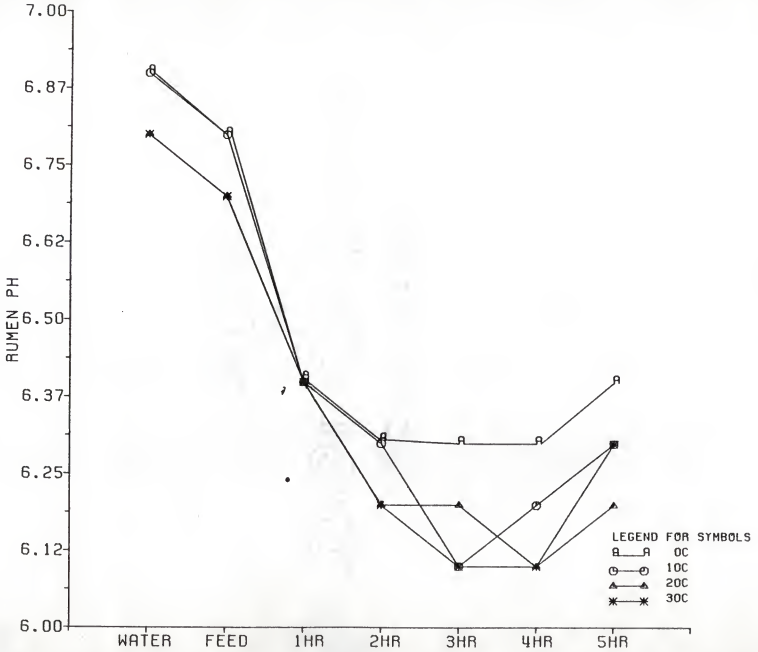
Temperature	Animal 1	2	3	4	AVG
0	38.65	36.54	34.74	47.77	39.43
10	49.06	37.80	33.62	39.23	39.93
20	45.77	39.54	43.53	41.87	42.68
30	46.28	36.08	-	41.41	41.26

[1]Expressed as a %.

TABLE 7. MEAN VALUES FOR RUMEN FLUID pH OVER TIME

Time	Temperature			
	0	10	20	30
Water	6.97	6.97	6.89	6.85
Feed	6.81	6.81	6.72	6.73
1 hr	6.47	6.47	6.41	6.42
2 hr	6.29	6.31	6.25	6.28
3 hr	6.30	6.19	6.22	6.18
4 hr	6.32	6.24	6.17	6.18
5 hr	6.42	6.33	6.25	6.34

Figure 9. Rumen pH over time in rumen fermentation study.


7.00
6.87
6.75
6.62
6.50
6.37
6.25
6.12
6.00
RUMEN PH
WATER
FEED
1HR
2HR
3HR
4HR
5HR
LEGEND FOR SYMBOLS
0C
10C
20C
30C

Results for the volatile fatty acids (VFA's) and ammonia-N are shown in Tables 8 and 9 and Figures 10 to 13. There was a general trend for the concentration means to increase slightly from watering to feeding then increase sharply to 1 hr post-feeding. From 1 hr to 4 hrs post-feeding, concentration separations occurred with increasing concentrations belonging to the higher water temperature treatments. Highest concentrations of VFA's and ammonia-N for the 0 C water temperature were obtained at 4 hrs post-feeding; and at 5 hrs post-feeding, the 0 C treatment was lowest in concentrations of ammonia-N and VFA's (except acetate). In contrast, the 30 C treatment had the highest concentrations of ammonia-N and VFA's (except butyrate and isobutyrate) at 5 hrs post-feeding.

There was a trend for the concentration means of the VFA's and ammonia-N over the entire sampling time to decrease as water temperature decreased, as shown in Table 10.

The data for the study were statistically analyzed by the ANOVA program of SAS (Barr et al., 1976). The water temperature had no significant effect on rumen pH at any one of the sampling time periods or of the mean of the entire sampling time. Likewise, VFA's and ammonia-N concentration were not significantly effected by water temperature at any one of the sampling times or of the mean of the entire sampling time. Although not significant, the data suggest an increasing suppression of microbial activity with decreasing water temperature. This is evident by the relatively lower concentrations of VFA's and ammonia-N and relatively higher pH values at post-feeding with the 0 C temperature compared to the 10, 20, or 30 C temperature

TABLE 8. MEAN VALUES FOR VFA's OVER TIME[1]

Temperature	Time	Acetate	Propionate	Isobutyrate	Butyrate	Valerate	Isovalerate
0	Water	31.40	9.73	0.74	5.56	0.34	0.69
0	Feed	35.43	11.44	0.85	6.11	0.53	0.83
0	1	62.09	23.04	1.10	9.63	1.21	1.40
0	2	84.25	29.52	1.19	11.95	1.35	1.32
0	3	77.03	31.62	1.27	12.95	1.53	1.31
0	4	85.13	34.91	1.48	15.07	1.91	1.57
0	5	82.87	33.40	1.36	14.67	1.55	1.36
10	Water	28.97	9.00	0.72	5.01	0.38	0.70
10	Feed	33.56	10.79	0.81	5.75	0.48	0.79
10	1	58.72	21.62	1.07	9.01	1.00	1.10
10	2	76.24	30.73	1.27	12.24	1.36	1.29
10	3	82.95	34.44	1.37	14.06	1.61	1.38
10	4	89.59	36.33	1.48	14.88	1.79	1.47
10	5	82.53	34.89	1.44	15.63	1.69	1.46
20	Water	32.98	10.34	0.80	5.89	0.45	0.77
20	Feed	35.17	11.78	0.81	5.91	0.50	0.66
20	1	64.79	25.48	1.14	10.37	1.29	1.27
20	2	77.55	32.24	1.39	13.01	1.65	1.40
20	3	84.56	34.52	1.39	14.80	1.75	1.50
20	4	89.98	36.39	1.50	16.29	1.80	1.54
20	5	91.40	36.55	1.58	17.06	1.95	1.67
30	Water	31.80	9.96	0.76	5.73	0.41	0.71
30	Feed	37.79	12.67	0.86	6.45	0.51	0.83
30	1	64.27	25.04	1.08	9.99	1.07	1.20
30	2	83.28	34.91	1.34	13.94	1.63	1.39
30	3	88.09	36.67	1.40	14.88	1.81	1.53
30	4	90.17	38.92	1.54	16.61	1.90	1.61
30	5	91.75	37.15	1.57	15.99	1.84	1.64

[1]All values expressed as μMoles/ml.

TABLE 9. MEAN VALUES FOR AMMONIA-N OVER TIME[1]

Time	Temperature			
	0	10	20	30
Water	70.59	55.96	68.91	52.03
Feed	83.70	71.92	52.98	90.34
1 hr	184.65	196.68	179.03	191.83
2 hr	222.25	210.88	191.10	249.56
3 hr	216.92	214.33	220.77	268.28
4 hr	232.68	224.22	266.13	230.20
5 hr	183.05	226.50	214.99	250.05

[1]Expressed as ppm.

Figure 10. Rumen acetate concentration over time in rumen fermentation study.

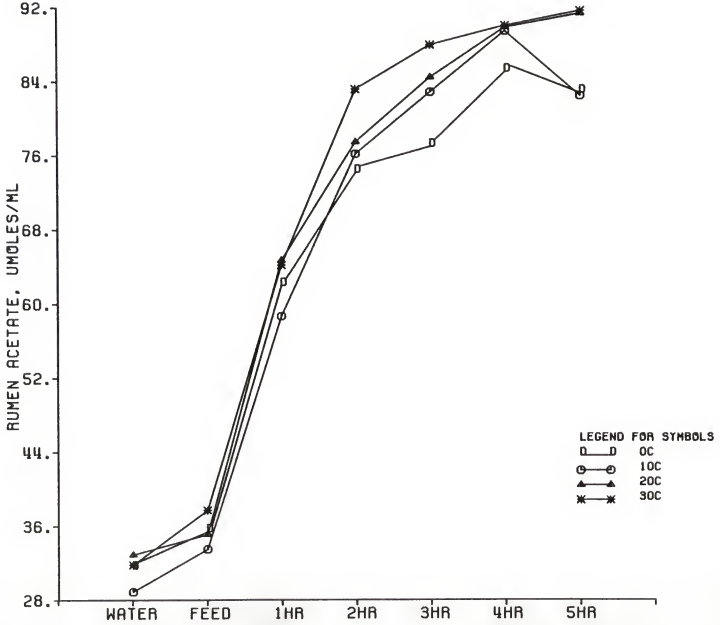

92.
84.
76.
68.
60.
52.
44.
36.
28.
RUMEN ACETATE, UMOLES/ML
WATER
FEED
1HR
2HR
3HR
4HR
5HR
LEGEND FOR SYMBOLS
0C
10C
20C
30C

Figure 11. Rumen propionate concentration over time in rumen fermentation study.

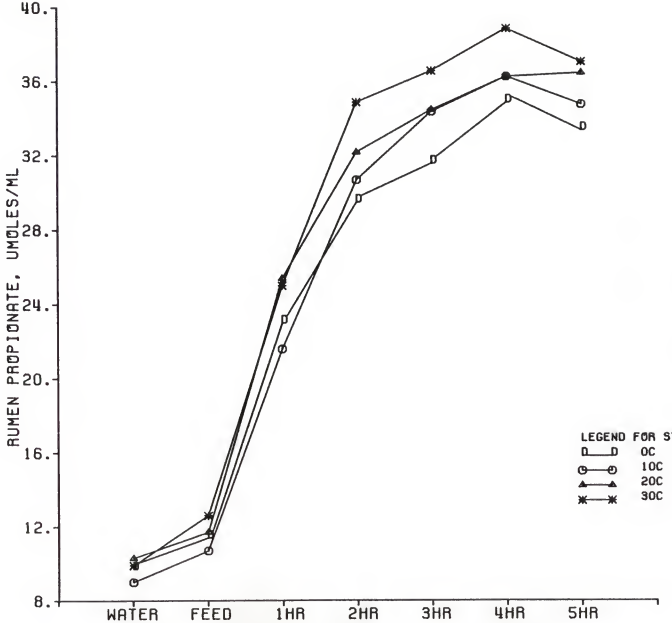

RUMEN PROPIONATE, UMOLES/ML
40.
36.
32.
28.
24.
20.
16.
12.
8.
WATER
FEED
1HR
2HR
3HR
4HR
5HR
LEGEND FOR SYMBOLS
0C
10C
20C
30C

Figure 12. Rumen butyrate concentration over time in rumen fermentation study.

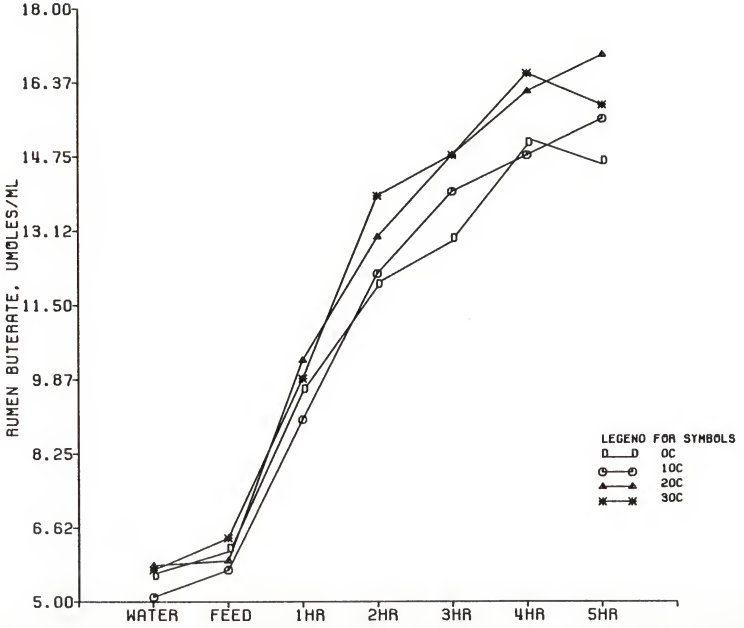

18.00
16.37
14.75
13.12
11.50
9.87
8.25
6.62
5.00
RUMEN BUTERATE, UMOLES/ML
WATER
FEED
1HR
2HR
3HR
4HR
5HR
LEGEND FOR SYMBOLS
0C
10C
20C
30C

Figure 13. Rumen ammonia-N concentration over time in rumen fermentation study.

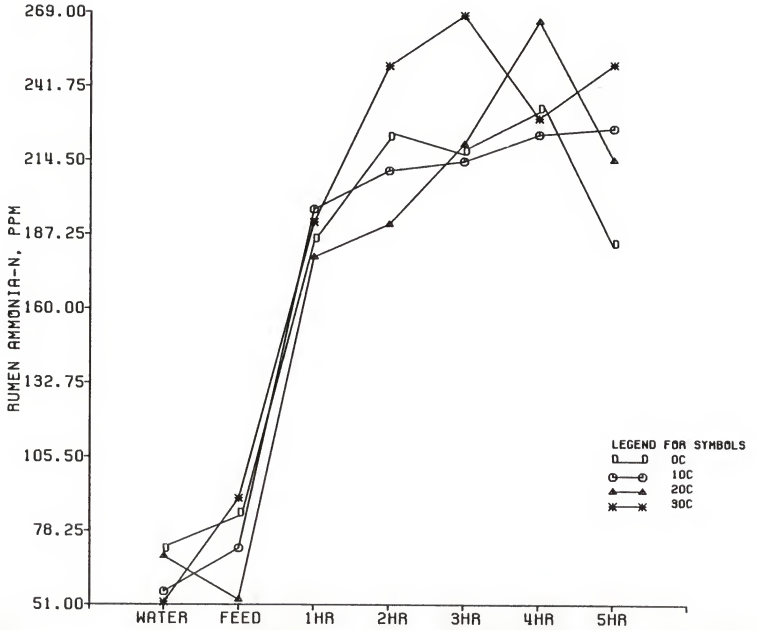

269.00
241.75
214.50
187.25
160.00
132.75
105.50
78.25
51.00
RUMEN AMMONIA-N, PPM
WATER
FEED
1HR
2HR
3HR
4HR
5HR
LEGEND FOR SYMBOLS
0C
10C
20C
30C

TABLE 10. MEAN VALUES FOR VFA's AND AMMONIA-N

VFA's	Temperature			
	0	10	20	30
Acetate[1]	64.03	64.65	68.08	69.33
Propionate[1]	24.81	25.40	26.73	27.83
Isobutyrate[1]	1.14	1.17	1.23	1.22
Butyrate[1]	10.85	10.95	11.92	11.92
Isovalerate[1]	1.21	1.17	1.28	1.27
Valerate[1]	1.25	1.23	1.39	1.35
Ammonia-N[2]	170.55	171.50	172.83	190.33

[1]Expressed as μMoles/ml.

[2]Expressed as ppm.

treatments. At 4 hrs post-feeding, the 0 C treatment had reached its maximum concentrations of all VFA's and ammonia-N, whereas not all of the VFA's or ammonia-N concentrations had reached a respective maximum for the 10, 20, or 30 C temperatures. When this is considered along with the general trend of the means of the entire sampling time of VFA's and ammonia-N concentrations to be lowest for the 0 C treatment, these data suggest that there is a depression of rumen fermentation from 0 C water.

SUMMARY

Research data on the effect of water temperature on the ruminant animal's metabolism is not conclusive and it was the intent of these three studies to examine the effect of water temperature on rumen temperature, digestion, and fermentation. Four, two-year-old wethers fitted with ruminal fistulas were used in a Latin-square design among four water temperature treatments: 0, 10, 20, and 30 C.

In the rumen temperature study, wethers received their respective water treatments via the fistula and rumen temperature was monitored from two thermistor probes; one in the ventral rumen sac, another in the mid-rumen. The ration was a dehydrated pelleted alfalfa. Rumen temperature was depressed the greatest by the 0 C water (6.44 C) followed by the 10 C (4.62 C), 20 C (4.01 C), and 30 C (2.36 C) water. Temperature was monitored until the rumen temperatures reached .5 C of the initial rumen temperature. For the 0, 10, 20, and 30 C water treatments, respectively, 108, 96, 96, and 72 min were needed to reach the initial temperature.

For the digestion study, a 5-day acclimation period of each wether to his respective water temperature treatment was followed by a 5-day total collection of feces and urine. The ration was pelleted alfalfa. Water temperature had no significant effect on nitrogen balance or percents dry matter digestibility (0 C, 56.4; 10 C, 58.3; 20 C, 58.7;

30 C, 58.3), crude protein digestibility (0 C, 59.8; 10 C, 63.2; 20 C, 63.4; 30 C, 63.0), and crude fiber digestibility (0 C, 39.4; 10 C, 39.9; 20 C, 42.7; 30 C, 41.3) although lowest digestion coefficients were observed for the 0 C treatment.

In the rumen fermentation study, using chopped alfalfa hay, samples were collected at prefeeding (after the water had been given via the fistula) and at hourly intervals from 0 to 5 hours post-feeding. Samples were immediately recorded for pH, transferred to glass vials to which mecuric chloride was added to prevent artifact ammonia formation, and frozen. Samples were later analyzed for ammonia-N and concentrations of individual volatile fatty acids (VFA's). Water temperature had no significant effect on rumen pH, but pH reached a maximum depression at 2 hrs post-feeding for the 0 C water (6.29), 3 hrs for the 10 C water (6.19), and 4 hrs for both the 20 C (6.17) and 30 C (6.18) water treatments. Although numerical differences were observed, water temperature had no significant effect on VFA or ammonia-N concentrations in the rumen. The VFA's and ammonia-N were characterized over time by increasing concentrations from 1 to 4 hrs post-feeding as the water temperature increased, for all temperature treatments. At 4 hrs post-feeding, the 0 C water treatment had reached its maximum concentrations of all VFA's and ammonia-N, whereas not all of the VFA's or ammonia-N concentrations had reached a respective maximum for the 10, 20, or 30 C water temperatures. At 5 hrs post-feeding, the 0 C water treatment was the lowest of the four water treatments in concentrations of ammonia-N and VFA's (except acetate).

Overall, water temperature had no significant effect on digestion or rumen fermentation in these studies. A possible reason for the non-significance would be low sampling numbers and large variations. In most of the rumen fermentation study analysis, there was a significant ($P<.10$) difference within sheep at each time period. This, accompanied by a low number of samples, most likely was a cause for the non-significant results. This statement is justified by the theory that if the variation within a trial is constant and if the sample size increases, the significance will increase. A possible way to alleviate this would be to use more animals and, instead of using a Latin-square, experiment on each animal as an individual thereby eliminating any hidden animal interactions.

At 5 hrs post-feeding the concentrations of the VFA's and ammonia-N from the 0 C treatment were declining and the concentrations from the 30 C treatment were still increasing, suggesting depressed microbial activity from the 0 C water. If, in fact, there was a significant effect on fermentation from the water temperatures, especially from the 0 C treatment, it would seem likely that there were compensatory effects as indicated by the non-significant effect of the treatments on the digestion factors. Should this be the case, it is possible that it would be advantageous to heat the water to 30 C thereby having essentially no depression of fermentation and virtually no energy loss to heat the water. The energy required to raise 0 C water to body temperature is about 78 kcal/2 l water, a relatively small expenditure to the animal. So the final choice is between "feed or fuel" to heat the water.

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THE EFFECT OF WATER TEMPERATURE ON RUMEN TEMPERATURE, DIGESTION, AND RUMEN FERMENTATION IN SHEEP

by

DANIEL LOUIS BROD

B.S., Kansas State University, 1977

AN ABSTRACT OF A MASTER'S THESIS

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Manhattan, Kansas

1979

Water is the single most abundant nutrient in the adult mammal, comprising some 60% of the total body mass. Its role in metabolism and related bodily functions has been well documented. The only variation that occurs among pure, clean water is its temperature; however, research data on the effect of water temperature on the ruminant animal's metabolism are not conclusive. The intent of these three studies was to examine the effect of water temperature on rumen temperature, digestion, and fermentation. Four, two-year-old wethers fitted with ruminal fistulas were used in a Latin-square design among four water temperature treatments: 0, 10, 20, and 30 C.

In the rumen temperature study, wethers received their respective water treatments via the fistula and rumen temperature was monitored from two thermistor probes; one in the ventral rumen sac, another in the mid-rumen. The ration was a dehydrated pelleted alfalfa. Rumen temperature was depressed the greatest by the 0 C water (6.44 C) followed by the 10 C (4.62 C), 20 C (4.01 C), and 30 C (2.36 C) water. Temperature was monitored until the rumen temperature reached .5 C of the initial rumen temperature. For the 0, 10, 20, and 30 C water treatments, respectively, 108, 96, 96 and 72 min were needed to reach initial temperature.

For the digestion study a 5-day acclimation period of each wether to water temperature treatments was followed by a 5-day total collection of feces and urine. The ration was pelleted alfalfa. Water temperature had no significant effect on nitrogen balance or percents dry matter digestibility (0 C, 56.4; 10 C, 58.3; 20 C, 58.7; 30 C, 58.3), crude protein digestibility (0 C, 59.8; 10 C, 63.2; 20 C, 63.4;

30 C, 63.0) and crude fiber digestibility (0 C, 39.4; 10 C, 39.9; 20 C, 42.7; 30 C, 41.3) although lowest digestion coefficients were observed for the 0 C treatment.

In the rumen fermentation study, using chopped alfalfa hay, samples were collected at prefeeding (after the water had been given via the fistula) and at hourly intervals from 0 to 5 hrs post-feeding. Samples were immediately recorded for pH, transferred to glass vials to which mercuric chloride was added to prevent artifact ammonia formation, and frozen. Samples were later analyzed for ammonia-N and concentrations of individual volatile fatty acids (VFA's). Water temperature had no significant effect on rumen pH, but pH reached a maximum depression at 2 hrs post-feeding for the 0 C water (6.29), 3 hrs for the 10 C water (6.19), and 4 hrs for both the 20 C (6.17) and 30 C (6.18) water treatments. Although numerical differences were observed, water temperature had no significant effect on VFA or ammonia-N concentrations in the rumen. The VFA's and ammonia-N were characterized over time by increasing concentrations from 1 to 4 hrs post-feeding as the water temperature increased, for all temperature treatments. At 4 hrs post-feeding, the 0 C water treatment had reached maximum concentrations of all VFA's and ammonia-N, whereas not all of the VFA's or ammonia-N concentrations had reached respective maximums for the 10, 20, or 30 C water treatments. At 5 hrs post-feeding, the 0 C water was the lowest of the four water treatments in concentrations of ammonia-N and VFA's (except acetate).

Overall, water temperature had no significant effect on digestion or rumen fermentation in the three studies. These data, however, indicate a supression of microbial activity in the rumen with 0 C water.