CHAPTER IV

THE EFFECT OF SODIUM CHLORIDE ON THE OESOPHAGEAL GROOVE REFLEX

SUMMARY

Flow rates and volumes of rumen fluid were measured in Merino sheep, Angora goats and castrated males of Australian feral goats fed *ad libitum* on a mixed chaff diet (50% lucerne chaff and 50% oaten chaff). Fresh water was available *ad libitum*. The aim of the study was to clarify the extent to which oesophageal groove closure occurs when animals are given drinking water containing 1.35% salt. The soluble marker, CrEDTA, was administered orally and intraruminally.

Feed and water intakes of the animals on oral and intraruminal routes were not different. The results revealed that 15 to 25 % of the marker administered orally bypassed the rumen, which caused an overestimate on the flow rates and volumes of rumen fluid measured by oral dosing.

INTRODUCTION

Studies on the closure of the oesophageal groove in young and adult ruminants have intrigued a number of researchers for many years. Several substances have been shown to elicit closure of the groove. Solutions containing sodium bicarbonate, sodium chloride, copper sulphate or barium sulphate administered orally were reported to stimulate the closure in adult ruminants (sheep and cattle) with different degrees of response (Ross, 1931; Watson, 1941; Riek, 1954).

Concerning sodium chloride in drinking water, Tomas and Potter (1975) considered that some amounts of fluid may bypass the reticulorumen during drinking and directly enter the omasum. The purpose of the present study was to determine the amount of salt water bypassing the reticulorumen in sheep and goats. It is hypothesised that 1.35% sodium chloride would not influence the bypass of orally administerd marker.

MATERIALS AND METHODS

Animals

Five Merino ewes, 5 Angora does and 5 castrated males of Australian feral goats were used. All animals were freshly shorn. They were fitted with permanent rubber rumen cannulae 2 months earlier (Godwin and Chaffey, 1988), and they were held in individual pens for 2 weeks before the commencement the experiment. Mean body weights were 34.3 ± 2.9, 28.6 ± 2.8 and 31.1 ± 2.1 kg for Merino, Angora and feral goats respectively, and the ages varied between 2 - 3 years. They were fed a mixed roughage diet consisting of 50% lucerne and 50% oaten hay chaff *ad libitum*, and fresh water was offered freely.

Procedure

The marker solution, CrEDTA, was prepared in accordance with the procedure of Binnerts, et al (1968). Sodium hydroxide was used to neutralise the solution. The concentration of the sodium in the solution was 235 mmol/l (≈ 1.35% NaCl w/v)

Marker administration and rumen sampling: A dose of 100 ml of marker solution, CrEDTA complex (Binnerts, et al. 1968), was administered by 2 different routes; intra-ruminally by a syringe and orally with a drenching gun, with 14 days between treatments. Serial rumen fluid samples of ≈ 50 ml were obtained at 0, 2, 4, 6, 8, 10 and 24 h after dosing. Samples were treated as in Chapter 3.

Chemical analysis : Chromium concentration in the rumen fluid was determined by the same method as described in Chapter 3.

Statistical analysis

The experiment was based on 3 x 2 factorial design with repeated measurement, 3 ruminant species and 2 administration routes (Wilkinson, 1990). The mean values were tested according to the Newman-Keuls procedures (Winer, 1971).

RESULTS

Treatment means with standard errors and statistical significances of main effects are shown in Table 4.1. Dry matter intake (g/kg$^{0.75}$W/d) and ingested water (ml/kg$^{0.82}$W/d) were not significantly different at the times of marker administration in the Merino, Angora or feral goats. The volume and flow rates of rumen fluid calculated after oral dosing were significantly higher than those after intra-ruminal dosing. Mean percentages of overestimates of volumes and flow rates of rumen fluid were 23.9 and 24.4, 17.2 and 18.4, 22.4 and 23.9 in Merino, Angora and feral goats respectively. When dilution rates were expressed as percentages of rumen fluid volume per hour, there were no significant differences between the two routes.

Table 4.1. Feed and water intakes, and rumen dynamics in Merino sheep, Angora and Feral goats calculated from different routes of Cr-EDTA administration

Parameters	Methods	Animals		
		Merino Sheep n=5	Angora Goat n=5	Feral Goat n=5
Dry matter intake (g/kg $W^{0.75}$/d)	Ruminally	48.1 ± 1.8 a	65.7 ± 2.1 b	50.8 ± 2.2 a
	Orally	49.4 ± 2.7 a	65.1 ± 4.3 b	50.8 ± 3.1 a
	R Vs. O	ns	ns	ns
Ingested water (g/kg $W^{0.82}$/d)	Ruminally	96.4 ± 5.5 a	89.5 ± 2.8 b	60.9 ± 2.5 c
	Orally	96.9 ± 5.3 a	89.2 ± 2.2 b	60.8 ± 2.9 c
	R Vs. O	ns	ns	ns
Rumen fluid volume (ml/kg $W^{0.82}$)	Ruminally	262.7 ± 9.4 a	249.1 ± 7.6 b	253.0 ± 5.5 b
	Orally	325.4 ± 6.5 a	291.9 ± 7.4 b	309.7 ± 6.0 c
	R Vs. O	**	**	**
	% diff.	23.9 ± 2.0	17.2 ± 1.8	22.41 ± 0.66
Rumen fluid volume (% W)	Ruminally	13.9 ± 0.6 a	13.6 ± 0.6 b	13.7 ± 0.3 b
	Orally	17.2 ± 0.5 a	16.0 ± 0.7 b	16.7 ± 0.4 c
	R Vs. O	**	**	**
Flow rate of rumen fluid (ml/kg $W^{0.82}$/h)	Ruminally	23.7 ± 0.9 a	23.0 ± 1.2 b	21.9 ± 0.6 c
	Orally	29.5 ± 1.0 a	27.2 ± 1.5 b	27.1 ± 0.8 b
	R Vs. O	**	**	**
	% diff.	24.4 ± 2.1	18.4 ± 2.5	23.9 ± 1.8
Flow rate of rumen fluid (% rum.vol/h)	Ruminally	9.0 ± 0.1 a	9.2 ± 0.4 b	8.6 ± 0.4 c
	Orally	9.1 ± 0.3 a	9.3 ± 0.5 b	8.8 ± 0.4 c
	R Vs. O	ns	ns	ns

Mean values on the same row with different subscripts are significantly different (P< 0.05)
Mean values in the same cell (Rum Vs. Or) :
**** = differ significantly at level P< 0.01**
ns = non-significant

DISCUSSION

The result of this experiment indicates that some of the orally administered marker bypasses the reticulorumen, and hence the values of volume (ml/kg $W^{0.82}$) and flow rate of rumen fluid (ml/kg $W^{0.82}$/h) were overestimated. Mackintosh (1985) used two soluble markers, CrEDTA administered into the oral cavity and CoEDTA directly into the rumen, and reported a similar overestimate for the oral route in sheep.

Marker can bypass the reticulorumen following the closure of the oesophageal groove. The groove, which is bounded by two well-developed lips, extends from the cardia orifice directly to the reticular-omasal orifice (Church,1969), thus preventing swallowed fluid entering the reticulorumen.

It is generally agreed that the closure mechanism of the oesophageal groove is a reflex response, and the reflex is perfectly functional in young ruminants in response to milk, but as the animals grow older, the reflex weakens. However, some substances have been examined which elicit the reflex in adult ruminants. Titchen and Newhook (1975) indicated that the groove reflex operates before, during and after development of fermentative digestion in the rumen-reticulum. Weston (1944) using barium sulphate solution deduced sufficient evidence that the regions from which functional activity of the groove was elicited by mechanical stimulation were situated in the mouth or the pharynx, or both; and that the functional activity occurred as a reflex response to excitation of receptors in the mucous membranes of these regions.

Wester (1930 cited by Ruckesbusch, 1980) found that although in 2 year old cattle the reflex sensitivity for milk is diminished, strong sodium chloride solution (0.5 to 1%) elicited a vigorous reflex response. In sheep, Ross (1931) demonstrated that 2% copper sulphate solution was more effective than 1 - 2% sodium chloride solution in evoking the reflex. This result was confirmed by Reid and Titchen (1985) using an electromyographic

technique to indicate the response. Moreover, Reid, Post and Titchen (1991) emphasised the probable importance of taste in the activation of the reticular groove mechanism.

Sodium concentration in the marker solution used in the present study was 235 mmol/l or about equal to 1.35 % sodium chloride. Apparently this concentration stimulated neuroreceptors in the mouth or pharynx that to some extent resulted in the closure of the groove.

Mikhail, Brugère, Bars and Colvin (1988) reported that the closure of the oesophageal groove in dehydrated adult goats was observed during drinking, and this response was attributed to the alteration in plasma osmolarity which then stimulated antidiuretic hormone (ADH) release. In cattle, the contraction of the groove is triggered by vasopressin (Scholz, 1990). Concerning the present results, therefore, it is relevant to note that possible osmotic dehydration resulting from drinking salt water by sheep or goats will induce the closure of the groove to some extent.

There appeared to be little difference in the overall determination of the rumen fluid parameters when comparing sheep and goats under the conditions of this experiment, although the actual values differed quite significantly between the species.

Clearly the hypothesis outlined in the introduction was not supported by the experiment and in fact substantial marker bypassed the rumen when given with 1.35% NaCl.

CHAPTER V

A COMPARATIVE STUDY OF FEED AND SALT WATER INTAKES, AND ITS EFFECTS ON DIGESTION IN MERINO SHEEP AND ANGORA GOATS

SUMMARY

Three Merino ewes and three Angora does fitted with permanent rumen cannulae were fed oaten, lucerne and mixed chaff in random order. Fresh water was offered first, and followed by 1.35% salt water for each diet to each animal. Food and water were offered *ad libitum*. Daily intakes of water, salt and organic matter, daily urine and faeces were measured to determine apparent digestibility, absorption, water and sodium excretion. Dynamics of rumen fluid (volume and flow rate) were measured by CrEDTA disappearance.

The intakes of salt water (ml/kg $W^{0.82}$/d) by the sheep were significantly higher than fresh water regardless of diet, and they were markedly higher when compared to the intakes of the goats.

The organic matter intakes (g/kg $W^{0.75}$/d) of oaten and mixed chaff of the sheep and goats were decreased by drinking salt water; the decrease being greater in the sheep than in the goats. However, the organic matter intakes of lucerne chaff by the sheep increased with saline drinking, and for the goats it was decreased.

Organic matter digestibility (OMD) in the sheep and goats fed any of the current roughages were not significantly different. However, the effect of drinking salt water was to decrease OMD in the sheep fed oaten chaff, and the goats fed lucerne chaff.

Rumen fluid volume (ml/kg $W^{0.82}$) in the sheep and goats fed oaten chaff were significantly greater compared to those when mixed or lucerne chaff was fed. There was no significant effect of drinking salt water when either species was fed oaten chaff. Drinking salt water increased the volume in the sheep fed mixed or lucerne chaff, but the volume in the goats fed these roughages were not significantly affected.

There were positive relationships between ingested water and flow rate of rumen fluid in the sheep ($y = 16.11 + 0.08 x$; $r = + 0.93$) and in the goats ($y = 17.35 + 0.04 x$; $r = + 0.32$), but the relationship in the goats was not significant.

There were no significant effects of species, diets or drinking water on the proportions of water loss through urination (45-50%), defaecation (15-20%) and evaporation (35-40%).

INTRODUCTION

Although there have been considerable studies concerning species differences between sheep and goats in their feeding behaviour and digestive efficiency, all of these comparative studies have been conducted with animal given fresh water. Some differences between sheep and goats in their responses to an intraruminal salt infusion were found in the previous study (Chapter III). In this previous study, the animals freely adjusted the intake of fresh water in accord with the level of salt load.

Wilson and Dudzinski (1973) studied the effects of saline drinking water on sheep. They examined the differences in taste in addition to the differences in the tolerance of the animals to water salinity. The differences in physico-chemical characteristics between forages, for example, between oaten and lucerne chaff, to some extent are responsible for the intake and digestibility (Van Soest, 1975).

The present study, therefore, was undertaken to examine the combined effects of offering salt water to sheep and goats fed oaten, lucerne and mixed chaff. This experiment examines the combined effects of foods with different digestibilities and ingestion of drinking water that contains considerable salt. Compared to the studies in chapter 3, the animals in this study could not adjust their water intake without a concomitant adjustment in their salt intake.

It is hypothesised that provision of drinking water containing 1.35% NaCl would have no effect on the intake of food, its digestibility or on rumen fluid dynamics in sheep or goats.

MATERIALS AND METHODS

Design and technique of experiment

The experiment was based on a duplicated 3 x 2 Latin Square design (3 diets and 2 drinking waters) with repeated measurement. There were 6 measurement periods of 18 d. Each period consisted of 10 d for adjustment time, and followed by an 8 d collection time.

Three roughages were used in the study: 100% of oaten chaff , mixed chaff (50% of oaten and 50% of lucerne chaff), 100% of lucerne chaff. Three Merino ewes and three Angora does were fitted with rumen cannulae and fed *ad libitum* each diet in random order. Fresh water was offered firstly, and followed by 1.35% salt water on each diet. The drinking water (fresh or salt water) was freely available. The study was conducted in a room with thermoneutral condition (20-25°C / 40-45% rh).

The body weights of the animals were monitored on the first, tenth and last day of each period. The bladders were catheterised on day ten with the same technique as described previously in Chapter 3. A day before catheterising, a dose of penicillin-streptomycin (Pen-Strep, 2 ml/50 kg W containing 200 mg procaine benzylpenicillin/ml and 250 mg dihydrostreptomycin/ml) (Norbrook Laboratories, U.K.) and a dose of terramycin (1 ml/10 kg W containing 200 mg oxytetracycline/ml) (Pfizer Agricare Pyt.Ltd, NSW Australia) was intra-muscularly injected. A dose of Penstrep was repeated daily, and terramycin was repeated every third day until the catheters were removed.

Total faecal and urine output (balance trial) were collected daily for 7 days, and followed by determination of volume and flow rate of rumen fluid for 2 days using CrEDTA disappearance as described in Chapter III.

The samples of food, faeces, urine and rumen fluid were prepared and analysed with the same methods and techniques as described in Chapter III.

Total water influx was calculated by adding ingested water (drinking water + free water in food) and metabolic water. Metabolic water was calculated by assuming 0.56 g water per g digestible organic matter (Degen and Kam, 1991).

Statistical analysis

Data were analysed by a repeated measures analysis of variance as a duplicated 3 x 3 Latin Square design according to Wilkinson (1990). The Newman-Keuls procedure (Winer, 1971) was applied to test differences between all possible pairs of mean values.

RESULTS

Body weights and intakes of food, water and sodium (Table 5.1)

The body weights of the sheep and goats were not affected by any of the treatments. The body weights of the goats were about 65% of that of the sheep.

The organic matter intake of oaten and mixed chaff by the sheep and goats was decreased by drinking salt water. The decrease was greater in the sheep compared to the goats. However, drinking salt water increased the organic matter intake of lucerne chaff by the sheep, but decreased the intake by the goats.

The intake of salt water by the sheep was higher than the intake of fresh water regardless of diet. The intake of salt water compared to fresh water by the goats varied

with different diets: No differences when oaten chaff was fed; greater when mixed chaff was fed; and lower when lucerne chaff was fed. In addition the intakes of salt water by the goats fed any diet were significantly lower than the intakes by the sheep. Consequently, the sodium intake was significantly higher for the sheep. However, there were no significant differences in sodium intake between the species when fresh water was drunk.

Digestibility, absorption and rumen fluid dynamics (Table 5.2)

Organic matter digestibility of the three diets in the sheep and goats were not significantly different either when fresh or salt water was drunk. Interestingly, the effect of drinking salt water was to decrease the digestibility in the sheep fed oaten chaff, while in the goats this occurred when lucerne chaff was fed. There was no significant effect of salt water when the mixed diet was offered to both species, although the trend was to increase in the sheep and to decrease in the goats.

The calculated digestible energy for both species fed any diet was significantly decreased with saline water except when the sheep were fed lucerne chaff. When saline water was presented the oaten chaff and lucerne chaff provided the lowest digestible energy intake for the sheep and goats respectively. This low intake was still apparently sufficient to maintain their body weights.

Sodium digestibility and water absorption were not significantly different between the species, and they were not significantly affected by the different diets. However, drinking salt water increased the digestibility and absorption to the same extent in both species.

Rumen fluid volumes (ml/kg $W^{0.82}$) in the sheep drinking fresh or salt water and fed any diet were significantly greater than those in the goats, but when the volumes are expressed as percentage of body weight, there are no significant differences between sheep and goats. The volumes in the sheep and goats fed oaten chaff were greater compared with the other two diets, and there was no significant effect of drinking salt

water with this diet for either species. In the sheep fed mixed or lucerne chaff, drinking salt water increased the volumes significantly to about the same extent as when oaten chaff was fed. In the goats fed mixed or lucerne chaff, however, the volumes were not significantly affected by drinking salt water.

The flow rates of rumen fluid (ml/kg $W^{0.82}$/h) in the sheep fed oaten, mixed or lucerne chaff were significantly increased by drinking salt water. In the goats, however, the effects of drinking salt water on flow rate varied with different diets: No significant effect when oaten chaff was fed; significant increase when mixed chaff was fed; and significant decrease when lucerne chaff was fed. The flow rates in the sheep fed any diet were significantly faster than in the goats either when fresh or salt water was drunk.

The relative contribution of ingested water to the flow rate of rumen fluid in the sheep was increased by drinking salt water, while in the goats it was relatively unchanged, except when lucerne chaff was fed, the flow rate was slower. The relationships between ingested water and flow rates of rumen fluid in the sheep and goats are shown in Figure 5.1.

Total water influx and its distribution (Table 5.3 and Figure 5.2)

Total water influx in the sheep and goats followed the trend of ingested water, since only 10-15% of the influx water was contributed by metabolism calculated from digestible organic matter (Figure 5.2)

Urinary, faecal and insensible water losses (ml/kg $W^{0.82}$/d) from the sheep fed mixed or lucerne chaff were significantly increased by drinking salt water. However, the effect of drinking salt water on the losses from the goats varied with different diets: Urinary, faecal and insensible water losses from the goats fed oaten chaff were not significantly affected; with mixed chaff, urinary and insensible losses increased, while faecal loss was not significantly affected; with lucerne chaff, the losses through these three routes were significantly decreased which accompanied the decrease in the influx of water.

Concerning the relative importance of each route in water loss, the results indicated that there were no significant effects of different species, diets or drinking salt water. The values for urinary, faecal and insensible losses varied from 45 to 50, 15 to 20 and 30 to 35% of the total influx water for sheep and goats respectively.

Urinary and faecal sodium excretion (Table 5.4)

Sodium concentration in the urine (mmol/l) and faecal water concentration in the sheep and goats were increased significantly by drinking salt water. The relative importance of urination in sodium excretion from the sheep and goats was increased by drinking salt water. On the other hand, the percentage of sodium intake excreted through defaecation decreased significantly.

Positive balances of sodium were measured for both sheep and goats for all diets and these were increased by drinking salt water.

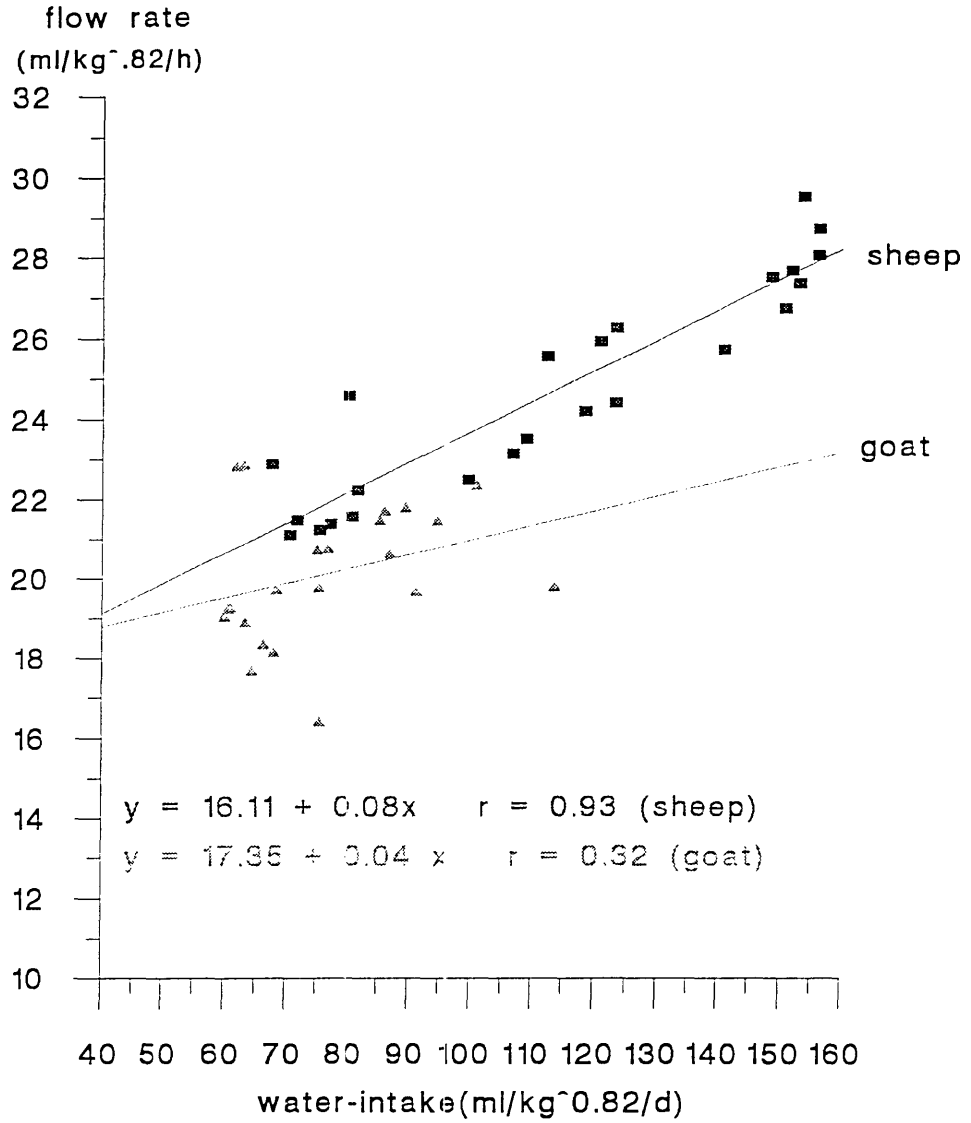

Figure 5.1. Relationship between water intake (x) and flow rate of rumen fluid (y) in sheep and goats

Lines significantly different for slope ($P<0.05$)

Each point is the mean value for three animals

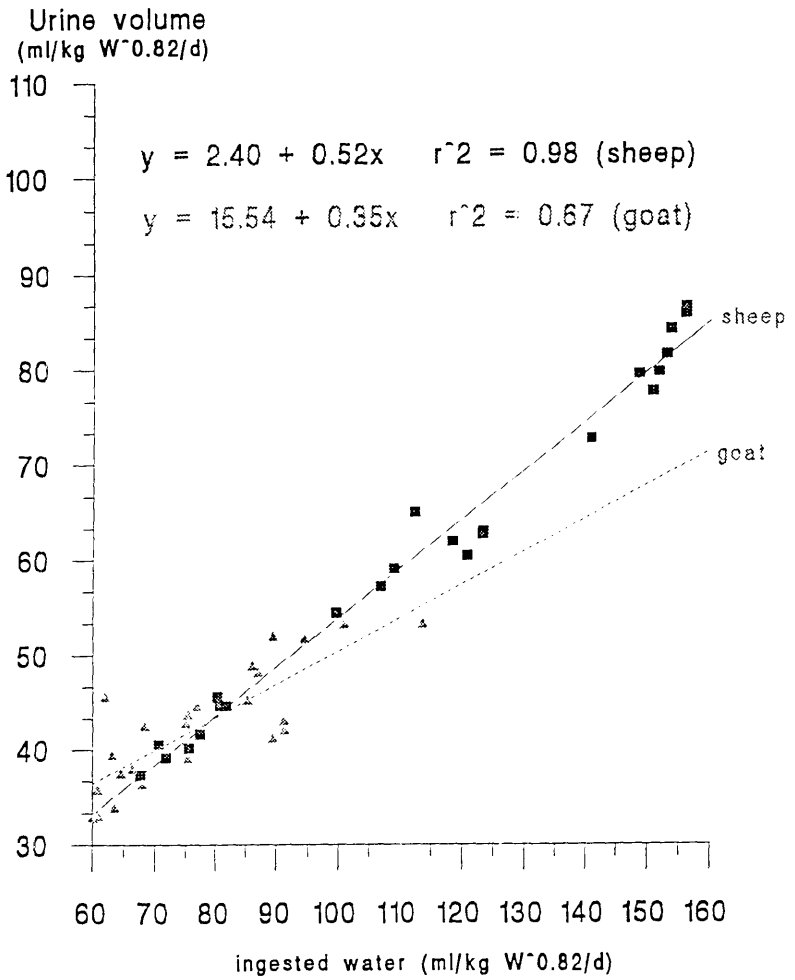

Figure 5.2. Relationship between ingested water (x) and urine volume (y) in sheep and goats

Each point is the mean value for three animals

Table 5.1. Mean values of body weights and intakes of food, water and sodium

PARAMETERS		Oaten chaff		Mixed chaff		Lucerne chaff	
		Fresh	Salt	Fresh	Salt	Fresh	Salt
Body weight (kg)	Sheep	47.8 ± 1.0 ^{a}	45.7 ± 4.7 ^{a}	49.0 ± 1.5 ^{a}	48.4 ± 2.8 ^{a}	48.4 ± 2.5 ^{a}	47.8 ± 2.4 ^{a}
	Goat	30.7 ± 1.4 ^{a}	30.8 ± 1.0 ^{a}	31.2 ± 1.3 ^{a}	31.5 ± 2.1 ^{a}	31.3 ± 0.8 ^{a}	30.5 ± 0.8 ^{a}
	S vs G	**	**	**	**	**	**
Organic matter intake	Sheep	28.1 ± 1.3 ^{a}	23.8 ± 0.5 ^{b}	45.0 ± 1.7 ^{a}	37.6 ± 1.9 ^{d}	34.0 ± 1.5 ^{d}	41.6 ± 0.9 ^{c}
(g/kg $W^{0.75}$/d)	Goat	32.4 ± 5.4 ^{ac}	29.1 ± 6.8 ^{a}	39.6 ± 4.5 ^{b}	34.5 ± 2.0 ^{c}	33.9 ± 4.0 ^{c}	22.0 ± 4.1 ^{d}
	S vs G	ns	**	**	ns	ns	**
Ingested water	Sheep	71.4 ± 3.3 ^{a}	121.4 ± 2.3 ^{b}	106.9 ± 5.4 ^{c}	149.0 ± 6.3 ^{d}	80.0 ± 1.9 ^{a}	153.5 ± 1.8 ^{d}
(ml/kg $W^{0.82}$/d)	Goat	68.4 ± 5.1 ^{ac}	74.6 ± 9.4 ^{a}	75.1 ± 9.7 ^{a}	92.5 ± 6.7 ^{b}	84.7 ± 5.8 ^{b}	61.6 ± 2.0 ^{c}
	S vs G	ns	**	**	**	ns	**
Ingested water	Sheep	317.3 ± 15.3 ^{a}	635.1 ± 20.9 ^{b}	291.0 ± 8.3 ^{a}	486.1 ± 13.2 ^{c}	281.9 ± 4.3 ^{a}	441.1 ± 6.4 ^{c}
(ml/100 g dmi/d)	Goat	260.2 ± 43.2 ^{ab}	314.6 ± 35.9 ^{ac}	225.7 ± 27.9 ^{b}	319.2 ± 18.6 ^{c}	294.9 ± 50.9 ^{a}	333.9 ± 56.3 ^{c}
	S vs G	ns	**	**	**	ns	**
Sodium intake	Sheep	2.5 ± 0.1 ^{a}	33.9 ± 0.6 ^{b}	4.2 ± 0.2 ^{a}	42.6 ± 1.8 ^{c}	3.4 ± 0.1 ^{a}	44.4 ± 0.6 ^{c}
(mmol/kg $W^{0.82}$/d)	Goat	2.8 ± 0.4 ^{a}	22.1 ± 3.1 ^{b}	3.5 ± 0.1 ^{a}	27.5 ± 1.9 ^{c}	3.2 ± 0.4 ^{a}	18.4 ± 0.8 ^{d}
	S vs G	ns	**	ns	**	ns	**

notes :

Mean values on the same row with different superscript are significantly different (P<0.05)

Mean values in the same column of each parameter (S vs G) :

* = differ significantly at level P < 0.05

** = differ significantly at level P < 0.01

ns = non significant

n = 3 sheep and 3 goats

Table 5.2. Mean values of digestibility, absorption and rumen fluid dynamics

PARAMETERS		Oaten chaff		Mixed chaff		Lucerne chaff	
		Fresh	Salt	Fresh	Salt	Fresh	Salt
App.org.mat.digestibility	Sheep	61.8 ± 0.9 ^{a}	56.2 ± 2.6 ^{b}	61.6 ± 1.9 ^{a}	63.7 ± 1.4 ^{a}	59.4 ± 4.4 ^{a}	62.0 ± 1.6 ^{a}
(%)	Goat	58.4 ± 3.0 ^{a}	55.0 ± 4.9 ^{a}	63.5 ± 2.8 ^{b}	59.5 ± 6.8 ^{ab}	63.6 ± 0.5 ^{b}	58.2 ± 3.1 ^{a}
	S vs G	ns	ns	ns	ns	ns	ns
Est.digestible energy	Sheep	330.2 ± 20.1 ^{a}	254.0 ± 9.8 ^{b}	527.2 ± 27.6 ^{c}	455.3 ± 30.5 ^{d}	383.3 ± 26.3 ^{a}	490.0 ± 16.4 ^{d}
(kJ/kg $W^{0.75}$/d)	Goat	361.5 ± 39.9 ^{a}	300.6 ± 44.8 ^{b}	477.6 ± 34.4 ^{c}	388.8 ± 29.6 ^{d}	408.8 ± 45.0 ^{d}	242.2 ± 38.4 ^{e}
	S vs G	ns	ns	ns	*	ns	**
App.Na digestibility	Sheep	78.3 ± 1.6 ^{a}	93.7 ± 0.6 ^{b}	78.4 ± 0.9 ^{a}	93.2 ± 0.6 ^{b}	78.9 ± 1.0 ^{a}	93.7 ± 1.0 ^{b}
(%)	Goat	78.5 ± 1.2 ^{a}	93.6 ± 0.7 ^{b}	78.6 ± 2.4 ^{a}	93.8 ± 0.6 ^{b}	79.2 ± 0.8 ^{a}	94.4 ± 0.6 ^{b}
	S vs G	ns	ns	ns	ns	ns	ns
App.water absorption	Sheep	80.9 ± 0.9 ^{a}	84.4 ± 0.4 ^{b}	80.1 ± 1.6 ^{a}	87.5 ± 0.6 ^{bc}	81.1 ± 2.7 ^{a}	90.2 ± 1.2 ^{c}
(%)	Goat	79.1 ± 1.2 ^{a}	84.9 ± 3.7 ^{b}	79.1 ± 0.8 ^{a}	88.0 ± 3.3 ^{bc}	82.5 ± 1.4 ^{a}	90.7 ± 2.8 ^{c}
	S vs G	ns	ns	ns	ns	ns	ns
Rumen fluid volume	Sheep	296.9 ± 13.0 ^{a}	296.2 ± 1.9 ^{a}	272.3 ± 9.4 ^{b}	291.3 ± 8.2 ^{a}	273.4 ± 6.5 ^{b}	295.7 ± 3.4 ^{a}
(ml/kg $W^{0.82}$)	Goat	276.0 ± 6.3 ^{a}	274.1 ± 1.6 ^{a}	260.0 ± 11.3 ^{b}	265.5 ± 2.1 ^{ab}	247.1 ± 7.1 ^{c}	240.3 ± 4.4 ^{c}
	S vs G	**	**	**	**	**	**
Rumen fluid volume	Sheep	14.8 ± 0.6 ^{a}	14.9 ± 0.2 ^{a}	13.6 ± 0.4 ^{b}	14.5 ± 0.4 ^{a}	13.6 ± 0.4 ^{b}	14.8 ± 0.2 ^{a}
(% W)	Goat	14.9 ± 0.4 ^{a}	14.8 ± 0.2 ^{a}	14.0 ± 0.6 ^{b}	14.3 ± 0.4 ^{ab}	13.3 ± 0.4 ^{c}	13.0 ± 0.3 ^{c}
	S vs G	ns	ns	ns	ns	ns	ns
Flow rate of rumen fluid	Sheep	21.7 ± 0.8 ^{a}	25.2 ± 1.1 ^{b}	24.9 ± 1.3 ^{b}	27.1 ± 1.3 ^{c}	25.2 ± 1.5 ^{b}	28.1 ± 0.9 ^{c}
(ml/kg $W^{0.82}$/h)	Goat	18.3 ± 1.4 ^{a}	18.9 ± 1.1 ^{a}	21.0 ± 1.3 ^{b}	23.1 ± 0.4 ^{c}	21.3 ± 1.3 ^{b}	18.8 ± 0.8 ^{a}
	S vs G	**	**	**	**	**	**
Flow rate of rumen fluid	Sheep	7.3 ± 0.1 ^{a}	8.5 ± 0.3 ^{b}	9.1 ± 0.2 ^{c}	9.3 ± 0.2 ^{cd}	9.2 ± 0.3 ^{cd}	9.5 ± 0.3 ^{d}
(%/h)	Goat	6.7 ± 0.6 ^{a}	6.9 ± 0.4 ^{a}	8.1 ± 0.3 ^{b}	8.7 ± 0.2 ^{c}	8.6 ± 0.4 ^{c}	7.8 ± 0.4 ^{b}
	S vs G	**	**	**	**	**	**
Ingested water	Sheep	13.8 ± 1.0 ^{a}	20.1 ± 0.8 ^{b}	17.9 ± 0.5 ^{c}	22.9 ± 0.4 ^{d}	13.3 ± 0.9 ^{a}	22.8 ± 0.7 ^{d}
(% flow rate of rum.fluid)	Goat	15.7 ± 2.4 ^{a}	16.4 ± 1.1 ^{a}	15.0 ± 2.6 ^{a}	16.7 ± 1.1 ^{a}	16.7 ± 1.9 ^{a}	13.7 ± 1.0 ^{b}
	S vs G	ns	**	**	**	**	**

notes :

Mean values on the same row with different superscript are significantly different (P<0.05)

Mean values in the same column of each parameter (S vs G) :

* = differ significantly at level P < 0.05

** = differ significantly at level P < 0.01

ns = non significant

n = 3 sheep and 3 goats

Table 5.3. Mean values of influx and outflux of water

PARAMETERS		Oaten chaff		Mixed chaff		Lucerne chaff	
		Fresh	Salt	Fresh	Salt	Fresh	Salt
Total influx of water	Sheep	78.4 ± 3.4 ^{a}	127.1 ± 2.4 ^{b}	117.8 ± 5.9 ^{c}	159.2 ± 6.9 ^{d}	88.6 ± 2.0 ^{a}	164.5 ± 1.9 ^{d}
(ml/kg $W^{0.82}$/d)	Goat	76.3 ± 5.3 ^{a}	81.6 ± 10.5 ^{a}	86.3 ± 10.2 ^{a}	101.5 ± 7.0 ^{b}	94.2 ± 5.0 ^{b}	67.5 ± 2.6 ^{c}
	S vs G	ns	**	**	**	ns	**
Urinary water loss	Sheep	39.3 ± 1.4 ^{a}	62.0 ± 1.2 ^{b}	58.9 ± 4.5 ^{b}	79.0 ± 5.7 ^{c}	44.2 ± 1.7 ^{a}	82.7 ± 2.8 ^{c}
(ml/kg $W^{0.82}$/d)	Goat	38.4 ± 3.5 ^{a}	39.7 ± 4.8 ^{a}	43.6 ± 3.6 ^{a}	50.6 ± 3.6 ^{b}	48.1 ± 3.9 ^{b}	34.8 ± 2.2 ^{c}
	S vs G	ns	**	**	**	ns	**
Urinary water loss (% influx)	Sheep	49.9 ± 1.7 ^{a}	48.7 ± 1.0 ^{a}	49.5 ± 1.7 ^{a}	49.6 ± 1.7 ^{a}	49.8 ± 1.3 ^{a}	50.3 ± 1.1 ^{a}
	Goat	50.1 ± 4.6 ^{a}	48.8 ± 0.4 ^{a}	50.7 ± 2.2 ^{a}	49.8 ± 1.9 ^{a}	51.0 ± 2.1 ^{a}	51.8 ± 2.3 ^{a}
	S vs G	ns	ns	ns	ns	ns	ns
Faecal water loss	Sheep	13.6 ± 0.9 ^{a}	22.6 ± 3.5 ^{b}	21.2 ± 1.4 ^{b}	27.8 ± 1.2 ^{c}	15.1 ± 2.1 ^{a}	28.2 ± 1.4 ^{c}
(ml/kg $W^{0.82}$/d)	Goat	14.3 ± 2.4 ^{a}	16.3 ± 4.8 ^{a}	15.7 ± 1.6 ^{a}	17.0 ± 2.9 ^{a}	14.8 ± 1.7 ^{a}	10.1 ± 1.9 ^{b}
	S vs G	ns	*	**	**	ns	**
Faecal water loss	Sheep	17.3 ± 0.7 ^{a}	17.9 ± 0.5 ^{a}	18.0 ± 1.5 ^{a}	17.5 ± 0.3 ^{a}	18.0 ± 2.5 ^{a}	17.2 ± 0.6 ^{a}
(% influx)	Goat	18.6 ± 2.0 ^{a}	19.8 ± 3.3 ^{a}	18.2 ± 0.6 ^{a}	16.8 ± 3.1 ^{a}	15.7 ± 1.1 ^{a}	15.0 ± 2.4 ^{a}
	S vs G	ns	ns	ns	ns	ns	ns
Est.insens.water loss	Sheep	25.8 ± 2.1 ^{a}	42.4 ± 2.2 ^{b}	38.7 ± 3.5 ^{b}	52.4 ± 2.5 ^{c}	29.4 ± 3.3 ^{a}	53.6 ± 2.2 ^{c}
(ml/kg $W^{0.82}$/d)	Goat	24.0 ± 4.4 ^{ac}	25.5 ± 0.9 ^{a}	27.0 ± 5.2 ^{a}	33.9 ± 3.6 ^{b}	31.2 ± 1.6 ^{b}	22.3 ± 2.4 ^{c}
	S vs G	ns	*	**	**	ns	**
Est.insens.water loss (% influx)	Sheep	32.8 ± 1.6 ^{a}	33.4 ± 1.3 ^{a}	32.4 ± 2.6 ^{a}	33.0 ± 1.9 ^{a}	32.1 ± 3.4 ^{a}	32.6 ± 1.7 ^{a}
	Goat	32.3 ± 5.4 ^{a}	31.5 ± 2.9 ^{a}	31.1 ± 2.8 ^{a}	33.5 ± 3.6 ^{a}	33.2 ± 2.4 ^{a}	33.2 ± 1.1 ^{a}
	S vs G	ns	ns	ns	ns	ns	ns

notes :

Mean values on the same row with different superscript are significantly different (P<0.05)

Mean values in the same column of each parameter (S vs G) :

* = differ significantly at level P < 0.05

** = differ significantly at level P < 0.01

ns = non significant

n = 3 sheep and 3 goats

Table 5.4. Mean values of urinary and faecal sodium excretion

PARAMETERS		Oaten chaff		Mixed chaff		Lucerne chaff	
		Fresh	Salt	Fresh	Salt	Fresh	Salt
Urinary sodium (mmol/l)	Sheep	46.4 ± 1.8 [a]	496.3 ± 8.6 [b]	54.4 ± 4.9 [a]	486.8 ± 18.3 [b]	32.1 ± 3.4 [a]	486.5 ± 13.5 [b]
	Goat	35.8 ± 6.4 [a]	519.3 ± 5.2 [b]	45.7 ± 1.9 [a]	509.9 ± 21.1 [b]	41.8 ± 5.6	495.5 ± 23.9 [b]
	S vs G	ns	*	ns	**	ns	ns
Urinary sodium (% Intake)	Sheep	74.1 ± 1.6 [a]	90.7 ± 0.6 [b]	75.8 ± 0.4 [a]	90.2 ± 0.8 [b]	76.1 ± 1.0 [a]	90.6 ± 0.6 [b]
	Goat	77.7 ± 1.2 [a]	93.4 ± 0.9 [b]	77.0 ± 3.0 [a]	93.6 ± 0.6 [b]	77.3 ± 1.3 [a]	93.8 ± 0.6 [b]
	S vs G	ns	ns	ns	ns	ns	ns
Faecal sodium (*mmol/l fae.water*)	Sheep	39.2 ± 3.4 [a]	94.1 ± 11.2 [b]	43.0 ± 3.4 [a]	104.2 ± 10.6 [b]	48.6 ± 9.1 [a]	98.9 ± 13.0 [b]
	Goat	41.9 ± 6.2 [a]	87.4 ± 3.9 [b]	49.0 ± 8.4 [a]	101.1 ± 8.9 [b]	45.4 ± 7.5 [a]	93.8 ± 0.6 [b]
	S vs G	ns	ns	ns	ns	ns	ns
Faecal sodium (% Intake)	Sheep	21.7 ± 1.6 [a]	6.3 ± 0.7 [b]	21.6 ± 0.9 [a]	6.8 ± 0.6 [b]	21.1 ± 1.0 [a]	6.3 ± 1.0 [b]
	Goat	21.5 ± 1.2 [a]	6.4 ± 0.7 [b]	24.1 ± 2.4 [a]	6.2 ± 0.6 [b]	20.8 ± 0.8 [a]	5.7 ± 0.6 [b]
	S vs G						
Sodium balance (mmol/d)	Sheep	+ 2.5 ± 0.1 [a]	+ 23.6 ± 4.0 [b]	+ 2.6 ± 0.4 [a]	+ 30.3 ± 5.4 [c]	+ 2.3 ± 0.2 [a]	+ 32.6 ± 3.8 [c]
	Goat	+ 2.3 ± 0.2 [a]	+ 15.2 ± 1.7 [b]	+ 2.3 ± 0.3 [a]	+ 19.2 ± 1.5 [c]	+ 2.3 ± 0.2 [a]	+ 11.9 ± 1.4 [d]
	S vs G	ns	**	ns	**	ns	**

notes :

Mean values on the same row with different superscript are significantly different (P<0.05)

Mean values in the same column of each parameter (S vs G) :

* = *differ significantly at level P < 0.05*

** = differ significantly at level P < 0.01

ns = non significant

n = 3 sheep and 3 goats

DISCUSSION

In the present study salt was presented through drinking water in which differences in taste or oral factors could have influenced the intake of the salt water by the animals.

The results showed that with any roughage diet, the intakes of salt water by the sheep were markedly greater than in the goats, especially when lucerne chaff was fed. This result contradicted the findings of Goather and Church (1970) who showed that goats consume salty water more readily than sheep. The differences may presumably be attributed to the different breeds of goat and sheep used in the present study. In the previous study (Chapter III) when 50 mmol/kg $W^{0.82}$ /d sodium chloride (the medium level of salt treatments) was infused directly into the rumen, the goats consumed the same amount of fresh water as the sheep.

The present result indicated, therefore, that acceptability of salt water by the Angora goats is less compared to the sheep, or possibly that Angora goats need a longer time than Merino sheep to accept salt water to the same level.

From an experiment on sheep fed mixed chaff (25% lucerne hay + 75% wheaten hay) Potter, Walker and Forrest (1972) reported that the osmolality of rumen fluid in sheep accustomed to drink 1.3% salt water were significantly higher than in sheep drinking fresh water. The importance of rumen osmolality as a controller of food intake in ruminant animals has been examined in a number of experiments (Ternouth, 1968; Bergen, 1972; Phillip, Buchanan-Smith and Grovum, 1981; Carter and Grovum, 1988; Grovum and Bignell, 1989). Raising the osmolality of rumen fluid resulted in increasing the osmolality of digesta further down the gastrointestinal tract and blood, either of which might mediate the effect on intake. Osmoreceptors in the reticulorumen seem to be of primary importance as Carter and Grovum (1988) demonstrated that infusion of hypertonic solution into abomasum had little effect on intake, even though the increased

plasma osmolality was higher than that obtained after intraruminal infusion. Ternouth (1968) indicated that the stimulus to drink is not directly associated with ruminal osmolality, but rather an alteration in plasma osmotic pressure and extracellular fluid volume are proposed as the controlling factors for water consumption in addition to food satiation.

The results of the present experiment showed that the effect of drinking salt water on organic matter intake of oaten chaff was greater in the sheep than in the goats. These different responses were apparently attributable to species differences in addition to the fact that the sheep consumed more salt than the goats. Generally, when compared with sheep, goats in their natural habitat, tend to consume more dry matter of low quality roughage, drink less water and excrete less urine (Gihad, El-Badawy and Mehrez, 1980; Antoniou and Hadjipanayiotou, 1985; Wahed and Owen, 1986). These characteristics have also been reported for Angora goats in comparison with Merino sheep (Doyle and Egan, 1980; Gamble and Mackintosh, 1982; Boer, Milton and Ternouth, 1982). Concerning the effect of drinking salt water, the present results revealed that these advantages were apparently most pronounced on oaten chaff, a poorer quality roughage, since the goats fed lucerne chaff, a high quality roughage, showed a reverse response when salt water was drunk.

Distention and fill of the reticulorumen is thought to be one of the determinant factors involved in the control of feed intake by ruminants (Campling, 1970; Baile and Forbes, 1974; Dulphy, Remond and Theriez, 1980). In the present experiment when fresh water water was offered, the organic matter intakes of oaten chaff by the sheep and goats were less compared to those of the other two diets, yet rumen fluid volume in both species fed oaten chaff was greater. Van Soest (1975) pointed out that a striking difference exists in hemicellulose content between cereal straw or grasses and legumes. The much higher amount of hemicellulose in the monocotyledons indicates a higher cell wall content.

Presumably, oaten chaff with a higher proportion of cell wall content, the slowest digestion fraction in the forage (Van Soest, 1975), would lead to a higher retention of fluid in the rumen, and a slower flow rate of fluid flow to the omasum compared to mixed or lucerne chaff either on fresh or salt water. From an experiment on sheep fed various grass species containing a varied cell wall content, Moir, Laws and Blight (1975) reported a significant negative relationship between cell wall content and voluntary intake, and organic matter digestibility.

On the other hand, in addition to higher nitrogen content, lucerne chaff has lower cell wall content and higher content of soluble fractions compared to oaten chaff. These properties of lucerne chaff allow a higher rate of digestion, greater digestibility and rate of passage (shorter retention time) (Demarguilly and Chenost, 1969; Church, 1975; Malbert and Baumont, 1989). From an experiment with sheep, Baumont, Sequier and Dulphy (1990) reported that rumination time, number of rumination cycles and chewing time per kg dry matter intake required by the sheep fed lucerne chaff were less than when mixed grass hay was fed. In agreement with these previous findings, the higher influx of salt water in the sheep fed lucerne chaff resulted in faster flow rate of rumen fluid. Apparently, this situation reduced the effect of salt on the composition of rumen fluid, or enabled the rumen micro-organisms to resist the changes in the composition of rumen fluid. Potter, Walker and Forrest (1972) reported that the metabolic activity of the rumen microbial population, measured calorimetrically, was not altered when 1.3% salt water was drunk, while flow rate of rumen fluid increased and total microbial population decreased.

In the goats, however, a lower ingestion of salt water resulted in a slower flow rate of rumen fluid turnover. Presumably, such a situation would lead to a further increase of osmotic pressure of rumen fluid, particularly from fermentation products. It is clearly indicated, therefore, that a lower influx of salt water into the rumen in the goats, because of lower salt water acceptability, would lead to a further decrease in organic matter intake of lucerne chaff. This reduced intake of lucerne chaff being due to the combined effects of

a higher osmotic pressure in the rumen and a reduced turnover of rumen contents. It should also be noted that differences in salivary flow are likely to have occurred due to the differences in food intake between the two types of chaff and the greater proportional time spent eating and chewing oaten chaff (Carter and Grovum, 1990).

Wilson (1966a) observed that sheep on salt bush regulated their water intake according to salt ingested with the food. A similar result has also been found when salt solution was infused intra-ruminally (Godwin and Williams, 1986) and in the previous study (Chapter III). In the present experiment, however, salt in drinking water caused the animals to receive more salt as they increased water consumption.

The result indicated that water influx in the sheep on salt water was 62, 35 and 85% higher than on the fresh water when oaten, mixed and lucerne chaff were fed respectively. A similar result has also been reported by Wilson (1966 b) who fed sheep on mixed straw + lucerne chaff or lucerne chaff alone. The increased water intake associated with increased salt input was greater with the lucerne chaff compared to the mixed chaff ration. This result is also in agreement with other studies comparing water requirements of animals fed on legumes and grasses (Thomson, Cruickshank, Poppi and Sykes, 1985; Grenet, 1989; Baumont, Seguier, and Dulphy, 1990). In addition to the higher nitrogen content, lucerne chaff has a higher potassium content compared to mixed or oaten chaff (Wilson and Dudzinski, 1973) which presumably produced an increased water requirement. In the goats, salt was to increase the intakes of water only when oaten or mixed chaff were fed, but the increase in intakes were markedly lower than those in the sheep. The reduced water intake in the goats fed lucerne chaff masks a real increase in ingested water when expressed as ml per 100g dry matter intake. Lucerne chaff intake was dramatically reduced by the ingestion of salty water.

Compared with the previous result (Chapter III), the lower influx of salt water in the sheep and goats were probably mostly produced by taste or oral factors, and it was lower in the goats compared to the sheep. In accordance with the relationship between

water and sodium absorption in the sheep and goats, such a situation would lead to higher sodium concentration in the urine from the goats compared to that from the sheep.

Interestingly, the present result showed that the relative importance of urine, faeces and evaporation (insensible loss) as routes of water loss from the sheep or goats fed any of the diets were not altered by drinking salt water. The previous results (Chapter III) showed that the urinary proportion was increased by salt infusion, while faecal and insensible loss decreased. These different results may be attributed to the differences in the routes of administration of the salt. In the previous study, intraruminally infused salt with freely available fresh drinking water would give an opportunity for the sheep or goats to adjust the intake of water relative to salt. The total intake of salt was also markedly greater compared with the present experiment.

The possibility that stimulation of the oesophageal groove bypass reflex by 1.35% salt drinking water (Chapter 4) and not by fresh water may indicate that some of the effects of differences in rumen fluid dynamics may be due to ingested fluid bypass.

In summary, the hypothesis outlined in the introduction is rejected with both sheep and goats showing substantial effects on food intake and digestibility and rumen fluid dynamics. The effects appear to be of greater magnitude in goats compared to sheep.

CHAPTER VI

EFFECTS OF SODIUM CHLORIDE INGESTION THROUGH DRINKING WATER ON DIGESTION, WATER AND SALT METABOLISM IN AUSTRALIAN FERAL GOATS IN A HOT ENVIRONMENT

SUMMARY

The effects of sodium chloride ingestion through drinking water on digestion, rumen fluid dynamics, water and salt metabolism in goats at 40°C/30-55% rh was examined. Four castrated male Australian feral goats were fed *ad libitum* a mixed roughage diet containing 50% lucerne chaff and 50% oaten chaff. The animals were offered tap water containing either 0.6 (medium), 0.003 (low) or 1.35% (high) sodium chloride in that order as the only source of drinking water.

The results suggest that during the medium salt water treatment, the animals were still adjusting to the hot environment. This was indicated by a substantially lower food intake and a higher water intake compared to the other two levels of salt treatment. The responses in tritiated body water space (TBWSp), rumen fluid dynamics and inulin space (ECFSp) were in between the values obtained for the other two levels of salt water.

In the acclimated condition, the intake of organic matter by the goats was not significantly influenced by drinking salt water, but ingested water, digestibility of organic matter and sodium increased significantly.

Although the outflow rates of rumen fluid expressed as ml/kg$W^{0.82}$/h were not significantly different between the low and high intake of salt, but as a proportion of rumen fluid volume (% rumen fluid volume/h) it was decreased significantly. In addition, calculated influx of endogenous water into the rumen was significantly decreased by drinking 1.35% salt water.

TBWSp, ECFSp and volume of rumen fluid were increased significantly by drinking salt water from 1155.8, 353.0 and 252 with low level of salt water to 1442.1, 461.5 and 298.8 ml/kg $W^{0.82}$ with the high level respectively. However, the proportion of body water distributed into the rumen and ECFSp were maintained constantly.

Water turnover rate (WTOR) was significantly increased from 194.3 with low salt water to 241 ml/kg $W^{0.82}$/d with high salt water. The increase in WTOR was proportionate to the increases in urinary water loss without a significant change in faecal and insensible water losses. However, as proportions of WTOR, urinary water loss increased significantly from 31.3 to 46.2%, whereas insensible water loss decreased significantly from 60.2 to 47%, but faecal water loss was not significantly decreased (from 8.5 to 6.9%).

Plasma-inulin disappearance rate was increased by drinking salt water.

Increased sodium intake increased sodium digestibility and urinary sodium excretion. The increased urinary sodium excretion was achieved by both increases in urinary sodium concentration and urinary water loss.

INTRODUCTION

Australian feral goats (Capra hircus) breed and survive, and are widespread throughout the Australian arid areas (Leigh, 1974; Wilson, Leigh, Hindley and Mulham, 1975). However, up to date information about physiological aspects and adaptive mechanisms in this animal are scarce.

In general, under hot and dry environments, the goat has ability to thrive with limited water, and this ability is only excelled by camel, but better than sheep and cattle (Macfarlane and Howard, 1972). Under a thermoneutral environment, water turn-over rate of normal hydrated Australian feral goats was about 170 ml/kg $^{0.82}$/d, while at 50% of *ad libitum* water intake it was about 82 ml/kg$^{0.82}$/d (recalculated from mean values reported by More, Howard and Siebert, 1983).

In view of the scanty information available, the purpose of the experiment reported here was to investigate the effects of drinking salt water on digestion and metabolism of water and salt in a hot environment.

It is hypothesised that there would be no changes in food intake, digestibility or rumen fluid dynamics in goats under different conditions of salt and thermal loading.

MATERIALS AND METHODS

Animals, feed and water

Four castrated Australian male feral goats used in the present experiment were chosen from five used in the previous experiment (Chapter IV). They were freshly shorn and held in metabolism crates in a climate room for 10 d before the commencement of the experiment. They were fed *ad libitum* on a mixed roughage diet consisting of 50% lucerne chaff and 50% oaten chaff. Drinking water was also offered *ad libitum*.

Protocol and techniques of the experiment

The whole experiment was conducted over 76 d. This included a 12 d preliminary period during which the temperature and humidity of the room were gradually increased from 25°C and 30% rh to 40°C and 35% rh. In the first 6 d the animals were given fresh water, and in the remaining 6 d they were given 0.6% salt water. The environmental condition of 40°/35% was maintained throughout the three periods of salt treatment.

There were three consecutive periods of 20 d salt water treatment : 0.6 %; 0.003% (based on Na^+ content in tap water, henceforth termed 0% or fresh water); and 1.35% salt water (These treatments were allocated randomly as a crossover design was logistically impossible). The first 6 d were adjustment periods to the treatments. The next 10 d were used to collect faeces and urine (balance trial) and the last 4 d to determine rumen fluid responses followed by a determination of body fluids. There were two intermediate periods between 0 and 1.35% salt water: 0.9 and then 1.2% salt each for 2 d.

Faeces of each animal was collected each morning (bulk sample), and a fresh faecal sample was obtained when the animal defaecated by catching some of the falling

pellets (≈50-100 g/d). Faecal water content of the fresh sample was used to determine whether the bulk sample was higher or lower in the water content, and adjustments were then made to both the measured urinary and faecal water losses as appropriate.

Body weights of the animals were monitored before and after the balance trials, and at the end of each salt treatment.

Rumen fluid and tritiated body water responses were determined by the same techniques used in the previous study (Chapter III). Tritiated body water (volume and turn-over rate) was determined directly after measuring extracellular water space by the inulin dilution technique (Godwin and Williams, 1986). In accordance with the characteristics of inulin, the value of the plasma-inulin disappearance rate was used as a parameter of glomerular filtration rate.

Chemical analysis

The samples of feed, faeces, urine, rumen fluid and blood plasma were prepared and analysed with the same methods and techniques as used in the previous study (Chapter III). The concentration of inulin in the plasma was determined by the colourimetric method of Bacon and Bell (1948)

Statistical analysis

Statistical analysis of the results was based on a single factor experiment with repeated measurement of salt treatments (Wilkinson, 1990), and the mean values were tested according to Newman-Keuls procedures (Winer, 1971).

RESULTS

Temperature and humidity (Table 6.1)

The variations of temperature and humidity within each period of salt treatment are shown in Table 1. The temperature and humidity in the first, second and third periods were maintained relatively constant at 40° and 35%, except on the last 4 d of the third period in which the temperature fluctuated between 35 to 42°.

Body weights and intakes of food , water and sodium (Table 6.2)

In accord with salt treatments (0, 0.6 and 1.35% salt water), sodium intakes (mmol/kg $W^{0.82}$/d) were significantly different. It is, therefore, reasonable to attribute the results to low, medium and high salt intakes.

Body weights of the goats in the respective treatment periods indicated a significant decrease when medium salt intake was replaced by fresh water, but it was regained with high salt intake.

On medium salt intake, feed intake was significantly lower than on the fresh water or high salt intake, while water intake was in the reverse order. There were no significant differences in feed intake between low and high salt intakes, but the goats on high salt intake consumed significantly more water than on the low salt intake.

Digestibility, absorption and dynamics of rumen fluid (Table 6.3).

The digestibility of organic matter with the medium or high salt intake was significantly higher than with the low, while there were no significant differences between the medium and the high salt intakes.

The absorption of sodium (%) increased with salt intake. Although there were no significant differences in the water absorption (%) between the low and high intakes of

salt, values for both these treatments were significantly lower compared to the medium intake.

Rumen fluid volume (ml/kg $W^{0.82}$) increased significantly with increased salt intake from the low to medium and from the medium to the high intake. The outflow rate (% fluid volume per h) of the fluid was significantly faster on the low intake compared to the medium or high salt intakes, but when it was expressed in absolute value (ml/kg $^{0.82}$/h), there were no significant differences with different salt intakes.

Distribution and dynamics of body fluid (Table 6.4 and 6.5)

Tritiated body water space (TBWSp) and inulin space (ECF) expressed as ml/kg$^{0.82}$bw or percentage of body weight were increased with increased salt intake while rumen fluid volume expressed as percentage of TBWSp was not significantly altered with increased salt intake (Table 6.4).

Water turn-over rates (WTOR) on the medium and high intakes of sodium were not significantly different, but they were significantly higher compared to the low intake.

Estimated metabolic water increased significantly with increased salt intake.

Inulin disappearance rate from plasma increased with increased salt intake, but it was only significantly increased by the high level of salt.

Urinary water loss (ml/kg $W^{0.82}$/d) with the medium intake of salt was significantly higher than with the low or high intake, while it was higher on high salt intake compared to that on low intake. When it was expressed as a percentage of WTOR, there was a significant increase in urinary water loss from low to high salt intake.

Faecal water loss (ml/kg $W^{0.82}$/d or % WTOR) on low and high intakes of salt were not significantly different, but they were significantly higher compared to the medium intake. Faecal moisture content (%) was not significantly altered with increased salt intake.

Estimated insensible water loss (ml/kg $W^{0.82}$/d) was significantly higher in the medium salt intake compared to the low or high salt intake which were not significantly different. However, when it was expressed as a percentage of WTOR, the loss on the low salt intake was significantly higher compared to the medium and high salt intakes which were not significantly different.

Sodium excretion and plasma electrolyte concentration(Table 6.6)

Sodium concentration in the urine (mmol/l) increased significantly with increased salt intake, and also as a percentage of salt intake.

Sodium concentration in faecal water (mmol/l faecal water) decreased significantly from the medium to the low intake of salt, and it increased significantly from the low to high intake. However, the concentration with the medium intake was significantly higher compared to the high.

Sodium concentration in the plasma was not significantly altered by different salt intakes. The plasma potassium concentration on the high intake of salt was significantly higher than with the medium and low intakes, but there were no significant differences between low and medium intakes. Plasma ionised calcium concentration was not significantly altered with the different salt intake.

Positive sodium balance was measured, and it was increased from 4.4 in the low salt intake to 29.6 in the medium and to 50 mmol/d in the high.

Table 6.1. Salt treatments and variations of temperature and humidity

Salt treatment (% w/v)	Days	Temperature min - max (° C)	Humidity min - max (%)
0	2	20 - 25	30 - 30
0	2	25 - 30	30 - 30
0	2	30 - 35	30 - 30
0.6	2	35 - 40	30 - 30
0.6	4	40 - 40	30 - 35
0.6	6	40 - 40	35 - 35
0.6	10	40 - 40	35 - 35
0.6	4	40 - 40	35 - 35
0	6	40 - 40	35 - 35
0	10	40 - 40	35 - 35
0	4	40 - 40	35 - 35
0.9	2	40 - 40	35 - 35
1.2	2	40 - 40	35 - 35
1.35	6	40 - 40	35 - 35
1.35	10	40 - 40	35 - 35
1.35	4	35 - 42	35 - 35
Sum	76		

Table 6.2. Mean values (n=4) of body weights, feed, water and sodium intakes

Parameters	Salt treatment		
	0	0.6	1.35
Body weight (kg)	31.0 ± 1.4 a	32.1 ± 1.6 b	33.3 ± 1.3 b
Sodium intake ($mmol/kgW^{0.82}/d$)	3.7 ± 0.4 a	33.1 ± 7.0 b	61.1 ± 4.1 c
Organic Matter Intake ($g/kgW^{0.75}/d$)	39.8 ± 2.4 a	25.3 ± 4.9 b	40.8 ± 0.9 a
Ingested Water ($ml/kgW^{0.82}/d$)	188.4 ± 9.2 a	264.4 ± 8.2 b	219.0 ± 13.5 c
Ingested Water (ml/100 g DMI/d)	562.5 ± 53.9 a	1337.7 ± 267.5 b	641.3 ± 30.8 c

Mean values on the same row with different letters are significantly different
($P<0.05$)

Table 6.3. Mean values (n=4) of digestibility and absorption, and dynamics of rumen fluid

Parameters	Salt Intake		
	Low	Medium	High
Digestibility and Absorption			
App.organic matter Dig. (%)	62.8 ± 0.1 a	66.2 ± 0.2 b	64.7 ± 0.3 b
App.water absorption (%)	91.2 ± 0.72 a	96.2 ± 0.75 b	92.4 ± 0.81 a
App. Na absorption (%)	86.4 ± 1.75 a	95.2 ± 1.29 b	97.3 ± 0.30 b
Dynamics of rumen fluid			
Rumen fluid volume ($ml/kgW^{0.82}$)	252.3 ± 5.5 a	274.5 ± 3.5 b	298.8 ± 5.9 c
Rumen fluid volume (%W)	13.6 ± 0.5 a	14.7 ± 0.4 b	15.9 ± 0.6 c
Flow rate of rumen fluid ($ml/kgW^{0.82}/h$)	20.5 ± 1.7 a	20.3 ± 1.5 a	19.1 ± 0.4 a
Flow rate of rumen fluid (% rumen fluid volume/h)	8.1 ± 0.6 a	7.4 ± 0.5 b	6.4 ± 0.1 c
Calculated influx of endogenous fluid into the rumen ($ml/kgW^{0.82}/d$) §	341.9 ± 21.1 a	286.3 ± 16.8 b	299.9 ± 15.4 b

Mean values on the same row with different letters are significantly different ($P<0.05$)

§ = flow rate of rumen fluid - 76% ingested water (see Chapter IV)

Table 6.4. Mean values (n=4) of body water space and its distribution

Parameters	Salt treatments		
	0	0.6	1.35
Tritiated body water space ($ml/kgW^{0.82}/d$)	1155.8 ± 31.3 a	1283.6 ± 46.4 b	1442.1 ± 24.8 c
Tritiated body water space (% W)	62.3 ± 0.7 a	68.7 ± 2.3 b	76.7 ± 1.5 c
Extra-cellular Sp (Inulin sp) ($ml/kgW^{0.82}/d$)	353.0 ± 12.5 a	427.1 ± 13.1 b	461.5 ± 14.7 c
Extra-cellular Sp (Inulin sp) (% TBWSp)	30.5 ± 0.4 a	33.3 ± 0.5 b	32.0 ± 0.7 a b
Rumen fluid volume (% TBWSp)	21.3 ± 0.8 a	21.7 ± 1.0 a	21.9 ± 0.8 a

Mean values on the same row with different letters are significantly diffe ($P < 0.05$)
TBWSp = tritiated body water space

Table 6.5. Mean values (n=4) of body water dynamics

Parameters	Salt treatments		
	0	0.6	1.35
Water turnover rate ($ml/kgW^{0.82}/d$)	194.3 ± 12.1 a	278.4 ± 15.8 b	241.6 ± 9.7 b
Estimated metabolic water ($ml/kgW^{0.82}/d$)	5.8 ± 1.6 a	14.0 ± 2.7 b	22.4 ± 1.4 c
Inulin disappearance rate (ml/min)	85.5 ± 16.6 a	108.7 ± 9.9 a	174.2 ± 15.3 b
Urinary Water Loss ($ml/kgW^{0.82}/d$)	60.8 ± 8.2 a	140.9 ± 11.7 b	111.6 ± 5.8 c
Urinary Water Loss (% WTOR)	31.3 ± 4.3 a	50.6 ± 4.3 b	46.2 ± 3.8 b
Faecal Water Loss ($ml/kgW^{0.82}/d$)	16.5 ± 2.3 a	9.7 ± 2.1 b	16.4 ± 0.9 a
Faecal Water Loss (% WTOR)	8.5 ± 1.3 a	3.6 ± 1.2 b	6.9 ± 1.6 a
Faecal Moisture (%)	55.4 ± 3.9 a	55.6 ± 2.1 a	56.4 ± 2.0 a
Insensible Water Loss ($ml/kgW^{0.82}/d$)	117.0 ± 4.5 a	127.8 ± 4.6 b	113.6 ± 3.7 a
Insensible Water Loss (% WTOR)	60.2 ± 5.7 a	45.9 ± 5.2 b	47.0 ± 4.7 b

Mean values on the same row with different letters are significantly different ($P < 0.05$)

Table 6.6. Mean values (n = 4) of sodium excretion (urir and faeces), and plasma electrolyte concentrations

Parameters	Salt treatments		
	0	0.6	1.35
Sodium excretion			
Urinary Na excretion (mmol/l)	38.9 ± 17.5 a	195.7 ± 31.5 b	561.1 ± 81.9 c
Urinary Na excretion (% Na-intake)	78.9 ± 4.8 a	89.6 ± 2.5 b	92.7 ± 0.5 c
Faecal Na excretion (mmol/l faec.water)	30.5 ± 4.2 a	157.2 ± 35.9 b	90.1 ± 17.8 c
Faecal Na excretion (% Na-intake)	13.6 ± 3.5 a	4.9 ± 2.5 b	2.4 ± 0.2 c
Na balance (mmol/d)	+ 4.4 ± 1.9 a	+ 29.6 ± 9.9 b	+ 50.0 ± 6.3 c
Plasma electrolyte concentrations			
Sodium (mmol/l)	139.9 ± 0.56 a	137.5 ± 0.59 a	139.6 ± 0.60 a
Potassium (mmol/l)	4.36 ± 0.12 a	4.38 ± 0.04 a	5.20 ± 0.29 b
Calcium (mmol/l)	1.22 ± 0.04 a	1.18 ± 0.03 a	1.15 ± 0.01 a

Mean values on the same row with different letters are significantly different ($P < 0.05$)

DISCUSSION

The results indicated clearly that in the first period with medium salt water (0.6% salt water) the animals were apparently in an adjustment condition to the hot environment (40°C / 40% rh) during which homeostatic responses acted to adjust to homeothermy. Under such conditions they consumed less food with a greater water intake compared to the next two periods of low and high salt water which were not different statistically.

In the previous studies (Chapter IV), the same goats under ordinary environmental conditions (7-20° and 70%) and offered fresh water consumed 100% more food and drank 70-80% less water compared to the present experiment when given medium salt water, but these differences were reduced when the animals were given low and high salt water. Such effects indicate that the goats on low and high sodium intake were adapted to the hot environments, while when the same animals were on medium salt intake the responses were apparently confounded between the salt load and to the new hot environment.

The body weight of the goats on the high salt intake was significantly heavier than when they were on the low salt intake. This apparently resulted from the increases in food utilisation (Table 6.3) and also from the expansion of body water space (Table 6.4). This would have affected body composition as a whole. From an experiment on sheep accustomed to drinking 1.3 % salt water, Walker, Potter and Jones (1971) reported that the amount of fat laid down was reduced, and it was largely replaced by water and to some extent by protein, and the composition of the fat was also changed to a less saturated type.

The digestibility of organic matter on the high salt intake was significantly greater than on the low (Table 6.3). This may be attributed to the lower proportion of rumen fluid flowing out to the omasum while the absolute flow rate of the fluid was maintained constant (Table 6.3). With an increased water consumption and no change in food intake (Table 6.2), there is an increased rumen fluid volume (Table 6.3). In addition a greater

proportion of digesta would stay in the rumen for a longer period. There is a negative relationship between the flow rate of digesta and organic matter digestibility. This is a reflection of the time dependence for microbial digestion in the rumen (Evans, 1981).

Tritiated body water space and water turnover rate increased with increased salt intake. This is in agreement with Macfarlane, Howard and Siebert (1967) for sheep grazing salt bush, and Jones, Potter and Reid (1970) for sheep drinking 1.3% salt water. Concerning the increased total body water, there was a proportional increase in rumen fluid volume and extra-cellular fluid space which contributed 25-30% and 35-40% of the total increase respectively. The remainder of the increase was apparently contributed by an increased lower gut fluid and possibly intra-cellular volume. This proportional increase is apparently important in maintaining constant distribution and dynamics of body fluid in the different compartments, and also to maintain a constant sodium concentration in blood plasma (Table 6.6) (Macfarlane, Morris and Howard, 1963).

The increase in water turnover rate resulted from the increases in water consumption, production and excretion. The increased total excretion of water was due to the change in fluid transport required to eliminate the excess salt. However, the result showed that the increased water turnover rate (ml/kg$W^{0.82}$/d) was proportionate with the increase in urinary water loss, whereas faecal and insensible water losses were not significantly altered by high salt intake (Table 6.5).

Although in a thermoneutral environment it was reported in Chapter III, Table 3.3, that insensible water loss (ml/kg$W^{0.82}$/d) increased by salt load in both the sheep and goats, in the present experiment there was no significant effect of salt load on the insensible water loss but this water loss in the present study was markedly greater compared to the previous study. Ariely *et al.* (1989) reported that the sheep fed on salt bush or given a high salt diet had higher energy expenditures compared to the low salt diet. Similarly Jackson, Kromann and Ray (1971) showed that energy retention and fat deposition in lambs was decreased with increased salt intake. This calorigenic effect of salt could result particularly from the supplementary work by the digestive tract,

cardiovascular and renal systems which relate to the increased sodium absorption, hemodynamics and urinary sodium excretion. However, these previous studies were conducted in the condition without thermal load in which the animals responded differently in the distribution of water loss.

Concerning the effect of salt intake on kidney function, calculation of plasma-inulin disappearance rate was based on the slope-intercept technique. Hall, Guyton and Farr (1977) in an experiment on dogs indicated that this technique consistently overestimates the GFR compared to the standard technique by about 30%. It is considered that the standard technique is the most accurate. Therefore, the values for the disappearance rate of inulin from plasma in Table 6 may overestimate GFR by about 30%, although it is assumed the overestimate is proportionately the same across the different treatments.

The disappearance rate of plasma inulin with the high salt intake was significantly greater than with the low salt intake. This situation would have led to an increased filtered load of salt within the kidney tubules. This in turn decreases the percentage reabsorption of sodium but increases the reabsorption of solute-free water by the kidney tubules (Potter, 1968). With an increase in extracellular fluid space (ECFSp), the absolute amount of sodium reabsorbed increases (although the percentage decreases) with an increased filtered load (Tomas, Jones, Potter and Langsford, 1973; Yesberg, Henderson, Budtz-Olsen, 1978). Consequently, in the present experiment there was a positive sodium balance due to the increased sodium reabsorption. This situation led to an increase in ECFSp without an alteration in plasma sodium concentration. Further intake of high salt water would maintain the expanded ECFSp, but the excessive intake of sodium was presumably balanced by the increased excretion.

A number of experiments on laboratory animals indicated that a peptide, atrial natriuretic peptide (ANP), is involved in the natriuresis which accompanies salt loading, increased GFR and expanded extra-cellular fluid (reviewed in 2.4.4; Lang, Tholken, Ganten, Luft, Ruskuoaho and Unger, 1985). The potent action of this peptide in

natriuresis has also been evaluated in goats (Olsson and Eriksson, 1987; Eriksson, Kokkonen, Makala and Olsson, 1988; Olsson, Dahlborn, Nygren, Karlberg, Anden and Ericksson, 1989) and sheep (Parkes, Coghlan, McDougall and Scoggins, 1987,1988). As ANP inhibits aldosterone production, it is presumably mediated by strong inhibition on renin secretion. In addition ANP inhibits ADH-stimulated water permeability in inner medullary collecting duct

In the present experiment, it is possible, therefore, that in addition to the increases in water turnover rate, plasma-inulin disappearance rate and extra-cellular fluid volume, the concentration of sodium in the urine was much greater when the animals were on a high salt intake due to the action of this hormone.

Godwin and Williams (1986) in an experiment in sheep under normal environmental conditions reported a similar increase in the urinary sodium concentration after the infusion of 1250 mmol (60.95 mmol/kg $W^{0.82}$) or more sodium chloride per day. However, the goats in the present experiment with the same level of salt intake consumed less water than Godwin and Williams' sheep. This result presumably relates to the differences in the behavioural characteristic of the goats to drink less water regardless of environmental temperature (Chapter III) (Gihad, 1976; Gihad, 1980; Louca, Antoniou, Hadjipanayiotou, 1982) and also in the ability of the goat kidney to produce a more concentrated urine (Maloiy, Macfarlane and Skholnik, 1979). On the basis of morphometric studies (Howe, 1985, unpublished data), the maximal urine osmolalities as predicted by relative medullary thickness index were 1590 and 2060 mosmol/kg W, and by percentage medullary thickness index were 2550 and 2660 mosmol/kg W for sheep (Merino x Border Leicester) and Angora goat respectively.

In the present experiment, the absorption of sodium increased with increased salt intake, as shown by the decrease in faecal sodium excretion from 13.6% on the low to 2.4% on high intake of salt. However, since there were no significant differences between the low and high salt intake in their faecal water loss (ml/kg$W^{0.82}$/d) (Table 6.5)

but the sodium concentration in the faecal water was higher in the high salt intake (Table 6.6), the quantity of sodium excretion per d, therefore, was greater in the high intake of salt. A similar result has also been indicated in the previous study on Angora goats in a thermoneutral environment (Chapter V).

Clearly, the hypothesis stated in the introduction can be rejected with substantial changes occurring in each of the parameters mentioned, both with salt and thermal loading individually and in combination.

CHAPTER VII

EFFECTS OF TEMPERATURE AND SODIUM CHLORIDE INGESTION THROUGH DRINKING WATER ON DIGESTION, WATER AND SALT METABOLISM IN MERINO SHEEP

SUMMARY

Six mature Merino ewes (4-5 y) fitted with permanent rumen cannulae were fed mixed chaff (50% of lucerne chaff and 50% of oaten chaff) *ad libitum*. They were offered tap water containing 0.0 (low), 0.6 (medium) or 1.35% (high) sodium chloride as the only source of drinking water. The animals were housed in a controlled environment at either 20 or 40°C. Accordingly, there were 6 treatment combinations which were repeatedly measured.

The intakes of fluid by the sheep were significantly greater when salt water was drunk, and they were greater at 40°, while the intakes of organic matter (OMI) decreased. However, there were no significant differences in the intakes when medium and high salt water were drunk at either temperature.

The decreased OMI was compensated by an increased apparent digestibility (OMD). This resulted in no differences in the availability of organic matter. Salt and thermal loads increased the OMD, but the increase at 20° was not significant.

The outflow rate of rumen fluid was not significantly altered by drinking salt water in the 20° environment. However, in 40° it was decreased. Similarly, a significant effect of salt load on the volume of rumen fluid only occurred at 40°C. In addition, the calculated influx of endogenous water into the rumen was significantly decreased by drinking salt water in 40°C, but it was not significantly affected in 20°C.

Tritiated body water space (TBWSp) and inulin space were increased by drinking salt water and increasing the temperature from 20 to 40°. However when expressed as a proportion of TBWSp, the inulin space (30-32%) and rumen fluid volume (22-23%) were not significantly altered by salt and thermal loads.

Water turn-over rate (WTOR) in the sheep was significantly increased by salt and thermal loads. On the same intake of salt (≈100 or ≈1000 mmol/d), WTOR in 40°

heat was about double of that in 20°. Metabolic water production was not significantly altered by drinking salt water in the climate 20°, but it was significantly greater at 40°.

Urinary and insensible water losses (ml/kg $W^{0.82}$/d) were markedly increased by salt and thermal loads. However, faecal water loss was not significantly altered by different intakes of salt either at 20 or 40°, but the loss at 40° was lower than that at 20°.

When water losses were expressed as proportions of WTOR, there were no significant effects of salt or thermal load on urinary losses (45-50% WTOR), except when fresh water was drunk at 40° in which urinary loss was lower (29%) but insensible loss (62%) was higher compared to the other treatment combinations. When salt water was drunk at 40°, insensible water losses (44-46%) were significantly greater than the losses at 20° (31-34%). The proportions of water loss through defaecation were not significantly influenced by the different intakes of sodium, but the loss at 20° (18-24%) was significantly higher compared to that at 40° (5-9%).

Plasma-inulin disappearance rates, which represented GFR, were increased by salt and thermal loads. It is proposed that, in relation to the increases in GFR, inulin space, urinary sodium and water losses associated with drinking the salt water, atrial natriuretic peptide (ANP) may be a major controlling factor. On the other hand, when fresh water was drunk in 40°C, water reabsorption by the kidney tubules was probably controlled largely by the actions of antidiuretic hormone (ADH).

INTRODUCTION

Interaction of various body control systems in responses to alterations of external environment has long been recognized. Naturally, changes in thermal and salt loads may occurs simultaneously. In general, exposure to heat increases evaporative water loss. However, this will aggravate body fluid regulation when salt load also exists.

Thermal exposure of sheep results in marked alterations in the circulatory system. Blood flow is shunted toward superficial tissues and respiratory muscles to support an increase in dissipation of heat, whereas blood flow to digestive tract tissues is reduced (Hales, 1973; von Englehardt and Hales, 1977).

The motor activity of the reticulorumen (Attebery and Johnson, 1969) and rumination activity (Appleman and Delouche, 1958) were reduced by thermal loads. Studies by Miller et al. (1974) in cattle, Kennedy, Young and Christopherson (1977) and Weston (1977) in sheep indicated that thyroid status influenced digesta retention time in ruminants.

On the other hand, in thermoneutral environments previous results reported in chapter III and V revealed that drinking salt water increased flow rate of rumen fluid in addition to the increases in the whole body water turn-over rate.

The experiment now reported herein was designed as a factorial repeated measurement experiment to investigate the effects of thermal and salt loads imposed singularly or simultaneously on digestion and metabolism of water and salt including fluid dynamics in the rumen and extracellular compartments.

It is hypothesised that there would be no changes in food intake, digestibility or rumen fluid dynamics in sheep under different conditions of salt and thermal loading.

MATERIALS AND METHODS

Animals and management

Six mature Merino ewes (3-4 y) were used throughout the experiment. They were fitted with permanent rumen cannulae, and freshly shorn a day before moving to a climate room. General management, including feeding, watering, faecal and urine collection, was the same as in the previous study (Chapter VI).

Protocol and techniques of the experiment

The experiment was based on 2 x 3 factorial design with repeated measurement. There were six consecutive periods of 23 d: 1). 20°C-0% salt; 2).20°-0.6% salt; 3). 20°-1.35% salt; 4). 40°-0% salt; 5). 40°-0.6% salt; 6). 40°-1.35% salt. As a whole, the experiment was conducted in over 157 d including a 7 d adjustment time to the strange environment before the commencement of the period 1 and a 12 d intermediary time before the fourth period. Each period consisted of 8 d for adjustment to the salt water treatment, followed by a 10 d balance trial (faeces and urine collection), a day for determination of rumen fluid responses using CrEDTA as a fluid marker, and 4 d for determination of extra-cellular fluid volume by inulin and total body water responses by tritiated water The intermediary time was used to gradually increase the temperature from 20 to 40°, while the humidity was in accord with the natural conditions (unadjusted).

The response of rumen fluid in the second period was not determined. The techniques used in determination of body fluid responses (rumen, extra-cellular fluid, and total body water) were the same as in the previous study (Chapter VI). However, the concentration of inulin in isotonic saline solution was different. They were 20% in

the first period as in the previous study (Chapter VI), 15% in the second period; 10% in the third and fourth periods, and 5% in the fifth and sixth periods.

Chemical analysis

The samples of feed, faeces, urine, Cr in rumen fluid and tritiated water in blood plasma were prepared and analysed with the same methods and techniques as used in the previous study (Chapter III). The concentration of inulin in the plasma was determined by the colourimetic method of Bacon and Bell (1948).

Statistical analysis

Statistical analysis of the results was based on an analysis of a single factor experiment with repeated measurement in accord with the six consecutive salt-water treatments (Wilkinson, 1991), and mean values were tested according to Newman-Keuls procedures (Winer, 1971).

RESULTS

Temperature and humidity (Table 7.1)

The temperature of the climate room fluctuated evenly on a weekly basis from 15 to 20° C and from 35 to 40°C for the expected temperature treatments of 20 and 40° respectively. However, the humidity fluctuated unevenly in accord with the natural humidity outside of the room. When the temperature was adjusted for 20°, the humidity varied from 30 to 60%, and it was from 30 to 50% when the temperature was adjusted for 40°.

General health and body weights of the animals (Table 7.2)

There were two cases of diarrhoea observed when high salt water was offered in 40°. Both cases indicated an adverse effect of high salt intake. The first case was for the sheep consuming 220g sodium chloride (3780 mmol) per day in 2 days, and the second

was for another sheep consuming 165 g (2730 mmol). These amounts were greater when compared with the other four sheep. Both cases were observed at the same time in the first 2-3 d of the adjustment period. The animals recovered within 3 d when they reduced water intake and hence salt simultaneously. However, later in the experiment these sheep randomly consumed the same amount or more salt without any diarrhoea.

Additionally, all sheep in this experiment showed a tremor 15-20 minutes after inulin infusion. It being more marked the greater the dose. However, food and water intakes were not affected.

The body weights of the sheep in 20° were not significantly altered by salt treatments, but at 40° they significantly increased from low to medium with no further increase with the high salt treatment. The weights were significantly heavier in the 40 compared to the 20° environment. The animals were weighed at the end of each treatment.

Sodium, water and organic matter intakes (Table 7.2)

In accordance with sodium content in drinking water, salt treatments were divided into low (tap water - 0% NaCl), medium (0.6% NaCl w/v) and high (1.35% NaCl w/v).

Sodium intake increased significantly with increased sodium content in the drinking water either at 20 or 40°. Accompanying water intake, the increased intake of sodium on medium and high salt treatments was significantly greater at 40° than at 20°. However, there were no significant differences in ingested water between medium and high salt treatments at either temperature (Table 7.2 and Figure 7.1). Concerning effects of temperature, there were no significant differences in sodium intakes between 20 and 40° on low salt water (≈ 100 mmol/d), and between high salt water in 20° compared to medium salt water in 40° (≈ 1000 mmol/d), but water intake at 40° was double that at 20°.

Organic matter intake decreased significantly with salt and thermal loads, but there were no significant differences in the intakes between medium and high salt treatments either in 20 or 40°.

Digestion, absorption and rumen fluid dynamics (Table 7.3, Figure 7.1 and 7.2)

Table 7.3 shows that apparent organic matter digestibility in the sheep in 20° was not significantly altered with increased sodium intakes, but in 40° the digestibility was increased significantly by medium and further by high salt water. The effect of temperature on digestibility was not significant when fresh water was offered, but when the sheep were on 1000 mmol salt intake per d, the digestibility was significantly higher at 40° compared to that at 20° (Table 7.3). However. there were no significant effects of salt or thermal load on the amounts of digestible organic matter ($g/kgW^{0.75}/d$).

The outflow rates of rumen fluid (% per h) in 20° (Table 7.3 and Figure 7.1) were not significantly altered by different salt intakes, but at 40° they decreased gradually and they were significant lower on high salt water. The effect of temperature on the outflow rates indicated a reverse pattern to that of the percentage digestibility. It was not significant when fresh water was offered, but it was significantly lower at 40° than at 20° when the sheep had consumed ≈1000 mmol salt per d.

There were significant negative relationships between the flow rates of rumen fluid and organic matter digestibility at the 20 and 40° (Figure 7.2). Six additional data for 20° were obtained from the previous study (Chapter V).

Apparent water and sodium absorption showed the same pattern of increasing with increasing salt consumption. The absorption was significantly higher at 40° than at 20°. There were highly significant positive relationships between apparent water and sodium absorptions as shown in Figure 7.3.

The rumen fluid volume of the sheep (Table 7.3) was not significantly altered with increased sodium intake at 20°, but at 40°, the volume increased significantly when the sheep were exposed to high salt water. The effect of temperature was not significant on low salt water, but it was significant when the sheep had consumed 1000 mmol salt per d. The volume was greater in 40° than in 20°.

Distribution and dynamics of body fluid (Table 7.4 and 7.5, Figure 7.5)

Tritiated body water space (TBWSp) (ml/kg$^{0.82}$ bw) in the sheep was increased by drinking salt water either at 20 or 40° (Table 7.4). Raising the temperature from 20 to 40° increased TBWSp significantly either on the intake of ≈100 or 1000 mmol salt/d. A similar response occurred in extracellular fluid volume (ECF). As a proportion of TBWSp (% TBWSp), however, ECF or rumen fluid volume were not significantly altered by salt or thermal loads.

Water turnover rate (WTOR) increased with increased salt intake and thermal load (Table 7.5). At 20°, the effect of salt was significant when high salt water was offered. At 40°, it was significant when medium or high salt water was offered. However, there were no significant differences between medium and high salt treatments either at 20 or 40°. The effect of raising the temperature with the same intake of salt (≈ 100 or 1000 mmol salt per d) was to increase WTOR significantly, and it was acccompanied by the increase in water intake with approximately the same increment (Table 7.2 and Figure 7.4).

Estimated metabolic water (ml/kgW$^{0.82}$bw/d) (Table 7.5) in the sheep showed different responses with different salt intakes at 20 and 40°. In 20°, there was no significant effect of increasing salt intakes on metabolic water production, but at 40° it was gradually increased. Increasing temperature from 20 to 40° increased metabolic water production either with ≈100 or 1000 mmol salt per d.

Urinary and insensible water losses (ml/kg$W^{0.82}$bw/d) (Table 7.5) were increased with increased temperature from 20 to 40° either on ≈100 or 1000 mmol salt per d, but faecal water losses were significantly lower at 40 than at 20°.

In accord with increased salt intake, the water losses through those routes indicated different responses. When expressed as ml/kg$W^{0.82}$/d, urinary and insensible water losses increased with increased salt intake either at 20 or 40°. However, there were no significant alterations in the faecal water losses at 20° or 40°, although the trend was to gradually increase with increased salt intakes at 20°.

When expressed as a proportion of WTOR (Table 7.5 and Figure 7.5), there was no significant effect of salt or thermal load on urinary losses except when fresh water was offered at 40° which was lower than at 20°. On the other hand, insensible water loss with this treatment (fresh water in 40°) was significantly higher compared with the other treatments. At 20 or 40°, different intakes of salt did not significantly influence the proportion of water losses through the urinary or insensible route, but insensible loss at 40° was significantly higher compared to those at 20°.

Faecal water losses (%WTOR) did not significantly decrease with the increased salt intake either at 20 or 40°, but the losses at 20° were significantly greater. Moisture content of the faeces increased significantly with salt load at 20 or 40°, but increasing the temperature from 20 to 40° decreased the moisture content significantly (Table 7.5).

Sodium excretion (Table 7.6)

Concentrations of sodium in urine at 20 or 40 °C increased significantly with increased salt intake. However, increasing temperature from 20 to 40° with ≈1000 mmol salt per d in which water intake (Table 7.2) and urinary water loss (Table 7.6) in 40° were about double of that in 20°, urinary sodium concentration was significantly lower in 40° compared to that in 20°. The proportion of sodium excreted in the urine increased significantly with increased sodium intake, and was higher at 40 than at 20°.

Faecal sodium concentration (mmol/l faecal water) increased significantly with increased salt intake, and was lower at 40 than at 20°. As a proportion of sodium intake, the excretion through faeces decreased significantly with increased salt intake at 20 or 40°, and the proportion was lower at 40 than at 20°.

Table 7.1. Salt Treatments and Variations of Temperature and Humidity

Salt Treatment (% w/v)	Days	Temperature min - max (° C)	Humidity min - max (%)
0	7	15 - 20	35 - 55
0	8	15 - 20	40 - 50
0	10	15 - 20	40 - 60
0	5	15 - 20	40 - 60
0.6	8	15 - 20	40 - 65
0.6	10	15 - 20	40 - 60
0.6	5	15 - 20	40 - 60
1.35	8	15 - 20	30 - 60
1.35	10	15 - 20	30 - 60
1.35	5	15 - 20	30 - 60
0	2	40 - 40	40 - 55
0	2	20 - 25	40 - 60
0	8	30 - 40	35 - 55
0	8	35 - 40	35 - 40
0	10	35 - 40	35 - 40
0	5	35 - 40	35 - 45
0.6	8	35 - 40	30 - 40
0.6	10	35 - 40	35 - 40
0.6	5	35 - 40	35 - 40
1.35	8	35 - 40	35 - 50
1.35	10	35 - 40	30 - 50
1.35	5	35 - 40	40 - 40
Sum	157		

Table 7.2. Mean values (n = 6) of body weights, feed, water and sodium intakes

Parameters	Temp. ° C	Salt Treatments		
		low	medium	high
Body weight (W) (kg)	20	42.9 ± 2.6 a	43.1 ± 2.9 a	43.5 ± 2.9 a
	40	44.9 ± 3.9 a	46.1 ± 3.0 b	46.1 ± 3.2 b
	20 vs 40	**	**	**
Organic matter intake (OMI) ($g/kgW^{0.75}/d$)	20	56.3 ± 9.8 a	50.6 ± 9.7 b	50.2 ± 7.5 b
	40	50.7 ± 9.7 a	45.2 ± 10.9 b	43.8 ± 8.8 b
	20 vs 40	*	*	**
Ingested water (IW.1) ($ml/kg\ W^{0.82}/d$)	20	106.3 ± 22.8 a	125.7 ± 34.4 a b	166.8 ± 44.9 b
	40	213.5 ± 22.0 a	336.1 ± 85.2 b	350.0 ± 62.3 b
	20 vs 40	*	**	**
Ingested water (IW.2) (ml/100g dmi/d)	20	229.9 ± 19.0 a	302.6 ± 52.1 a b	399.1 ± 66.4 b
	40	501.9 ± 44.4 a	866.1 ± 66.5 b	935.4 ± 80.2 b
	20 vs 40	**	**	**
Sodium intake (SI.1) (mmol/d)	20	106.8 ± 13.9 a	381.6 ± 93.3 b	1027.4 ± 152.7 c
	40	104.0 ± 17.3 a	972.7 ± 101 b	2092 ± 213.1 c
	20 vs 40	ns	**	**
Sodium intake (SI.2) ($mmol/kgW^{0.82}/d$)	20	4.9 ± 0.6 a	17.4 ± 4.3 b	46.6 ± 6.9 c
	40	4.6 ± 0.8 a	42.0 ± 4.6 b	90.4 ± 9.7 c
	20 vs 40	ns	**	**

Mean values on the same row with different letters are significantly different ($P < 0.05$)
Mean values in the same cell (Temp. 20 Vs. 40) :
* = differ significantly at level $P < 0.05$
** = differ significantly at level $P < 0.01$
ns = non-significant

Significance of differences between means of HIGH-20 and MEDIUM-40	
W	**
OMI	*
IW.1	**
IW.2	**
SI.1	ns
SI.2	ns

Table 7.3. Mean values (n = 6) of digestibility and absorption, and dynamics of rumen fluid

Parameters	Temp. (°C)	SALT TREATMENTS low	medium	high
Digestibility and absorption				
App. organic matter digestibility (OMD.1) (%)	20 40 20 Vs 40	58.0 ± 1.6 a 59.5 ± 1.6 a ns	58.7 ± 1.55 a 62.9 ± 1.75 b **	59.6 ± 2.5 a 65.4 ± 2.8 c **
App.digestible organic matter (OMD.2) (g/kgW$^{0.75}$/d)	20 40 20 Vs 40	32.5 ± 4.8 a 30.1 ± 5.6 a ns	31.0 ± 3.3 a 29.3 ± 4.8 a ns	30.5 ± 2.3 a 28.8 ± 4.7 a ns
App.water absorption (WA) (%)	20 40 20 Vs 40	72.1 ± 2.4 a 89.8 ± 3.2 a **	73.8 ± 5.1 a 93.9 ± 2.4 b **	79.5 ± 4.4 b 94.3 ± 1.0 b **
App. Na digestibility (NaD) (%)	20 40 20 Vs 40	60.0 ±0.8 a 85.9 ± 2.2 a **	70.9 ± 3.1 b 95.9 ± 2.1 b **	75.1 ± 1.4 c 96.5 ± 1.0 b **
Dynamics of rumen fluid				
volume (RV.1) (ml/kgW$^{0.82}$)	20 40 20 Vs 40	292.8 ± 13.6 a 301.3 ± 18.6 a ns	320.7 ± 23.1 a b	305.8 ± 12.2 a 348.6 ± 26.2 b **
volume (RV.2) (% bw)	20 40 20 Vs 40	14.9 ± 1.8 a 15.2 ± 1.9 a ns	16.1 ± 1.6 a b	15.5 ± 2.5 a 17.5 ± 2.1 b **
Flow rate (FR.1) (ml/kgW$^{0.82}$/h)	20 40 20 Vs 40	27.0 ± 5.2 a 26.3 ± 2.9 a ns	24.3 ± 3.0 a b	27.8 ± 5.8 a 23.8 ± 3.7 b **
Flow rate (FR.2) (% rumen vol./h)	20 40 20 Vs 40	9.2 ± 1.0 a 8.8 ± 0.4 a ns	7.6 ± 0.4 a b	9.0 ± 1.0 a 6.8 ± 0.6 b **
Endogenous fluid influx into the rumen (EFI) (ml/kgW$^{0.82}$/d) §	20 40 20 Vs 40	567.4 ± 68.1 a 468.6 ± 35.3 a *	326.5 ± 77.4 b	540.2 ± 70.6 a 304.4 ± 75.4 b **

Mean values on the same row with different letters are significantly different ($P < 0.05$)
Mean values in the same cell (Temp. 20 Vs. 40) :
* = differ significantly at level $P < 0.05$
** = differ significantly at level $P < 0.01$
ns = non-significant
§ = Flow rate of rumen fluid - 76% ingested water (see Chapter IV)

Table 7.4. Mean values (n = 6) of body water space and its distribution

Parameters	Temp. (° C)	SALT TREATMENTS		
		low	medium	high
Tritiated body water space (TBWSp.1) ($ml/kgW^{0.82}$)	20	1284 ± 35.1 a	1314 ± 40.0 ab	1360 ± 43.8 b
	40	1356 ± 51.1 a	1418 ± 40.4 b	1504 ± 48.3 c
	20 Vs 40	*	**	**
Tritiated body water space (TBWSp.2) (% bw)	20	65.3 ± 1.5 a	66.8 ± 1.5 ab	69.0 ± 1.7 b
	40	68.4 ± 1.7 a	71.2 ± 1.7 b	75.5 ± 1.9 c
	20 Vs 40	*	**	**
Extra-cellular fluid space (Inulin space)(ECF.1) ($ml/kgW^{0.82}$)	20	387.9 ± 26.6 a	397.1 ± 24.0 ab	413.82 ± 25.5 b
	40	420.5 ± 22.6 a	446.9 ± 20.2 b	484.51 ± 24.3 c
	20 Vs 40	**	**	**
Extra-cellular fluid space (Inulin space)(ECF.2) (% TBWSp)	20	30.2 ± 1.8 a	30.2 ± 1.5 a	30.4 ± 1.5 a
	40	31.0 ± 2.1 a	31.5 ± 2.6 a	32.2 ± 1.6 a
	20 Vs 40	ns	ns	ns
Rumen fluid volume (RV.3) (% TBWSp)	20	22.1 ± 1.1 a		22.8 ± 0.9 a
	40	22.2 ± 2.6 a	22.6 ± 1.8 a	23.1 ± 2.3 a
	20 Vs 40	ns		ns

Mean values on the same row with different letters are significantly different ($P < 0.05$)
Mean valuesd in the same cell (Temp. 20 Vs. 40) :
* = differ significantly at level $P < 0.05$
** = differ significantly at level $P < 0.01$
ns = non-significant
TBWSp = tritiated body water space

Significance of differences between means of HIGH-20 and MEDIUM-40

TBWSp.1	*
TBWSp.2	*
ECF.1	**
ECF.2	ns
RV.3	ns

Table 7.5. Mean values of water turnover rate and water losses

Parameters	Temp. (°C)	Salt treatments		
		low	medium	high
Water turn-over rate (WTOR) ($ml/kgW^{0.82}/d$)	20 40 20 Vs 40	122.8 ± 24.5 a 242.1 ± 76.3 a * *	147.6 ± 34.5 a b 367.2 ± 187.2 b * *	184.7 ± 45.7 b 385.6 ± 163.2 b * *
Est.metabolic water (EMW) ($ml/kgW^{0.82}/d$)	20 40 20 Vs 40	17.3 ± 2.9 a 30.0 ± 4.9 a * *	23.1 ± 6.6 a 33.3 ± 3.9 a b * *	19.0 ± 2.4 a 37.8 ± 7.8 b * *
Plasma-inulin dissp.rate (PIDR) (ml/min)	20 40 20 Vs 40	89.6 ± 9.0 a 139.4 ± 15.3 a * *	107.6 ± 12.9 a 152.2 ± 14.9 b * *	134.0 ± 17.2 b 206.3 ± 14.7 c * *
Urinary water loss (UW.1) ($ml/kgW^{0.82}/d$)	20 40 20 Vs 40	55.2 ± 8.2 a 70.6 ± 7.8 a * *	66.5 ± 12.9 a 175.6 ± 19.9 b * *	87.7 ± 15.7 b 192.9 ± 18.7 b * *
Urinary water loss (UW.2) (% WTOR)	20 40 20 Vs 40	44.9 ± 3.4 a 29.2 ± 3.2 a * *	45.1 ± 4.1 a 47.8 ± 7.6 b n s	47.5 ± 7.1 a 50.0 ± 8.5 b n s
Faecal water loss (FW.1) ($ml/kgW^{0.82}/d$)	20 40 20 Vs 40	29.4 ± 6.1 a 21.6 ± 6.9 a * *	32.6 ± 6.9 a 20.4 ± 8.6 a * *	34.0 ± 6.7 a 19.9 ± 7.4 a * *
Faecal water loss (FW.2) (% WTOR)	20 40 20 Vs 40	23.9 ± 2.2 a 8.9 ± 1.0 a * *	22.1 ± 4.1 a 5.6 ± 1.7 a * *	18.4 ± 3.2 a 5.2 ± 0.7 a * *
Faecal moisture content (FMC) (%)	20 40 20 Vs 40	59.7 ± 1.3 a 55.4 ± 1.7 a * *	64.8 ± 1.9 b 58.9 ± 3.1 b * *	66.6 ± 1.6 b 60.6 ± 2.9 b * *
Est.insensible water loss (EIW.1) ($ml/kgW^{0.82}/d$)	20 40 20 Vs 40	38.2 ± 8.1 a 149.9 ± 10.5 a * *	48.5 ± 6.8 b 171.2 ± 8.5 b * *	63.1 ± 6.7 c 172.8 ± 9.4 b * *
Est.insensible water loss (EIW.2) (% WTOR)	20 40 20 Vs 40	31.1 ± 2.5 a 61.9 ± 2.7 a * *	32.9 ± 3.4 a 46.6 ± 3.2 b * *	34.1 ± 2.2 a 44.8 ± 2.6 b * *

Table 7.6. Mean values (n = 6) for sodium excretion

Parameters	Temp. (° C)	Salt treatments		
		low	medium	high
Urinary sodium (U-Na.1) (mmol/l)	20	51.8 ± 16.8 a	184.7 ± 35.9 b	397.6 ± 65.1 c
	40	53.6 ± 34.8 a	230.9 ± 30.8 b	460.8 ± 39.5 c
	20 vs 40	ns	**	**
Urinary sodium (U-Na.2) (% Na intake)	20	58.4 ± 0.6 a	70.4 ± 0.5 b	74.9 ± 0.5 c
	40	82.3 ± 1.7 a	95.5 ± 0.8 b	96.3 ± 0.8 b
	20 vs 40	**	**	**
Faecal sodium (F-Na.1) (mmol/l fae.water)	20	66.3 ± 0.7 a	155.9 ± 13.5 b	341.6 ± 31.4 c
	40	30.0 ± 2.8 a	84.4 ± 11.4 b	158.8 ± 29.3 c
	20 vs 40	**	**	**
Faecal sodium (F-Na.2) (% Na intake)	20	39.8 ± 0.7 a	29.1 ± 0.4 b	24.9 ± 0.5 c
	40	14.1 ± 1.5 a	4.1 ± 0.8 b	3.5 ± 0.8 c
	20 vs 40	**	**	**
Na balance (mmol/d)	20	+ 1.95 ± 0.06 a	+ 2.00 ± 0.04 a	+ 2.02 ± 0.06 a
	40	+ 3.73 ± 0.03 a	+ 3.76 ± 0.03 a	+ 3.78 ± 0.03 a
	20 vs 40	**	**	**

Mean values on the same row with different letters are significantly different ($P < 0.05$)

Mean values in the same cell (Temp. 20 Vs. 40) :

* = differ significantly at level $P < 0.05$

** = differ significantly at level $P < 0.01$

ns = non-significant

Significance of differences between means of HIGH-20 and MEDIUM-40

U-Na.1	**
U-Na.2	**
F-Na.1	**
F-Na.2	**
Na-balance	**

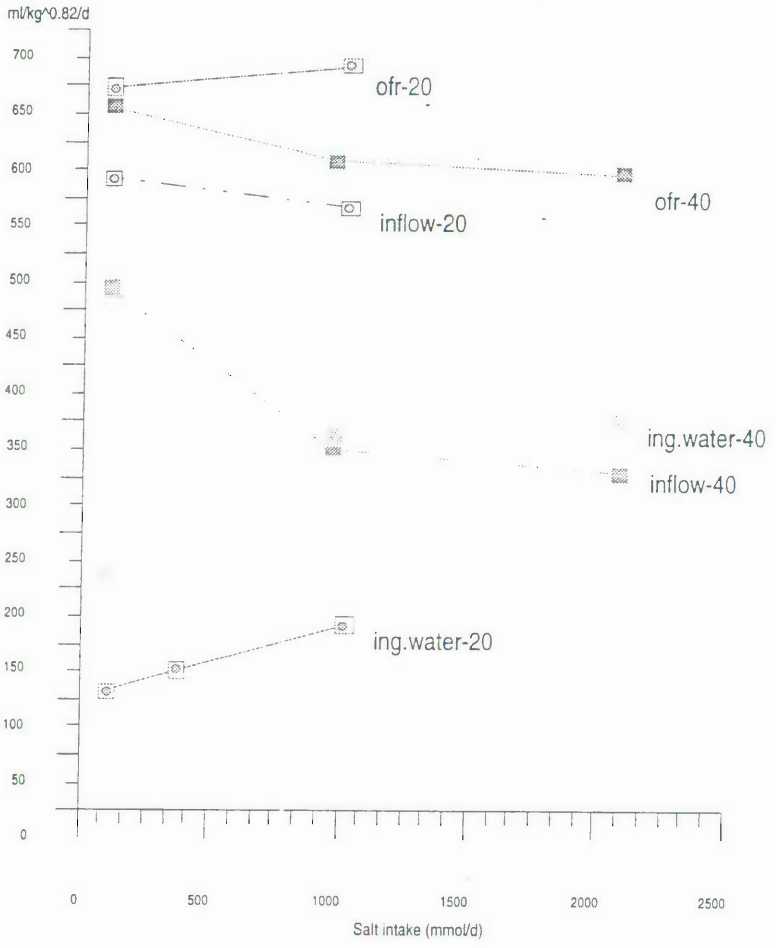

Figure 7.1. Outflow rate of rumen fluid (ofr), ingested water (ing.water) and endogenous fluid inflow into the rumen (inflow) in 20 and 40°C

Each point is the mean for 6 animals

$$Y = 87.54 - 3.18\,X \;;\; r = -0.82 \;(20)$$

$$Y = 79.47 - 2.16\,X \;;\; r = -0.78 \;(40)$$

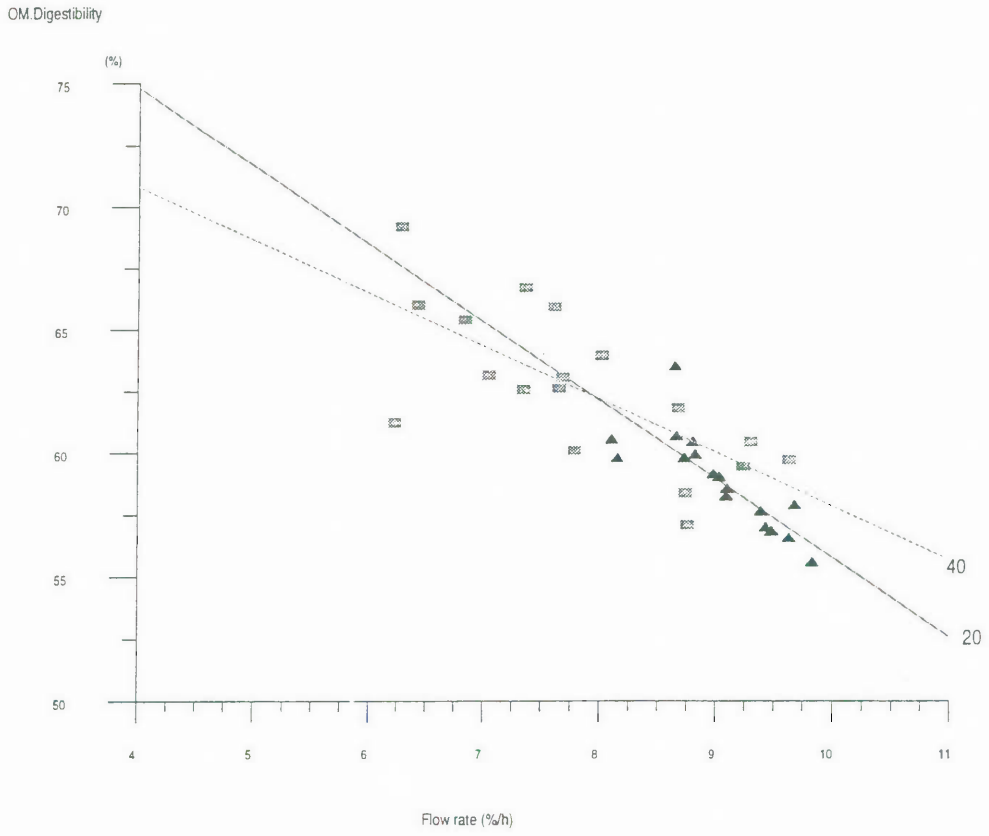

Figure 7.2. Relationships between flow rate of rumen fluid and organic matter digestibility in 20 and 40°C

Each point is the mean for 6 animals

$$Y = -43.08 + 1.35\,x \;;\; r = +0.89\,** \quad (20)$$
$$Y = 15.23 + 0.83\,x \;;\; r = +0.90\,** \quad (40)$$

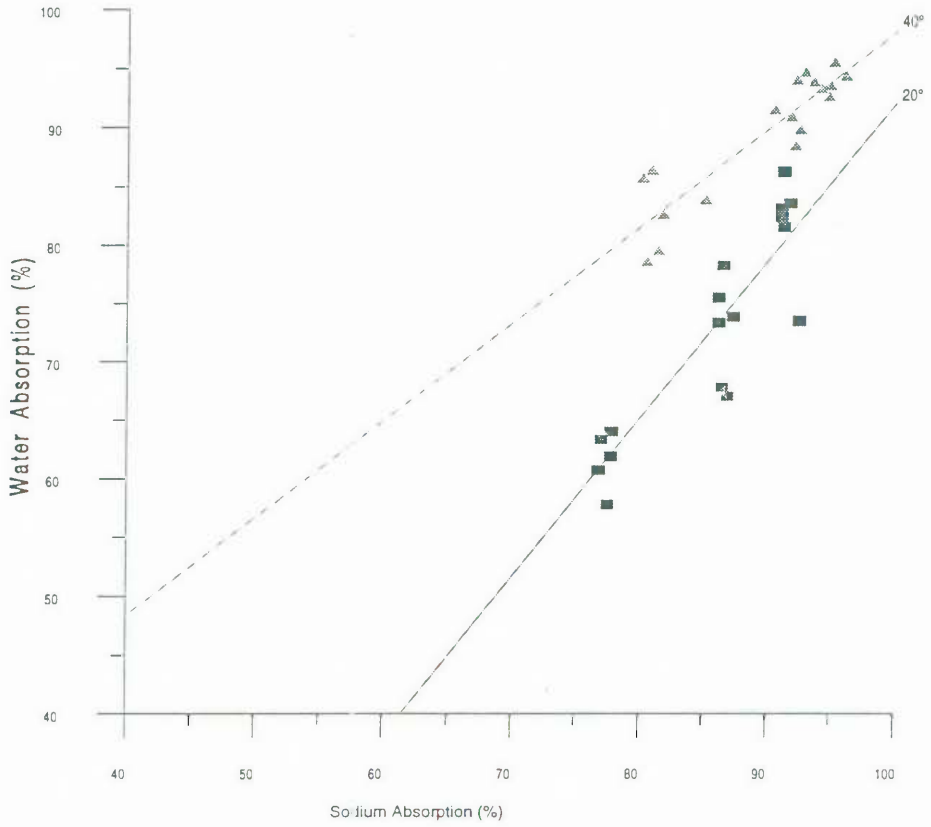

Figure 7.3. Relationship between water and sodium absorption from the gut in 20 and 40°C

Each point is the mean for 6 animals

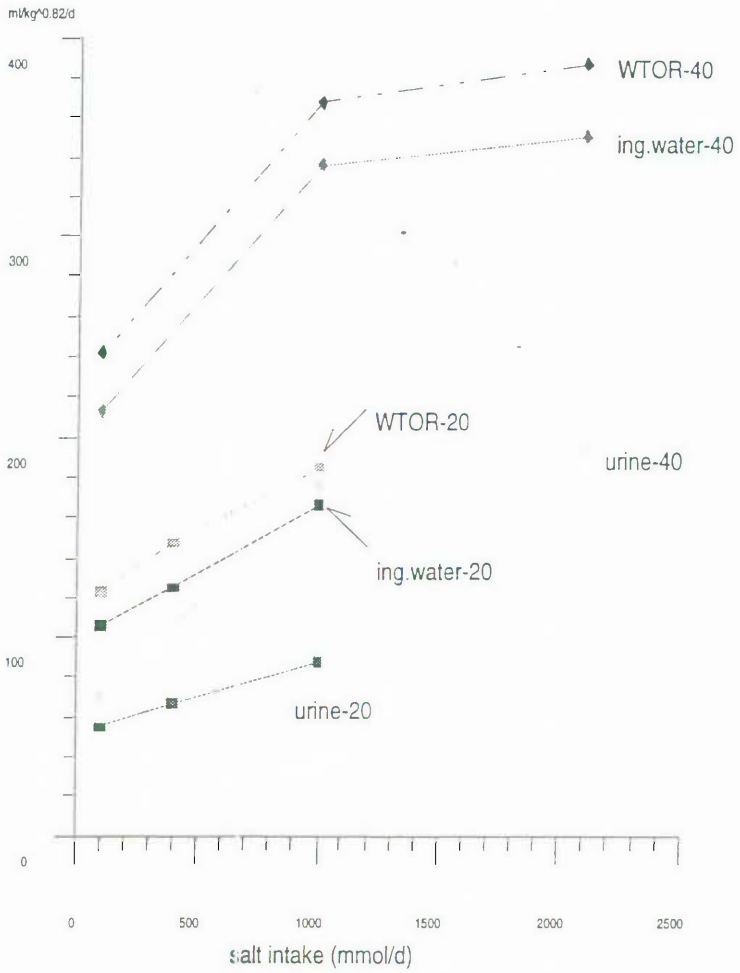

Figure 7.4. Ingested water (ing.water), water turn-over rate (WTOR) and urinary water loss (urine) in 20 and 40°C

Each point is the mean for 6 animals

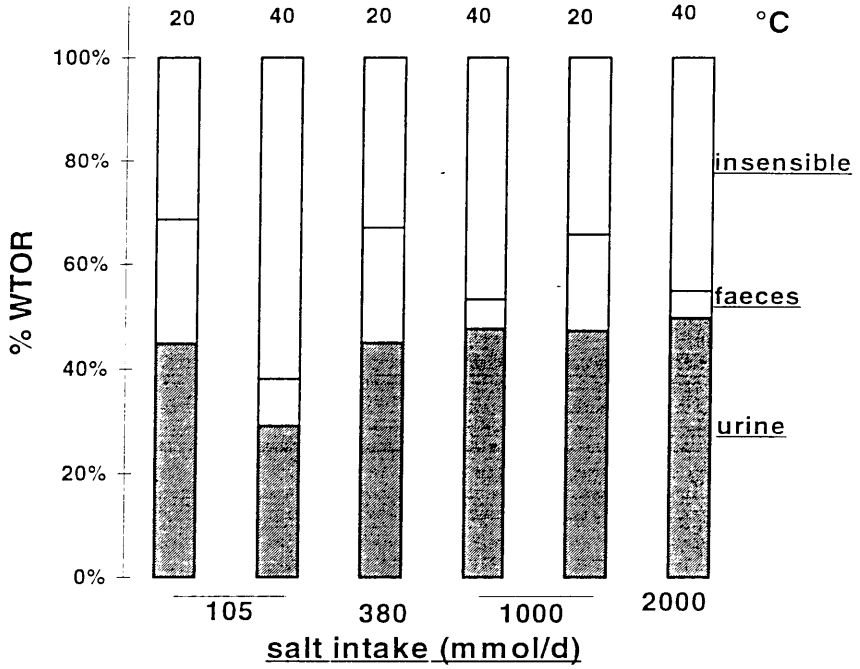

Figure 7.5. Distribution of water turn-over rate in 20 and 40°C into urine, faeces and insensible losses (% WTOR)

DISCUSSION

The aims of this study were primarily to elucidate the distribution and dynamics of body fluid in sheep in response to thermal and salt loads imposed simultaneously.

There is a possibility of confounding effects of the differences in feed and water intakes with salt and thermal loads, since feed or water intake is known to affect digestibility (Blaxter, 1967; More and Shani, 1981; Silanikove, 1991) and flow rate of rumen fluid (Grovum and Williams, 1977; Lindberg, 1988).

However, the results from the present study showed that the differences in feed and water intakes at 20° or between 20 and 40° on low salt water did not significantly influence the digestibility, volume and flow rate of rumen fluid. Results from other studies have revealed that hot environments do not depress flow rate or rumen activities of sheep and cattle by depressing feed intake (Attenbury and Johnson, 1969; Warren, Martz, Asay, Hidelbrand, Payne and Vogt, 1974). Grovum and Williams (1977) showed that increasing flow rate by 50% with increased chaff intake from 400 to 1300 g/d in sheep did not alter organic matter digestibility. Similarly, Silanikove (1992) concluded that a 10 to 30% reduction in feed intake does not appreciably affect digestion or flow rate.

Therefore, the possibility of confounding effects caused by different intakes of food and water in this experiment was inconclusive. In fact, the reduced feed intake as an effect of salt and thermal loads was compensated by the increase in digestibility, and therefore organic matter and energy availability were unchanged (Table 7.3).

The increased water intake and the decrease in feed consumption by the sheep drinking salt water are consistent with the previous studies (Chapter III and V), and are also in agreement with results reported by Pierce (1957) and Wilson (1966b). A similar result was shown as the effect of increasing temperature from 20 to 40°. This thermal load effect is also in agreement with previous studies on sheep (Bailey,1964; Bhattacharya and

Hussain, 1974; Guerrini, 1981), and steers (Colditz and Kellaway, 1972) although both of these studies were carried out in a lower temperature regime.

The alteration on food and water intakes are apparently responses of a complex mechanism involving neural and hormonal actions (Hafez, 1968). The simultaneous effects of salt and thermal loads increased water requirements to excrete the excesses of ingested salt (osmoregulation) and to dissipate the excessive heat load (thermoregulation). Additional heat loading presumably resulted not only from the hot environment but also from the animal's metabolic activities which were increased by salt load as indicated by increased insensible water losses (see Chapter III and V). In this situation, the decrease in food intake is an alternative way to reduce heat increment.

However, the further increases of salt intake from about 1000 to 2000 mmol per day at 40° did not markedly alter the intakes of water or food. (Table 7.2, and Figure 7.4). By comparison with the results reported in Chapter III, when the sheep were on high salt treatment (99 mmol/kg$W^{0.82}$/d or 1900 mmol/d) infused directly into the rumen, the present result suggests that the level of salt intake in both experiments was presumably associated with the inherent electrolyte-concentrating ability of the kidney to excrete the excessive salt. Anatomically, prolonged ingestion of sodium chloride does not induce an increase in the number of active tubules in kidney (Potter, 1963).

On these two occasions of different salt presentations, the sheep consumed about the same intakes of water and organic matter although fresh water in the previous study was freely available. It is surprising, therefore, that the sheep in the previous study drank fresh water to the extent that the salt/water ratio was about the same as in the present study (1.35 % sodium chloride w/v). This result is in agreement with previous studies reported by Pierce (1957, 1963) and Wilson (1966) that sheep have the ability to tolerate drinking salt water with concentrations between 1.0 and 1.5%, without ill effect.

There were some consequences of no alteration in water intake between 1000 and 2000 mmol sodium intake per d at 40°. Water turn-over rates and urinary water loss with these two levels of sodium intake were not markedly different (Table 7.5 and Figure 7.4). In addition faecal water and insensible losses were also unaffected. As a result, the concentration of sodium in the urine was significantly greater with the high sodium intake (Table 7.6).

However, concerning the effects of temperature, there were some differences compared to the previous study. These were in the proportions of sodium intake excreted through urine and faeces, and in the proportions of water loss through urination, defaecation and evaporation (insensible loss) albeit water turn-over rates were about the same.

The changes in digestibility and flow rate of rumen fluid (Table 7.3) are indicative of an interaction between salt and thermal loads. At 20°, the flow rate and digestibility were not significantly altered with different salt intakes, but at 40° the flow rate was gradually decreased with increased salt intake from 100 to 1000 and further to 2000 mmol/d, while digestibility had a reverse response.

The slower flow rate at 40° with increased salt intake may possibly be attributed to a number of factors, including higher brain centres which are responsible for reduction of rumen motility (Attenbery and Johnson, 1969; Christopherson and Kennedy, 1983; Miaron and Christopherson, 1992; Warren *et al.*, 1974) and rumination activity (Appleman and Delouche, 1958). These centres are affected to some extent by the temperature in the hypothalamus, regulating both food intake and rumen turnover rate. A lower environmental temperature such as $20^{o\ W}$ stimulates rumen motility (Christopherson and Kennedy, 1983).

A number of experiments have indicated that drinking salt water increased osmotic pressure and sodium concentration in rumen fluid (Warner and Stacy, 1966; Tomas and

Potter, 1975; Potter *et al.*, 1972; Barrio, Bapat and Forbes, 1991), and decreased the microbial population without a significant alteration in ruminal metabolic activity (Potter *et al.*, 1972). In addition to a determinant factor reducing feed intake (Grovum and Bignell,1989), the increase in osmotic pressure is well known to increase sodium absorption (Stacy and Warner, 1966; von Engelhardt, 1970), and to depress salivation flow rate (Tomas and Potter, 1975; Warner and Stacy, 1977; Silanikove and Tadmore, 1989), while net flux of water across the rumen wall is negligible (von Englehardt, 1970; Warner and Stacy, 1972). The absorption of fluid from the rumen will be increased during rehydration in sheep when osmotic pressure is decreased (Dahlborn and Holtenius, 1990).

In agreement with these findings, calculation of endogenous inflow fluid into the rumen from compartments other than ingested water minus bypassed water (Chapter IV), revealed that at 20° the endogenous inflow fluid was not significantly decreased by salt load (1000 mmol/d), but increasing temperature to 40° with 100 or 1000 mmol salt intake per d decreased the inflow fluid (Table 7.3. and Figure 7.3.), with no significant further decrease on 2000 mmol salt intake per d. In accord with the findings of Warner and Stacy (1972) and Tomas and Potter (1975), most of this inflow fluid apparently originated from saliva in addition to the net-flux fluid between rumen and blood.

Kay (1960a) showed that salivary flow rates in Merino and Scottish Black Face sheep vary from 8 to 16 liters per d. This flow rate constitutes 70-90 % of the rumen fluid dilution rate (Silanikove, 1992). The results of the present study indicate that the total amounts of saliva plus or minus net-flux of fluid rumen to or from the blood were 84 % of the outflow rate of rumen fluid at 20°, but at 40°, irrespective of salt intake, this was decreased to 74.8, 57.4 and 53.3% with 100, 1000 and 2000 mmol salt intake per day respectively (Table 7.3. and Figure 7.3.).

Additionally, the responses in volume and outflow rate of rumen fluid on salt or thermal load may also have resulted from responses in rumen motility. Christopherson and Kennedy (1983) in a review of various studies suggested that in addition to the direct

responses by neural mechanisms (parasympathetic and sympathetic), depression of thyroid hormone secretion with increased environmental temperature may play an important role by decreasing the motility of the reticulorumen and in turn causing in a slower flow rate of rumen fluid to the omasum. Reticulorumen motility is closely coordinated with the activity of the reticuloomasal orifice and may be important in determining flow rate of fluid and fine particles (Titchen, 1968; Reid, Post and Titchen, 1991).

Tritiated body water space (TBWSp) increased in response to both thermal and salt load imposed singularly or simultaneously (Table 7.4.). This response may possibly occur in the first few days of the treatments and then be maintained with the treatments (Hladky and Rink, 1986). The rise in TBWSp with increasing salt intakes at 20° from 100 to 400 and further to 1000 mmol salt per d seems to be inconsistent with the results shown in Chapter III. The different results may be attributed to the differences in the persentation of salt. In the previous study (Chapter III), salt solution was infused intraruminally and nearly salt-free water (0.003% Na) was freely available, which also may have affected the overall water and salt dynamics. With the same thermoneutral environment and with about the same intake of sodium (50 mmol/kg$W^{0.82}$/d), the sheep in the previous study had an opportunity to maintain the excreted urine relatively dilute. The animals indeed had a higher intake of water compared to the sheep in the present study.

Consistent with the results of the previous experiment in feral goats (Chapter VI), the sheep in 40° virtually maintained constant their distribution of body water to the rumen and extra-cellular fluid (% TBWSP) (Table 7.4) with no significant effect of different salt intakes. This phenomenon also applied at 20° with the different salt intakes or at 20 and 40° with the same salt intake (1000 mmol salt per d). Additionally, rumen fluid volume (% TBWSp) in the sheep and Angora goats reported in Chapter III (Table 3.2) also indicated a similar response with different amounts of salt being infused intraruminally. In accordance with the water pool model proposed by Faichney and Boston (1985), this

phenomenon indicates that the distribution of body water in normal hydration, whether with salt or thermal loads, is maintained relatively constant. This occurs because the free movement of water between compartments depends mostly on osmotic gradient. Under the conditions of dehydration or water restriction, however, this phenomenon will not occur, since continuous losses of water are not balanced with the influx of water. Calculation from data presented by Purohit, Ghosh and Taneja (1972) from dehydration experiments on sheep, shows that extra-cellular fluid volume relative to total body water was about constant, although the absolute values decreased during water restriction. From an experiment in cattle and camels, Siebert and MacFarlane (1971) suggested that under severe dehydration, plasma volume is reduced by only about 5%, and this volume is maintained by absorption of water from the alimentary tract. This observation has also been demonstrated in the sheep (Hecker, Budtz-Olsen and Ostwald, 1964)

The increased TBWSp in the sheep with the low salt intake as the response to increasing temperature has also been shown in other studies (Macfarlane, 1968), black Bedouin goats (Silanikove, 1987), dairy cattle and buffalo (Kamal and Seif, 1969; Seif, Johnson and Hanh, 1973). This response is presumably an adaptive mechanism to hot environments, since the expanded body water pool will allow the animals to store a greater amount of heat without drastic body temperature changes because of the high specific heat of water (Macfarlane, 1968; Quinton, 1979).

The responses in WTOR are indicative of the responses to intake of water (Table 7.2) and outflux of water through urine, faeces and insensible water losses (Table 7.5 and Figure 7.5). The mechanisms controlling water losses through these routes are very complex and are presumably different from each other, involving both neural and hormonal influences. The result of the present experiment shows that the relative importance (% WTOR) (Table 7.5) of each route does not appear to be influenced by different intakes of salt regardless of temperature, except when the sheep were on fresh water in the heat, the urinary loss was reduced concomitantly with the increased insensible loss. This suggests that under the condition of high temperature without an

excessive intake of sodium, conservation of water occurred not only from a decreased faecal water loss but also from a decreased urinary loss. This indicates an increased water reabsorption from the kidney tubules. However, the reduced urinary loss seem to be limited by the inherent concentrating ability of the kidney and the intake of sodium. With excessive intake of sodium at 40°, the mechanisms presumably resulted in a reduced water conservation by the kidney in association with the need to increase sodium excretion (natriuresis).

Presumably, there are two different mechanisms controlling water and salt excretion from the kidney with regard to the responses to salt and thermal loads. In the condition of low sodium intake (fresh water) at high temperature (40°), the mechanism is apparently under the influence of anti diuretic hormone (ADH) induced by prolonged excessive insensible water loss (Whittow, 1968; Hladky and Rink,1986) as indicated by the higher water loss through this route compared to the other treatments. On the other hand, the expanded extra-cellular fluid volume caused by salt loads at 20 or 40°, is an opposed mechanism, and it is probably under the influence of atrial natriuretic peptide (ANP) induced by stretching of the atria during the cardiac cycle which resulted in inhibiting ADH secretion, renin-angiotensin-aldosterone (RAA) mechanism and increased glomerular filtration rate (see review in Chapter 2.2.4, and Chapter VI). The later mechanism seems to be well suited to restore fluid balance in volume-expanded animals (Olsen, Dahlborn, Karlberg and Eriksson, 1991).

The reductions in faecal water loss (Table 7.5) in the response to the thermal loads are apparently not only due to less faecal mass as the appetite declined, but especially to the increases in the postruminal absorption of sodium and water as indicated by a decreased proportion of sodium intake in the faeces. Wilson (1989) suggests that reduction in faecal water loss is achieved by sodium absorption from the colon, accompanied by a return of water to the blood. Different mechanisms seem to be responsible for the reduction in faecal water under the conditions of salt and thermal loading. Under the condition of low sodium intake at 40° the mechanism is presumably

under the influence of aldosterone (Yagis and Etzion, 1979) and ADH (Nicholson, 1981; Yagil and Etzion, 1979) which promotes sodium and water conservation in the colon as well as the kidney. However, under the condition of excessive intake of sodium at 20 or 40°, the mechanisms are uncertain. Possibly, the presence of ANP is also responsible in addition to the natriuresis and diuresis as mentioned previously (Chapter VI).

Clearly, the hypothesis stated in the introduction can be rejected with substantial changes occurring in each of the parameters mentioned, both with salt and thermal loading individually and in combination.

CHAPTER VIII

GENERAL DISCUSSION

GENERAL DISCUSSION

A series of experiments on water and salt metabolism in sheep and goats have involved several factors, including different levels of salt load and its presentation, different nitrogen contents of roughage diets, thermal load and species differences. In all experiments the animals were in normal hydration (drinking water was freely offered), but there were two different ways of salt presentation: 1. in drinking water (Chapter V, VI and VII), and 2. continuous intraruminal infusion of salt solution and fresh water was freely offered (Chapter III).

The continuous intraruminal salt infusion was to avoid the effects of taste differences between or within species. In addition, free access to fresh water is an opportunity for the animals to adjust an appropriate amount of water input in accord with input of salt for maintaining homeostasis of body fluid. By comparison, salt presentation in drinking water will have resulted in proportional changes in salt intake with the changes in fluid consumption.

In a thermoneutral environment (≈ 20°C) with the same diet of mixed roughage and input of salt through infusion or drinking water was approximately the same (≈40-50 mmol/kg$W^{0.82}$/d), fresh water intake by the infused sheep was markedly greater compared to the intake of water containing 1.35% sodium chloride (Table 3.1; 5.1;7.2). The differences in the water intakes of the sheep in the control period of these three occasions were negligible, whereas the increase in water intake by the infused sheep was greater (≈100%) compared to that of the sheep drinking salt water (≈40-60%). It follows that there were some differences in overall water and salt metabolism.

The greater increase in fresh water intake by the infused sheep resulted in a greater reduction in organic matter intake (≈30%) compared to that of the sheep drinking salt water (≈11-19%). Moreover, apparent organic matter digestibility of mixed roughage diet in the infused sheep (Chapter III) was significantly reduced (≈11%), whereas there was no significant effect of drinking salt water. These differences can partly be attributed to

the out-flow rate of rumen fluid (% rumen fluid volume/h) (Table 3.2; 5.2; 7.3), which was increased in the infused sheep, whereas no significant change resulted in the sheep drinking 1.35% salt water, although rumen fluid volume (ml/kgW$^{0.82}$) tended to be increased on all three occasions. A similar result was obtained by Godwin and Williams, (1986).

Concerning these two ways of salt presentation to Angora goats, there were no comparable data obtained. In all occasions of salt treatment in drinking water on Angora goats, the intake of salt was considerably lower compared to the input by infusion, or compared to the sheep. It is interesting to note that the goats consistently, consumed less salt when they were able to do so, by reducing their intake of salt water. This may reflect an evolutionary mechanism that allows them to conserve water when environmental conditions dictate that it is prudent to do so. Sheep on the other hand, having evolved in a less arid habitat may be less efficient with this mechanism.

Tritiated body water space (TBWSp) in the infused sheep was not significantly increased, while water turnover rate (WTOR) is double that of the control condition (Table 3.3). TBWSp in the sheep drinking 1.35% salt water increased in addition to the increases in WTOR (Table 7.4 and 7.5). In both conditions, glomerular filtration rate (GFR) was relatively increased more than 30% (Table 3.3 and 7.5), but urine volume from the infused sheep was double that from the sheep drinking salt water, which paralleled the differences in water intake. Consequently, sodium concentration in the urine from the sheep drinking salt water was higher than from the infused sheep (Table 4.3 and 7.6).

As reviewed and discussed previously, the homeostatic response to chronic excessive intake of salt is to enhance sodium excretion and to maintain a balance between sodium intake and sodium excretion through the kidney in particular. As intake of sodium is increased, renal sodium excretion is increased. However, the sodium excretion initially lags behind the excessive intake. This time delay in sodium excretion results in an initial positive sodium balance and an increased extracellular fluid (ECF) volume. By the greater

increase in fresh water intake, this condition of increased bodily sodium in the infused sheep would not be maintained, and the excessive intraruminally input of salt was mostly excreted as a diluted sodium concentration of the urine (Table 3.4), and TBWSp was gradually returned to the control level (Table 3.3). On the other hand, this increased bodily sodium persisted in the sheep drinking salt water. The increased volume of ECF (Table 7.4) triggers various volume receptors throughout the body to increase sodium excretion to prevent a further increase in ECF volume. Normally, activation of these volume receptors suppresses the renin-angiotensin-aldosteron system and sympathetic nervous system, whereas natriuretic factors such as atrial natriuretic peptide (ANP) are likely to be activated. The responses of ADH secretion and thirst sensation are apparently affected by fluctuations in plasma osmolality rather than ECF volume. This was apparent in both the infused sheep and the sheep drinking salt water.

By comparison with the Merino sheep, continuous intraruminal infusion of 100 mmol salt/kg$W^{0.82}$/d into the Angora goats (Chapter III) resulted in an increased TBWSP. In fact, at this level of salt infusion the goats consumed significantly less fresh water compared to the infused sheep.

In addition to the different responses of TBWSp, the infused Angora goats had a slower outflow rate of rumen fluid, but a higher digestibility of organic matter and nitrogen of roughage diets (Table 3.2), and a greater production of metabolic water (Table 3.3) compared to the infused sheep.

It has been documented by other workers that generally goats drink less water compared the sheep. In the same environmental temperature and water salinity, the data obtained from the present studies for the Angora and feral goats showed the same characteristic compared to the Merino sheep (Chapter III, V, and VI versus VII). With this characteristic, the goats have slower outflow rate of rumen fluid compared to the sheep.

Taken together, these physiological differences would favour the survival of goats relative to sheep to cope with a water limitation such as in an arid environment.

In a thermoneutral environment (≈ 20°C), the Merino sheep and Angora goats drinking salt water decreased their organic matter intakes of oaten or mixed roughage chaff by about 10-20% (Table 5.1 and 7.2). However, when lucerne chaff (more digestible) was given, the intake by the sheep increased by about 20%, whereas the intake by the goats decreased by about 50% (Table 5.1). Moreover, under this thermoneutral environment regardless of different roughage diets, there was a positive significant relationship between water intake and outflow rate of rumen fluid in the Merino sheep (Figure 5.1), whereas in the Angora goats this relationship was not significant (Figure 5.1). The consumption of water containing 1.35% salt by both the sheep and goats was generally greater compared to fresh water consumption, but an exception was for the Angora goats fed lucerne chaff (Table 5.1) which was lower compared to the intake of fresh water. Accordingly, the effect of drinking 1.35% salt water on outflow rate of rumen fluid in the Angora goats varied with diets: No significant effect with oaten chaff; increase with mixed roughage; and decrease with lucerne chaff. Under such a condition, the evidence indicated that organic matter digestibility of the three roughages was decreased in the Angora goats. In Merino sheep, however, it occurred only when oaten chaff was fed. All these results suggest that the major influence of the salt ingestion is to increase rumen turnover rate. However, if turnover rate is increased then food digestibility of lower quality roughages is decreased. If food intake is reduced to compensate for a decreased digestibility, then this change in intake alone will increase the digestibility. It appears that the two species of animals compensate to maintain the most appropriate intake digestibility regimen for the environment most suited to that animal.

The less intake of salt water by the Angora goats fed lucerne chaff would lead to a decreased outflow rate of rumen fluid for this diet. Because of the physico-chemical characteristics of lucerne chaff, which is more easily fermented compared to oaten chaff or mixed chaff leading to a normally high outflow rate, the decreased outflow rate may

indirectly cause a decreased intake of lucerne chaff and its digestibility. This may be mediated by a slower alteration in the rumen fluid environment which then leads to the accumulation of salt and digested substances in the rumen fluid.

In a hot environment (≈ 40°C), the relationship between salt water intake and outflow rate of rumen fluid in the sheep was reversed (Figure 7.1). Increasing temperature from 20 to 40°C did not significantly decrease the outflow rate. However, simultaneous imposition of salt and thermal loads decreased the outflow rate in the sheep (Table 7.3). As well as in the Merino sheep, the outflow rate of rumen fluid in the feral goats at 40°C was also decreased by drinking salt water (Table 6.3), although in such a situation the intakes of salt water by the sheep and feral goats were greater compared to the intakes of fresh water (Table 6.2 and 7.2). The decreased outflow rate of rumen fluid in both species may be partly attributed with a decreased influx of endogenous water into the rumen (≈ 35%) which was not significantly affected by drinking salt water in the thermoneutral environment(≈ 5-9%) (Table 5.2 and 7.3). In addition, it is possible that a greater proportion of ingested salt water bypassed the reticulorumen compared to that in the thermoneutral environment in which it was 15-25% (Chapter IV). This slower outflow rate of rumen fluid would then lead to a greater organic matter digestibility of mixed roughage in both species.

The studies of body fluid dynamics as affected by drinking salt water included dynamics between fluid compartments in the body (total body water, extracellular and rumen fluid compartments), and between animals and their environments to balance the excessive intake of water and salt by their excretion through defaecation and evaporation in addition to urination as the primary route. The adaptive significance of these findings in relation to environmental stressors is difficult to reconcile. The availability of fresh water in thermoneutral environments is more likely than that in hot environments. It should also be noted that in all the experiments contained in this thesis water was readily available, whereas in the natural environment animals may have access to water only once or even less per day. This would result in bigger differences in water (and salt) loads at any given

time. These facts may explain differences in the ingestive behaviour of sheep and goats of the salt water. In addition in the experiments in the hot environment, the drinking water was in small vessels and hence approximated room temperature, whereas in the natural hot environment, larger water bodies would provide much cooler drinking water, providing a better cooling source for thermoregulation.

The evidence showed that tritiated body water space (TBWSp) in the sheep is increased by drinking salt water either at 20 or 40°C. Feral goats at 40°C showed a similar response. However, the proportions of body fluid (%TBWSp) distributed into extracellular and rumen fluid compartments did not significantly alter by drinking 1.35% salt water (Table 6.4 and 7.4) compared to that when fresh water was drunk. As percentages of body weight, rumen fluid volumes in the sheep and Angora goats fed oaten, mixed or lucerne chaff were also not altered by drinking salt water (Table 5.2). A similar result was also shown when salt was intraruminally infused (Table 3.3). In addition, there were no species differences (Table 3.3), and there was no significant effect of thermal load (Table 7.4) on the the proportion of body fluid distributed into the rumen and extracellular fluid compartments. The sheep and Angora goats fed oaten chaff had a greater proportion of rumen fluid volume (% body weight) (Table 5.2) compared to that when mixed or lucerne chaff was fed.

Taken together, the increases in tritiated body water space with drinking salt water were proportionately followed by increases in the fluid compartments in the body. Therefore, the proportions of body fluid distributed into the rumen and extracellular compartments in the sheep and goats were relatively constant.

It is established that salt load either by intraruminal infusion or by drinking water containing salt will increase water intake. hence water turnover rate (WTOR). Similar responses can also be identified as the effect of thermal load. Under salt load, the increased water requirement is to excrete the excess intake of salt (osmoregulation), whereas under thermal load the increase requirement of water is to dissipate the excess heat (thermoregulation). Simultaneous impositon of salt and thermal loads lead to the

interaction between these two homeostatic systems. In the present studies, salt was introduced in drinking water (Chapter V, VI and VII), in addition to intraruminal salt infusion while fresh water was freely available (Chapter III).

The evidence showed that in the thermoneutral environment, there were no species differences in the proportions of water loss (% WTOR) distributed into the urine, faeces and insensible loss when salt was infused intraruminally. However, intraruminal salt infusion increased the proportion of water loss through the kidney (from 30 to 60% of WTOR) (Table 3.3) in both the sheep and Angora goats, whereas faecal and insensible water losses decreased.

When salt was in the drinking water, there were no significant differences in the proportions of water loss (%WTOR) through urination, defaecation and insensible routes between the sheep and the goats (Table 5.3), between levels of salt load (Table 5.3 and 7.5), and between different roughage diets (Table 5.3). Under such conditions, the proportion of water loss through urine, faeces and insensible water losses were 45-50, 15-25 and 31-35% respectively.

Under thermal load (40°C) without excessive intake of salt, the sheep decreased the proportion of water lost through urination and defaecation to 20-30% and 8-10% respectively. The decreases in the urinary and faecal water losses may be attributed with the increase in insensible water loss to 60-62%.

When salt and thermal loads were imposed simultaneously on the sheep, the proportion of water loss through the kidney was maintained constant as in the thermoneutral environment, whereas faecal water loss decreased to 5-6% accompanying the decreased insensible water loss to 45-50%. This is, however, still higher compared to that in the thermoneutral environment.

Taken together that in the thermoneutral environment, the proportion of water loss (% WTOR) through urine, faeces and insensible loss from the sheep and Angora goats drinking salt water were constantly maintained regardless of the different species,

roughage diets and levels of salt load. Under thermal load, the sheep increased insensible water loss, whereas urinary and faecal water losses decreased. A similar proportion of water loss through urine, faeces and insensible loss was also indicated by feral goats as the effect of simultaneous salt and thermal loads.

The excretion of sodium through the body surface (skin) was not determined, but measurements carried out by other workers (see previous discussion in Chapter III) indicated that sodium excretion through the suint of the sheep was increased by drinking salt water. This may partly explain the positive balance which occurred in all experiments reported herein. In addition, it must be considered also that for animals receiving 1.35% salt water, a ± 1% error in measuring either sodium intake or urinary or faecal sodium excretion would lead to a variation of about 10-15 mmol/d in the sodium balance.

Together the experiments reported in this thesis have shown that substantial species differences exist between sheep and goats with regard to their response to salt and thermal loading. The differences appear to be largely in their ingestive behaviour and the ability to change rumen fluid dynamics. changes to kidney function appeared to be relatively similar across the species. Further studies comparing the effects of route of administration of the salt loads (food, water at different salt concentrations, oral drenching and intraruminal infusion) on rumen dynamics, digestibility and body fluid parameters is warranted. The study has furthered our knowledge of control of food intake and rumen fluid dynamics under different environmental conditions in both sheep and goats.