

**EFFECT OF WATER RESTRICTION ON ASPECTS OF DIGESTION IN BOER
AND TSWANA GOATS OFFERED ERAGROSTIS TEFF AND LUCERNE HAY**

by

Meshack Mzwandile Qinisa

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Faculty of Veterinary Science

Department of Anatomy and Physiology

University of Pretoria

South Africa

Supervisor

Professor: E. A. Boomker

Co- supervisor

Professor: H. B. Groenewald

Department of Anatomy and Physiology

University of Pretoria

South Africa

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DEDICATION

Dedicated to my four special roses:

My three daughters:

Lindiwe, Vuyiswa and Zandile

My wife Cynthia

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DECLARATION

I hereby declare that all the work in this thesis was done by me, unless otherwise specified, and that this dissertation has not been submitted either wholly or in part, to any tertiary institution for the purpose of awarding of a degree.

M M QINISA



ABBREVIATIONS

Ad lib	ad libitum
ADF	acid detergent fibre
C ₃	Carbon 3
C ₄	Carbon 4
Conc	concentration
CP	crude protein
DM	dry matter
DMI	dry matter intake
EDTA	ethylene diamine-tetra-acetic acid
g/d	grams per day
g/kg	grams per kilogram
HR	heart rate
Ht	haematocrit
Hrs	hours
Kg	kilogram
l/kg	litre per kilogram
LSD	least significant difference
LSM	least square means
l/kg	litre per kilogram
l/d	litre per day
Lucerne	<i>Medicago sativa</i>
ml/kgBW ^{0.75}	millilitre per kilogram metabolic body weight
ml/d	millilitre per day
mOsmol/l	milliosmol per litre
MRT	mean retention time
mmol/d	millimol per day
mMol/l	millimol per litre
N	nitrogen
NDF	neutral detergent fibre
OM	organic matter



OSM (P)	plasma osmolarity
PCV	pack cell volume
%	per cent
RR	respiration rate
SE	standard error
Teff	<i>Eragrostis teff</i>
Temp	rectal temperature
TPP	total plasma proteins
Trt	treatment
VFA	volatile fatty acid



ABSTRACT

The first part of this study was undertaken to investigate the effect of water restriction on aspects of digestion in Tswana goats offered *Eragrostis teff* hay. Twelve Tswana goat wethers approximately 15 months old weighing on average 28.67 ± 4.48 kg, were randomly allocated to form three groups of four animals in each. The groups were all exposed to the following treatments: Water *ad libitum* (This served as control); 50 % *ad libitum* water intake once in the morning, and 25 % of *ad libitum* water intake in the morning and 25 % *ad libitum* water in the afternoon. All the goats were adapted and fed *Eragrostis teff*. The final body weight of the *ad libitum* group was higher than that of treatment groups whilst no significant difference was observed between the water restriction treatments. Rectal temperature, heart and respiration rates were not affected by water restriction. Similarly haematocrit, total plasma protein, osmolarity and plasma urea levels were not affected by water restriction. Dry matter intake was reduced by water restriction from 848.69 to 740.16 g/d. Water to dry matter ratio dropped from 1.47 to 0.79. Faecal water was not affected by water restriction. However, urine output was reduced from 321.72 to 245 and 255.17 g/d for the half and quarter *ad libitum* water intake groups, respectively. Insensible water loss was at 549.7 g/d for the *ad libitum* water intake group compared to – 0.49 and 20.86 g/d of the half and quarter *ad libitum* water intake groups respectively. Water use efficiency was higher ($p < 0.05$) for the water restricted groups compared to the *ad lib* water group. Digestibility coefficients for DM, ADF, and NDF were all not affected by water restriction but apparent digestibility for nitrogen was reduced from 50.7 % to 44 %. Specific gravity of urine was higher ($p < 0.05$) for the water restricted groups while urea output and urea concentration were not significantly different among all the three groups. More of the nitrogen was lost through urine in all the groups leading to a negative nitrogen balance. The negative nitrogen retention was more pronounced in the water restricted groups. It was concluded that water restriction did not affect digestion and nutrient utilization of Tswana goats when offered *Eragrostis teff*.

In part II of this study, the aim was to investigate the effect of water restriction on aspects of digestion in Tswana and Boer goat wethers offered either *Eragrostis teff* or *Medicago sativa*. Twentyfour goats (12 Boer and 12 Tswana goat wethers) of 12 – 15 months old weighing 18.3 – 32.8 kg were randomly allocated to form 4 groups of 6 goats. Within each group, there were 3

Boer and 3 Tswana goat wethers. These were used into a 4 X 4 Latin square design with the following treatments : (1) Water and teff *ad libitum* (2) 50 % (Half) of *ad libitum* water and teff *ad libitum* (3) Water and lucerne *ad libitum* (4) 50 % (Half) of *ad libitum* water and lucerne *ad libitum*.

All the animals lost weight by the end of the water restriction period when fed either teff or lucerne. This weight was regained after a day of rehydration. Both Boer and Tswana goats lost 10 % of their body weight when offered lucerne while water – restricted and then regained 13 – 14 % of their dehydrated body weight. For both breeds, when teff or lucerne was offered, haematocrit, total plasma proteins, heart rate and rectal temperature were not affected by water restriction. Respiration rate increased in both breeds during water restriction. Plasma urea and osmolarity rose significantly from day 0 to day 4 but there was no significant difference between day 4 and the last day (day 7) when both breeds were fed either teff or lucerne .Regardless of the breed and treatment, water restricted goats had lower water use efficiency and higher urine specific gravity values compared to *ad libitum* water groups. On teff, water restriction did not have any significant ($p>0.05$) influence on dry matter intake but faecal dry matter was reduced ($p< 0.05$) from 360.15 to 315.16 g/d. The water to dry matter ratio was reduced ($p< 0.05$) from 1.71 to 0.83. The digestibility coefficients for DM, N, ADF, and NDF were unaffected by water restriction. However, ADF and NDF digestibility coefficients were higher than those of DM and N. On lucerne, dry matter intake was significantly ($p < 0.05$) reduced from 1022.75 to 756.28 g/d while faecal dry matter output decreased from 384.33 to 292.15 g/d. The water to dry matter ratio dropped significantly ($p < 0.05$) from 2.32 to 1.29. The digestibility coefficients did not differ between the *ad libitum* and half *ad libitum* water groups. However the digestibility coefficients for ADF and NDF were lower than those of DM and N. Water restriction did not improve nitrogen retention when either teff or lucerne was offered in both Tswana and Boer goats. It was concluded that goats are efficient in utilizing water and digesting high fibre feedstuffs when water is limited. However, both breeds did not display evidence for a mechanism of improving nitrogen retention when fed low and high nitrogen feedstuffs (teff and lucerne, respectively) while water intake is restricted.

Keywords: Tswana goats, Boer goats, crude protein, water restriction, digestibility, nitrogen retention.



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CHAPTER 1 INTRODUCTION

1.1 General introduction

Goats are deeply embedded in almost every African culture and are true friends to the rural poor in particular. Goats play a unique role in supporting some of the poorest people in Africa and can play a powerful role in lifting them out of poverty towards prosperity. After all Nelson Mandela, himself herded goats as a young boy in the Eastern Cape, drank their milk and look at his achievement (Peacock, 2005)!

Goats are multipurpose animals; they produce milk, meat, skin and fibre (Abdelatif, *et al.*, 2009), but these benefits are under-reported because the goat is less likely to enter commercial channels or attract the attention of policy makers than other types of livestock (Sherman, 1998). Smuts (1997) described goats as an important but under-utilised indigenous resource. Goats have been under-utilised because they are considered to be highly destructive of vegetation and the principal contributors to severe soil erosion (Huston, 1978). They are probably not the initial cause of rangeland deterioration, but may be the culprits during the later stages of destruction, as they remain productive in areas that are seriously overgrazed and eroded. With proper management, this can be corrected (Sherman, 1998; Qinisa, 1999).

The goat's small size and its ability to utilise a broader range of feeds than other ruminants, makes it an effective tool for development among the rural poor. It has been consistently shown in different countries and environmental conditions that goats indigenous to harsh environments perform better than other domesticated ruminants (Shkolnik & Silanikove, 1981). According to Silanikove (2000), the abundance of goats in the harsher environment of arid areas is most likely due to a better adaptation of this species to such environments.

Goats in South Africa can be grouped into four major categories namely Angora, milch, improved boer, and indigenous goats (Webb *et al.*, 1998). Goat numbers in South Africa in 2005 were estimated at 6.4 million (Table 1.1).

Table 1.1: South Africa statistics for livestock numbers for the period 1996-2005

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Cattle (m)	13.0	13.4	13.7	13.8	13.6	13.5	13.6	13.5	13.5	13.8
Sheep (m)	28.9	29.2	29.4	28.7	28.6	28.8	26.0	25.8	25.4	25.3
Goat (m)	6.7	6.6	6.6	6.5	6.7	6.6	6.5	6.4	6.4	6.4
Horse (th)	250	255	260	258	270	270	270	270	270	270

Source: FAOSTAT (2006).

At the end of November 2009, they were estimated at 6.454 million, of which approximately 2.385 million (36 %) were found in the Eastern Cape Province, Limpopo Province followed with 1.313 million (21 %) and KwaZulu-Natal with 855 380 (13 %) and the North West Province at 11.4 % with 735 thousand goats (Table 1.2).

Many grasslands in Southern Africa are used for animal production. Therefore, extensive animal production is of paramount importance, both for potential export and also to meet the rising local demand for animal protein in the subregion (Serfontein, 1989). The prevailing conditions in these grazing zones often lead to a scarcity of feed and water with adverse consequences on production. During the dry season, most livestock are subject to insufficient quantities of forage in the field. Reduced feed supply adversely affects body condition of the animals and in times of drought, the number of large

animals is reduced significantly. Alleviation of these seasonal scarcities of feed would result in improved production and lower mortality to enable the farmer to generate increased more income from his farming (Joshi, *et al.*, 2002). However, goats are well adapted to arid climates and have low water requirements (Gihad, 1976; Devendra, 1980; More & Sahni, 1981; Silanikove, 1992; Qinisa & Boomker, 1998).

In the North West Province, the majority of these goats are of the indigenous Tswana type followed by Boer goats and their crosses. The numbers fluctuate in response to high and low rainfall years.

Table 1.2: Estimated livestock numbers in the RSA (August 2009 and November 2009)

Province	Cattle		Sheep		Pigs		Goats	
	Aug	Nov	Aug	Nov	Aug	Nov	Aug	Nov
Thousands								
Western Cape	576	571	2 814	2 748	179	183	226	230
Northern Cape	509	518	6 295	6 215	27	28	528	528
Free State	2 306	2 393	4 876	4 886	134	133	262	258
Eastern Cape	3 078	3 235	7 354	7 590	102	102	2 311	2 385
KwaZulu-Natal	2 773	2 782	781	788	156	159	829	865
Mpumalanga	1 457	1 461	1 778	1 798	127	124	94	95
Limpopo	1 064	1 073	266	267	381	386	1 325	1 313
Gauteng	266	261	105	105	182	183	44	45
North West	1 733	1 800	720	706	324	327	738	735
Total	13 762	14 094	24 989	25 103	1 612	1 625	6 357	6 454

Newsletter: National Livestock Statistics February 2010

The Tswana goat is of large and long size, with a long neck, straight back and long legs. The croup has a moderate slope. The head is not very strong and relatively short, with a straight profile. Horns are present in 69 % of the males, projecting backwards and then outwards and in 75 % of the females, where they are lighter and narrower. Ears are medium – long, broad and lop. The coat is short and fine (39 %), intermediate and wavy (47 %) or long (14 %). The coat colour is highly variable with mixed colours predominating (40 %), followed by pure white (29 %) and black (17 %) (Gall, 1996; Porter, 1996). The apparent wide variation in coat colours and hair structure among Tswana goats is indicative of the fact that the breed has not yet been purified through

selective breeding and therefore great opportunities exist for its improvement; and that the propensity towards white coat colour and/or white in combination with other colours especially black and brown, appears to be an adaptive trait to withstand pronounced seasonal fluctuations in the intensity and duration of light, heat and cold (Katangole *et al.*, 1996).

The Tswana goats breed all the year round and experience a long dry period. Male goats grow faster and are heavier than female goats. Age significantly affects body traits (Devendra & Mcleroy, 1988). The low availability of forage may be responsible for their low prolificacy. Compared to Boer goats, Tswana goats have a lower twinning rate. This characteristic may also be environmentally induced as Tswana goats, having evolved in a harsh arid environment, might have adapted to producing single kids to reduce the demand for milk (Aganga *et al.*, 2005). Tswana goats have low maintenance requirements which become an advantage in unfavourable environments (Horst, 1984). If production is simply measured as growth rate or milk production, then the European breeds outperform the indigenous breeds, but if maintenance cost, reproduction and mortality are considered, then the indigenous breeds often outperform the improved breeds (De Lange, 1994).

The Boer goat is of medium to large size. The herd book requires white animals with red head and neck and a white blaze. The head is straight or slightly convex in the male. Ears are long and lop. Horns are scimitar-shaped bending backward. Hair is short but very dense. There is a long-haired type which is bigger and late maturing. The skin is loose and supple; males have a moderately developed dewlap (Porter, 1996). Malan (2000) reported that the Boer goat was undoubtedly one of the hardiest smallstock breeds in the world, with great capacity for adaptation. Furthermore, it is an excellent walker, with sturdy legs and able to move easily in rugged mountainous areas and through dense bush and that under drought conditions, the Boer goat survives without supplementary feeding.

The Boer goat is very fertile and is not seasonal. Multiple births are the rule rather than the exception, with an average kidding percentage of 180 (Erasmus, 2000; Malan, 2000).

Singles, twins, triplets, quadruplets, and quintuplets were reported in Boer goat does (Erasmus *et al.*, 1985; Els, 1995).

The North West Province of South Africa is semi-arid with low and erratic rainfall. The average annual summer and winter rainfalls are 868 mm and 265 mm respectively. The winter temperatures can go down to 3 °C and in summer up to 31 °C while the relative humidity is about 65 % for summer and 35 % for winter. The type of vegetation is the Savanna Bushveld (Acocks, 1975).

The powerful effects of solar radiation on water demand in arid and semi-arid areas are integrated with those of air, temperature and feed supply. Tropical and sub-tropical climates are known for high ambient temperatures, irregular and scanty rainfall along with low quality and quantity of available forages. Such environments exert nutritional stress on the ruminants inhabiting the area (Aganga *et al.*, 1988; Olsson, 2005).

Several researchers have studied the different physiological, biochemical and behavioural mechanisms, which enable goats to survive, produce, and reproduce under water restriction/deprivation (Singh *et al.*, 1976; Church, 1979; More & Sahni, 1981; Silanikove, 1992, 2000, Misra & Singh, 2002). Furthermore, water deprivation was found to improve the digestion and utilization of feed and enhance nitrogen utilization in poorly nourished small ruminants (Singh *et al.*, 1976; Mousa *et al.*, 1983; Mousa & Elkalifa, 1992). There are no reports on indigenous Tswana and Boer goats of South Africa when on shortage of both water and feed. The information on how much and how often goats should be watered when there is a shortage of water is also lacking. There is therefore a need to investigate these two aspects on indigenous Tswana and Boer goats.

Most small rural farmers in the North West Province breed with the Tswana goat followed by the Boer goat. The major challenge experienced by most of these farmers is lack of water especially during the winter season. Coupled with this is also a lack of adequate or low quality grazing during this time. In a survey of goat production in the province it was reported that drought accounted for 20 % and 3 % of the stock losses in

Boer and Village goats respectively (Lusweti, 2000). Limitations on water intake depress animal performance quicker and more drastically than any other nutrients (Aregheore & Ng'ambi, 2007). Where there is a deficient water supply, goats lose weight and the concentrations of blood biochemical constituents are raised due to dehydration (Adogla-Bessa & Aganga, 2000).

Knowledge gained from this study will reduce mortalities occurring in winter due to drought or lack of water. If these goats or one of the breeds can withstand water restriction, it would be of great importance because it will allow them to graze far away from watering points and the grazing will be evenly utilized reducing overgrazing of those areas around watering points. If water restriction and a low protein diet such as teff bring an improvement in digestibility and nitrogen retention, farmers can then avoid buying expensive high protein feedstuffs in winter.

1.2 Objectives of this study

The objectives of the study were:

- (a) To investigate the effect of water restriction on blood parameters, water utilization, digestibility and nitrogen retention in Tswana goat wethers fed teff
- (b) To investigate the effect of water restriction on blood parameters status of indigenous Tswana and Boer goat wethers fed teff and lucerne hay
- (c) To investigate the effect of water restriction on the water use efficiency and apparent digestibility in Tswana and Boer goat wethers fed teff and lucerne hay
- (d) To investigate the effect of water restriction on the nitrogen retention of Tswana and Boer goat wethers fed teff and lucerne hay



1.3 Hypotheses

The hypotheses to be tested were that:

- (a) When fed teff Tswana goats are more effective in their utilization of water, digestion and nitrogen retention under conditions of water restriction.

- (b) Blood and physiological parameters of Tswana goats are less affected than those of Boer goats when water restricted and fed teff and lucerne hay

- (c) Tswana goats utilize water and digest feed better than Boer goats when offered teff and lucerne hay under limited water conditions.

- (d) When water is restricted, Tswana goats will retain more nitrogen than Boer goats on teff and lucerne hay



CHAPTER 2

LITERATURE REVIEW

2.1 Water requirements for livestock

Water is an absolute necessity for all livestock and a lack of an adequate supply can be a serious limiting factor in many parts of the country. According to French (1956), the loss of only 10 percent of body water causes serious disorders while further losses may lead to death.

Water functions as a solvent in which nutrients are transported around the body and in which waste products are excreted. Many of the chemical reactions brought about by enzymes take place in solution and involve hydrolysis. Due to the high specific heat of water, large changes in heat production can take place within the animal with very little alteration in body temperature. Evaporation of water from the lungs and skin gives it a further role in the regulation of body temperature (McDonald *et al.*, 1988). Aganga *et al.*, (1990) also emphasized the importance of frequent and regular water supply to animals to meet the various needs of maintenance, pregnancy and lactation. Pregnant and lactating goats require more water and feed than they do at their maintenance level. Their metabolism increases and more catabolites are excreted through the kidneys (Forbes, 1968).

Animals may experience positive or negative water balance at a given point in time. Water balance is the condition where intake of free water, preformed water in feed, and metabolic water equals water loss through faeces, urine and cutaneous and pulmonary evaporation over a specific period of time (Louw, 1993). The animal therefore obtains its water from three sources: drinking water, water present in its feed and the water produced during the metabolism of food.



2.1.1 Drinking water

Unless the forage is moist, domestic animals must obtain most of the water they need as drinking water. Over-rapid absorption of water lowers the osmotic pressure of the blood to an extent that may cause the erythrocytes to burst and leads to a sometimes-fatal form of cerebral oedema (Kay, 1997). Ruminants are much less susceptible to over-rapid absorption as the water they drink first enters the rumen which serves as a capacious reservoir (More & Sahni, 1981; Silanikove & Tadmor, 1989; Silanikove, 2000). Black Bedouin goats of the Negev Desert withstood even greater dehydration (40 % of initial body weight) and could imbibe large volumes of water after haemoconcentration (Shkolnik *et al.*, 1980). The water stored in the rumen is slowly absorbed from the rumen or passed to the lower gut. This protects the ruminant from water intoxication and allows some extra water to be stored in the rumen when drinking is infrequent (Silanikove, 1994; Kay, 1997).

The water requirement of animals varies according to breed and species. The amount of water (1.4 ± 0.4 litres per day) consumed by indigenous Pedi goats (Qinisa & Boomker, 1998) was less than the 2.3 ± 0.28 , 4.8 ± 0.58 and 5.6 ± 0.85 litres for the Blackhead Persian, Dorper and Mutton Merino lambs, respectively (Schoeman & Visser, 1995). When the volume of water consumed was compared on a per kilogram feed intake basis (litres/kg feed intake), Pedi goats (1.6 ± 0.2) consumed less water than the Boer goats (1.8 ± 0.2) (Ferreira *et al.*, 2002). Shkolnik *et al.*, (1972), reported that Bedouin goats were sometimes watered only once every four days, even during the hottest part of summer. In Nigeria, during the long dry season of about 8 months and in certain Savanna zones, the Yankasa sheep, grazed along with cattle herded by Fulani men, go at times for about three days without water supply on the rough ranges (Aganga *et al.*, 1988). When the water intake of Maradi bucks was compared to that of Yankasa rams, they drank less water (Aganga, 1992).

2.1.2 Feed water

The water content of grass ranges from about 80 % as it begins to grow during the rains to 10 % at the end of the dry season. The trees and bushes on which browsing animals

feed have deeper roots and a slower growth surge, so that their leaves show less change in water content, from about 30 to 70 %. During the wet season herbivores may obtain all the water they need from their moist forage so that they do not need to drink for long periods. As the forage dries out, however, they must seek water more and more often, depending on their ability to store and conserve water. Grasses and shrubs often become moistened by dew or absorb water hygroscopically during cool nights even in the desert (Kay, 1997). Animals which will benefit from this are those grazing in the evening and early in the morning. In South Africa, most free ranging ruminants are enclosed in a shelter at night to protect them from predation and theft and so this denies them this source of water.

The amount of preformed water obtained from food depends not only on the moisture content of that food but also on the amount eaten. If more food is eaten, more preformed water is available. Restricted access to drinking water, either experimentally or under field conditions, also generally depresses food intake, thus further exacerbating the loss of water available from food (Wilson, 1989).

2.1.3 Metabolic water

When organic food molecules are aerobically catabolized, water is formed, as illustrated by this equation for glucose oxidation: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$

The water produced by catabolic reactions such as this is known as metabolic water or oxidation water (McDonald *et al.*, 1988; Kay, 1997; Hill *et al.*, 2004).

The amount of metabolic water formed depends on the amount of hydrogen in the food, which in turn depends on the proportions of starch, fat and protein contained by the food (Wilson, 1989). Carbohydrates and lipids consist primarily of carbon, hydrogen, and oxygen. Their oxidation during metabolism results mostly in formation of CO_2 and H_2O . The CO_2 is exhaled into the atmosphere, and the H_2O contributes to an animal's water resources. On the other hand, proteins contain large amounts of nitrogen, and their catabolism results in nitrogenous wastes. These nitrogenous wastes may affect the animal's water balance when they are excreted in urine. In mammals, for example, the

principal nitrogenous waste is urea, a highly soluble compound voided in urine. The amount of urinary water required to void urea depends on the urea-concentrating ability of an animal's kidney. When a mammal is producing urine with as high urea concentration as it can, a high-protein meal may well force the animal to void more water than a low-protein meal. In an environment where drinking water is hard to find, a high – protein meal may therefore increase the animal's water stress (Hill *et al.*, 2004).

2.2 Water intake

Total water intake is the sum of water consumed voluntarily by drinking and moisture contained in the feed, because metabolic water is an insignificant source compared with drinking water and feed water intake (Kume *et al.*, 2010). Water consumption of goats is influenced by diet, animal and environmental factors.

2.2.1 Dietary factors

There is a high correlation between water intake and dry matter intake. When goats are deprived of feed for slightly more than a day, water intake decreases as do the excretion of urine and production of milk (Dahlborn & Kalberg, 1986). Water intake is strongly influenced by the water content of the diet. When the percentage dry matter is less than 30 %, goats do not need to drink in order to satisfy their water intake needs (Giger-Reverdin & Gihad, 1991).

Diets high in salt, either added or distributed as saline water, will increase water intake. Rich protein diets increase water intake in goats by generating increased catabolic by-products including minerals and nitrogenous end products, such as urea, for which water serves as a solvent, thereby enhancing water secretion (Giger-Reverdin & Gihad, 1991).

Diets high in fibre may increase water intake by increasing the losses of water in the faeces (Harris & Vanhorn, 2003). Tastes will also influence water intake of goats. Goats are, however, more tolerant to bitter, sour, sweet and salty tastes (Goatcher & Church, 1970). Lack of palatability may result in poor acceptance of water by the animal and thus lower the intake of water (Dunbar & Miller, 1993).

2.2.2 Animal factors

The amount of water required depends on that needed for the maintenance of normal water balance and to provide satisfactory levels of production. The body water content of the goat varies with age and the amount of fat in the body, but it may be expected to exceed 60 % of the body weight (German, 2010). The water intake during pregnancy increases by 25 % at the third month and by 40 to 50 % at the end of pregnancy (Giger-Reverdin & Gihad, 1991).

High water intakes were observed among Nigerian dwarf male goats compared with females during the wet (July, August and September) and dry (January, February, March) season. Although not measured, this may suggest higher or extra activities and aggressions, usually more common among male goats compared with females, which may have led to their higher evaporative water loss through the skin surface, as well as the respiratory tract, thereby requiring compensatory water intake (Ogebe *et al.*, 1996). As reported by Ensminger (2002), mature goats consume approximately 4 l/d of water while growing kids require about half of this amount.

2.2.3 Environmental factors

Goats adapt to high temperatures more easily than other livestock and require less water evaporation to control body temperature (NRC, 1981). They keep the same dry matter level, reduce their water losses in urine and faeces and increase their pulmonary ventilation (Goatcher & Church, 1970).

When the ambient temperature is high, water is consumed in excess of metabolic needs, as it is essential for evaporative cooling (Devendra & Burns, 1983). Kutha (1976) has reported that raising the ambient temperature increased loss of water via the skin and lungs, and increased water requirement. Rao & Mullick (1965) cited by Devendra & Burns (1983), studied the effects of climate on the metabolism of nutrients in kids over four seasons during which the maximum temperatures were 10°, 32°, 40.3° and 27 °C respectively. They found that the intake of water and its ratio to the intake of dry matter increased with increase in temperature, while the water excreted in faeces and urine decreased.

The frequency of drinking is important because watering intervals may vary from 3 to 7 days depending on the season, availability of water, and the distance to be travelled by animals from one watering point to another (El Hadi, 1986). Under temperate climates, a twice daily allowance of water seems to be necessary for animals at a mean level of production. High yielding animals need to drink more often and present a high inter-individual variety. With *ad libitum* water supply, the animals drink just after milking and at the same time as they eat. In temperate zones water is abundant and inexpensive, while it is scarce in arid climates. Consideration must be given not only to the amount of water available, but to the frequency of water availability and water purity (Giger-Reverdin & Gihad, 1991). It is not clear whether there are any benefits of giving water to goats twice a day (morning and afternoon) or only once in the morning especially during times of scarcity.

2.3 Loss of water

The major avenues of water loss are through evaporation, in the faeces, in the urine, and in the milk of lactating females. In this study, the focus will be on the losses through the faeces and urine of wethers.

2.3.1 Faecal water

When ample water is available and animals are not dehydrated, considerable amounts of water are excreted with the faeces. Ruminants are able to extract large amounts of water from the intestinal contents, and this process is very much more efficient in arid-adapted animals when dehydrated (Maloiy *et al.*, 1978).

Reduction of the amount of water in the faeces is achieved by sodium absorption in the colon, accompanied by a return of water to the blood. Faeces with low water content are characteristically drier, harder, pelleted, and more obviously coated with mucus (French, 1956; Thornton & Yates, 1968; Wilson, 1989). The dryness of the faeces indicates a better water conserving mechanism (Aganga, 1992).

Goats and sheep in Kenya lost a much smaller proportion of total water via the faeces than did cattle. At 22 °C in the climatic chamber both Turkana goats and fat-tailed sheep lost about 20 % of water via the faeces when they were fully hydrated but under conditions of restricted water the loss was reduced by 61 % in goats and by 57 % in sheep (Maloiy & Taylor, 1971). In South Africa, the restriction of water intake of goats to 50 % led to a higher faecal water loss (34.3 %) compared to that of the control (18.1 %). Further restriction to 30 % of daily water intake produced a corresponding reduction in the percentage (29.7 %) of water lost through the faeces by this group (30 % group) relative to the 50 % water restriction group (Ajibola, 2000).

2.3.2 Volume of urine

Water intake influences both urine output and osmolarity (concentration of urine). These two are controlled largely by the kidneys. The renal control of fluid balance is simply by means of excreting diluted or concentrated urine. The osmoregulatory abilities of domestic and wild ruminants, that is, their ability to control water loss, have resulted in their being classified into three main physiological ecotypes (Maloiy *et al.*, 1979):

- High rates of water and energy use and a poor ability to concentrate urine, usually from wet tropical or wet temperate zones – buffalo, cattle, eland, waterbuck, moose and reindeer (elephant, pig and horse also fall into this group);
- Intermediate rates of water and energy turnover but with a high renal concentrating ability, mainly living in semi-arid warm savanna – sheep, wildebeest and hartebeest (and donkey);
- Low rates of water and energy use with a medium to high ability to concentrate urine and inhabiting the arid zones – camel, goat, oryx and gazelle (and presumably the musk ox).

Urine volumes can be reduced, depending on the breed or type of animal, by 50 % to almost 80 % when under water stress. In East African goats, urinary water loss was only about 10 to 15 % of total water loss in experimental animals when freely watered, but when water was restricted, the volume of urine fell to less than 50 % of that produced by watered animals (Maloiy & Taylor, 1971). In Botswana, the volume of urine voided by

Tswana goats at 24, 48 and 72 hour watering intervals decreased with an increasing level of water deprivation. The ratio of water intake to urine voided was similar for all treatments, which means that goats voided volumes of urine proportional to the volume of water drunk (Adogla-Bessa & Aganga, 2000).

Urine volume can also be influenced by the diet. Wilson (1970) found that when the sheep were fed lucerne chaff the urine volume produced was twice that when they were fed oaten chaff. This is probably due to the fact that animals tend to drink more water when fed a diet rich in proteins. When goats were water-restricted to 50 % of their *ad libitum* water intake and fed a low (8.8 % Crude Protein (CP)) and a high protein diet (15.9 % CP), those on a high protein produced $31.4 \pm 6.5 \text{ g/kg}^{0.75}/\text{d}$ compared to $16.1 \pm 3.0 \text{ g/kg}^{0.75}/\text{d}$ of urine from the goats on a low protein diet (Qinisa, 1999). So, almost double the volume of urine produced by goats on a low protein diet can be voided by the ones on a high protein diet.

The lower the amount of urine produced the higher its concentration or osmolarity. Reductions in urine volume ranging from 0 to 76 % and increase in urine osmolarity ranging from 3 to 239 % have been documented in comparisons of goats on *ad libitum* water and restricted water (Khan *et al.*, 1978; Maloiy *et al.*, 1979; Ali *et al.*, 1982; Olsson *et al.*, 1982; Wilson, 1989).

Urea is the main metabolic product excreted in the urine. Under dry conditions most forage is mature and contains rather little protein or other nitrogenous compounds, consequently production of urea is low and little water is needed for its urinary excretion. Much of the urea formed in the liver diffuses from the blood into the gut, and in the gut's fermentation chambers it may be used for production of microbial protein, provided sufficient fermentable carbohydrate is available. Microbial protein from the rumen is then digested and may be used by the animal, while that from the large intestine is excreted in the faeces, in both cases reducing the amount of urea to be excreted in the urine. Re-absorption of urea from the urine, and the amount recycled to the rumen, is increased in dehydrated animals, allowing an improved nitrogen balance where dietary energy is not

limiting (Kay, 1997). When goats were subjected to water restriction trials (50 and 30 % of free choice water), they produced less urea in their urine compared to the control group (Ajibola, 2006).

2.4 Digestive tract in goats

The digestive tract of goats is very similar to that of other ruminants (Morand-Fehr, 2005). The digestive tract of goats accounts for 7- 8 % of the weight of an adult goat. The mean size of the different compartments as a percentage of the total digestive tract is: stomach 48 %, small intestine 30 %, and the large intestine 22 %. In comparison to the abomasums, the reticulo-rumen is larger in goats than in sheep (Tisserand *et al.*, 1991).

2.5 Digestive efficiency of goats

Specific factors contributing to better digestibility of feeds by goats include differences in the nature of the diet, level of feed intake, mastication and rumination, salivary secretion, rumen fermentation and passage rate (Devendra, 1978).

2.5.1 Nature of the diet

Goats have been shown to be superior to sheep in digesting fibre throughout the year (Domingue *et al.*, 1991; Flachowsky & Tiroke, 1993).

In a comparative study by Gihad (1976) using sheep and goats, crude fibre digestibilities were found to be 60.3 % for goats and 56.5 % for sheep. The higher water intake by sheep found in this study may have diluted the bacterial population, hindering substrate – enzyme contact and reducing fibre digestibility (Gihad, 1976). Although results by Reid, *et al.*, (1990) indicated that goats were superior to sheep in digesting neutral detergent fibre (NDF), Antoniou & Hadjipanayiotou (1985), Brown & Johnson (1985) and Wahed & Owen (1986) all reported similar or a lower digestibility in goats compared to sheep, and thus refuted these results.

Adult goats are very selective and generally prefer leaves to stems and seeds to leaves. As a result of this, the nutritive value of the forage actually ingested is usually higher than that of the forage offered (Tisserand *et al.*, 1991) and could thus result in higher digestibilities under normal conditions than those found during experimental trials.

An associated factor concerned with digestibility is the protein content of forages. Wilson (1975), noted that the nitrogen intake in the diet of goats was greater than that of sheep when both were grazed on the same area. The selectivity of the animal breed and species will thus influence the protein intake and possibly the digestibility. The digestibility of protein and energy in low quality *Coastal Bermuda* grass hay was greater when fed to wethers than to mature beef cows (Devendra, 1978).

Huston & Shelton (1967), cited by Devendra (1978), reported that part of the improved apparent digestibility in goats is due to the associative effect; that is, the composition of other feeds consumed. They found, for example, that protein retention was increased when leaves of *Quercus virginiana* were included as an additional ingredient in diet. Natural selection of a range of plants found in the diet can thus influence the degree of digestion taking place in the rumen. Adverse conditions and few plant species available can thus also impact on the digestibility of the feed.

2.5.2 Level of feed intake

Forage quality and availability influence the level of feed intake. In turn, feed intake will affect faecal output. An increase in the quantity of feed eaten by an animal generally causes a faster rate of passage of digesta. The food is then exposed to the action of digestive enzymes for a shorter period, leading to a reduction in its digestibility (McDonald *et al.*, 1988).

2.5.3 Mastication and rumination

Particle breakdown, and the availability of cell contents, is affected by chewing during eating and rumination. While cattle masticate their feed only enough to form a bolus of

suitable size to swallow during eating, small ruminants masticate their feed more completely (Church, 1976).

Goats spend more time eating and less time ruminating than sheep. A greater number of chews per minute results in particle size of less than 1.0mm and is 85 % more effective in goats than in sheep (Domingue *et al.*, 1991). He also states that goats ruminated for a shorter period of time than sheep, and yet on the same high lignin diet, the reticular contents of goats had more fine particles than that of sheep.

2.5.4 Salivary secretion

Salivary secretion is important in the supply of water to the rumen and in the maintenance of the intraruminal environment.

Balch *et al* (1953) reported that water deprivation might lead to increased production of saliva with a favourable effect on rumen fermentation rate as a consequence. They found, using a fistulated cow, that it produced 5.8 kg/kgDM of saliva when water-restricted and only 4.6 kg/kgDM on *ad lib* water. Gordon (1965) however, found that during water deprivation and starvation, salivation was reduced. According to Louca *et al.*, (1982), saliva secretion per kg dry matter consumed was higher in goats than in sheep on the same diet. This resulted in the amount of urea entering the rumen through saliva also being higher in goats than in sheep. Increased urea can assist the digestive processes in the rumen when protein levels are low. Increased saliva secretion has also been found to help in the mastication of coarse and fibrous feedstuffs (Domingue *et al.*, 1991).

2.5.5 Pattern of rumen fermentation

The pattern of rumen fermentation in association with the rate of movement of the digesta through the digestive tract of goats probably holds the key to a better understanding of the higher digestive efficiency by goats. Water is the medium in which fermentation of rumen contents takes place. Thus any changes in this medium are likely to alter the fermentation pattern and, in turn, the function of the rumen (More & Sahni, 1981).

Restricting water intake to 50 % of *ad lib* had no significant effect on the rumen fermentation rate in *Bos indicus* or *Bos taurus* cattle. The rise in apparent digestibility of all nutrients in sheep given low feed-low water and high feed-low water was due to the low faecal output. The rumen contents of these sheep were more acidic due to higher levels of volatile fatty acids (VFA), although this might have been due to decreased absorption as a result of decreased moisture content (Asplund & Pfandes, 1972). To the contrary, Osman & Fadlalla (1974) observed no significant effect of water restriction in Sudanese desert sheep on changes in concentration of VFA. However, they did note that restricting water intake slightly increased the *in vitro* rate of fermentation of rumen contents, which is proportional to microbial activity in the rumen and therefore affects the retention of nitrogen.

According to El Hag (1976), VFA production was higher in goats than in sheep regardless of the diet. This difference increased even further as the forage quality decreased. Inter-species differences, as well as breed differences, in this parameter have also been found by other researchers. Silanikove *et al.* (1993) found that VFA production and concentration were 20 % and 30 % higher, respectively, in the Bedouin than in the Saanen goats when both breeds were fed the medium quality (*Chloris gayana* and *Medicago sativa*) hay. A decrease in forage quality is usually associated with an increase in the cellulose component in the forage. It is therefore quite likely that the tendency towards higher fibre digestibility is associated with a higher concentration of cellulolytic bacteria in the rumen (Devendra, 1978).

2.5.6 Passage rate of digesta along the gastro-intestinal tract

Passage rate terminology includes transit time or minimum retention, mean retention time and maximum retention time (Van Weyenberg *et al.*, 2006). It is usually measured by using markers in the feed which are collected from the faeces. Passage rate of digesta through the gastrointestinal tract is defined as the flow of material within or through the entire tract per unit of time. Transit time or minimum retention time is the time between feeding and the first appearance of the marker in the faeces. Maximum retention time is the interval between feeding and the last excretion of the marker. Mean retention time is

the integrated average time between marker ingestion and excretion (Robbins, 1993). In this study passage rate and mean retention time will be used interchangeably.

Digestibility of a ruminant diet is linked to the rate at which the feed particles move through the digestive tract (also known as the kinetics of food particle passage) of a particular animal and is solely a characteristic of the consumed diet (Huston *et al.*, 1988). The particle passage rate or mean retention time (MRT) is influenced by the following factors:

2.5.6.1 Feed related factors

Increasing the proportion of fibre in the diet increases the rate of passage (Warner, 1981), presumably by stimulating propulsive activity (Faichney, 1984). Treatment of dietary protein with formaldehyde to reduce its potential degradability in the rumen has been found to decrease marker MRTs in the rumen and large intestine and to increase them in the abomasum and small intestine (Faichney, 1975).

Grinding and pelleting of forages results in an increase in voluntary feed consumption, particularly with poorer-quality forages, leading to a reduced mean retention time (Minson, 1963). However, Faichney (1983a), cited by Faichney (1984) reported that when sheep were fed to appetite, grinding had little or no effect on rumen mean retention time. Campling & Freer (1966) found that grinding the forage decreased mean retention time when the intake of dairy cows fed ground roughages was restricted.

Digestibility of a feed and its mean retention time in the gastro-intestinal tract may be influenced by frequency of feeding. In a study by McGuire *et al.* (1966), where two groups of steers were fed either once, or six times per day, it was found that the increased frequency of feeding decreased the digestibility of crude protein due to the faster rate of passage. Warner (1981) reported overall mean retention times of 85 ± 16 hrs and 60 ± 24 hrs in animals fed once and twice a day respectively. Therefore increased feeding frequency seems to reduce mean retention time.

2.5.6.2 Animal related factors

(i) Gestation and lactation

A pregnant uterus might be expected to influence the rate of passage of digesta by compressing the gut (Warner, 1981). Rumen MRT's are known to decrease as pregnancy progresses as well as during lactation (Faichney & White, 1980). The utero-placental-foetal complex may also restrict the space available for the rumen and its contents. However, no differences were found in mean retention time in cattle between 5 and 7 months of pregnancy (Putnam *et al.*, 1967). In sheep fed a constant ration, mean retention time fell by 1.0-1.5 hrs for each 100g increase in the estimated weight of the foetus (Graham & Williams, 1962). Milk production requires increased nutrients and water. Shellenberger & Kesler (1961) found a faster rate of passage in those cows producing milk at the higher levels and consuming greater quantities of feed and water.

(ii) Age and body weight

Very young ruminants might be expected to have shorter rumen MRTs than their mature counter parts (Faichney, 1984), probably due to the size of the rumen. Weston & Margan (1979) did not find any consistent effect of age on the MRTs of ⁵¹Cr-EDTA in weaned lambs studied at 15, 24, and 40 weeks of age. Comparison of data from young, crossbred, weaned lambs weighing 10 – 12 kg, which were reared in isolation but inoculated with rumen fluid, with those from mature Corriedale ewes indicated a highly significant effect of age on rumen mean retention time (Faichney, 1984). Little change in mean retention time with age after weaning was seen in kids (Castle, 1956).

Uden *et al.* (1982) could not detect a relationship between mean retention time and body size in ruminants, equines and rabbits given timothy hay. In contrast Robbins (1993) stated that mean retention time increased as body weight of ruminants and macropod marsupials increased. Mean retention times are longest in ruminants, macropod marsupials with complex forestomachs; they are shortest in carnivores and insectivores. Fluids and the very small particles (< 1.2 mm) of some pelleted diets move through the gastro-intestinal tract of ruminants and macropods approximately twice as fast as long forages (Martz & Belyea, 1986). Larger particles (5 mm) even when pelleted, move at

the slower rates of long forages (Schaefer *et al.*, 1978). Residence time in the rumen accounts for 55 to 65 % of the total retention time in ruminants (Baker & Hobbs, 1987). Ruminants and macropods of similar size have similar rates of passage as was also observed by Hume (1974) in euros and domestic sheep. Therefore as animals grow and body weight increases, the mean retention would increase but between species of similar weight the rates of passage are similar.

(iii) Species and breed

Silanikove (2000) reported two opposing views on the digestive efficiency of goats. The views are:

Firstly, that goats are not truly efficient exploiters of cellulosic matter and their success in tropical areas relies on their ability to exploit forages with different leaves of less lignified material and stems (Van Soest, 1982). Goats also have a small gut in relation to body weight leading to a faster passage rate of digesta.

Secondly, with high-fibre low-quality forages, goats have a better digestive efficiency than other ruminants. The reason being that they have a longer mean retention time of digesta in the rumen (Tisserand *et al.*, 1991). A solution to these contrasting views may be obtained from digestion trials.

Compared to cattle, goats and sheep have a shorter retention time, but this does not necessarily imply better digestion by cattle, because cattle chew their food less completely, have a larger number of omasal leaves (which reduce the rate of passage) and have slower rumen turn-over rates (Church, 1976). Goats digest low quality forages better than sheep and this is due to their longer ruminal retention time of feed (Reid *et al.*, 1990; Tisserand *et al.*, 1991).

The passage rate of food particles and liquid in the rumen and along the entire gastro-intestinal tract was slower than in the Saanen goat. The mean retention time of food particles in the gastro-intestinal tract in the Bedouin goats was 56.4 hours compared to 45.2 hours in the Saanen goats (Silanikove, 1984; 1986).

2.5.6.3 Climatic factors

Warren *et al.*, (1974), found an increase in the MRT of a particle – associated marker in the whole GI tract of cattle when the temperature was increased from 18 to 32 °C. Cold exposure resulted in shorter MRT's of markers (Christopherson & Kennedy, 1983). There appears therefore to be a positive relationship between MRT and temperature.

2.5.6.4 Water availability

When water is restricted, goats decrease the amount of dry matter ingested, especially with food of good quality (Giger-Reverdin & Gihad, 1991). This reduced feed intake increases the potential of the diet to yield nutrients by extending its retention time in the GIT. This results in the digesta being broken down into smaller particles, which increases surface area available to attack by microbes (Brosh *et al.* 1986). According to Hungate (1966), smaller particles are known to be washed rapidly away from the rumen by the flow leaving it. However, with water restriction, fluid flow through the rumen is decreased and its ability to carry away particles is also reduced.

In steers, Phillips (1961) and Thornton & Yates (1968) concluded that restriction of water intake usually resulted in digesta being retained longer in the rumen and the digestive tract as a whole. On the contrary Balch *et al.*, (1953), considered that a 60 % reduction in water intake did not affect the rate of passage in dairy cows. Maloiy *et al.*, (1970), did not observe any increased mean retention time in sheep offered large or small amounts of water and protein.

2.6 Nitrogen conservation

There are conflicting reports on the effect of water restriction on nitrogen conservation, or retention, in ruminants. Some authors claim that water restriction and or deprivation improves nitrogen retention. Others claim that improvement in nitrogen retained is only when animals are on a low protein diet and water restricted while others only observed increased nitrogen retention on high or medium protein diets.

Literature on the nitrogen balance of water restricted animals can thus be categorised under two broad headings:

2.6.1 No improvement in nitrogen retention

With respect to N retention, Balch *et al.* (1953) found no effect of water restriction. In contrast, Thornton & Yates (1969) reported that water restriction decreased N retention when compared with cattle fed a similar amount of digestible energy but unrestricted water. The reason attributed to the reduced N balance was due to a combination of more faecal excretion and urinary urea excretion.

The nitrogen balance of goats was also not improved by water restriction when they were fed a diet containing 8.1 % CP (Freudenberg & Hume, 1993). Furthermore, water deprivation did not affect nitrogen retention in goats when offered medium (10.83 and 10.34 % CP) and high protein (21 % CP) diets (Misra & Singh, 2002).

2.6.2 Improvement in nitrogen retention

A number of authors have found an improvement in nitrogen retention by ruminants when water intake was restricted. In steers, Utley *et al.* (1970) observed that water restriction increased digestibility of DM. N retention also tended to increase, thus suggesting increased N recycling. When the quality of grazing is low, cattle voluntarily restrict their intake and turnover of water, thereby controlling their nitrogen balance and achieving protein maintenance on diets which would normally be below maintenance requirements (Payne, 1963). The reason is that, on a low nitrogen diet, a high water intake leads to a high urine volume which will flush urea out of the plasma so that it is not available for re-use in protein formation or to stimulate microbial digestion (King, 1983). Differences between the performance of animals on a low N diet, or those grazing pastures low in N, may be due to differences in nitrogen metabolism caused by differences in water intake (Vercoe, 1971).

Van der Walt *et al.*, (1999), reported that when sheep were fed a diet containing adequate CP (10.3 %), restricting water intake by 50 % severely reduced the amount of nitrogen



retained. However, in contrast when sheep were fed a diet low in CP (5.4 %), the same water restriction (i.e. 50 % of *ad lib* water) appeared to increase the amount of nitrogen retained. On a medium protein diet (10.5 % CP) fed *ad libitum*, it was found that when the water intake was restricted to 30 and 50 % of the goats normal *ad libitum* intake, the nitrogen retention of the goats was 31.9 and 19.3 % for each group respectively, in contrast to the control group that lost 2.4 % (Ajibola, 2006). In a trial where goats were fed lucerne (19.65 % CP) or sorghum (5.33 % CP) and then restricted to 40 % of the water consumed by the control group, the amount of nitrogen retained was higher ($P < 0.05$) when fed with lucerne than the amount retained on the sorghum hay (Muna & Ammar, 2001).

In an attempt to find answers which could explain the above differences, an experiment was conducted to investigate the performance of Tswana goats under water restriction when offered a low nitrogen diet of *Eragrostis teff*. Since it is not clear how much and how often goats are to be watered in times of water scarcity, the frequency of watering, (25 % of normal water intake in the morning and again in the afternoon), was also included in the experiment.



PART 1
EFFECT OF WATER RESTRICTION ON ASPECTS OF DIGESTION IN
TSWANA GOATS OFFERED ERAGROSTIS HAY
CHAPTER 3
PHYSIOLOGICAL RESPONSES, NUTRIENT DIGESTIBILITY AND
NITROGEN RETENTION IN TSWANA GOATS

3. 1 Introduction

All animals require access to water to enable them to perform normal body functions. The more continuous the access, the better the animal's metabolism and the higher its production. In many parts of the world, South Africa included, where water is scarce, animals are faced with irregular, infrequent and inadequate water supply. In practical terms, however, watering animals usually takes place once or twice daily or even every other day (Steele, 1996). Where they are given water twice a day, it is usually once in the mornings before they are going out to graze and at kraaling time. During the dry season, the availability and quality of fodder, which is usually low, limit the productivity of goats. Breeds of desert goats and sheep are known for their adaptability to water shortages (Singh, More & Sahni, 1976; Silanikove, 1984; Brosh, Shkolnik & Choshniak, 1987).

The North West Province of South Africa is semi-arid, and is mostly inhabited by Tswana goats. Tswana goats are characterised by fine, glossy and short coats. Horns and beard are common in both sexes (Aganga *et al.*, 2005). Despite their importance in terms of meat and milk, there is little known and unfortunately, little documented information about Tswana or other indigenous breeds under conditions of water shortages (Qinisa & Boomker, 1999). It is, therefore, important to understand how goats respond to water scarcity and low quality forages so that this valuable animal may be better employed to boost the economy of dry regions. In this study, an attempt has been made to investigate the effect of water restriction on blood parameters, water intake and balance. Feed intake and digestibility, as well as whole body nitrogen balance of Tswana goats was also



investigated while they were being fed on *Eragrostis teff* hay, which has a CP content of 7.1 %, and is therefore regarded a low quality forage.

3.2 Materials and Methods

3.2.1 Study site

This study was conducted at Onderstepoort (Faculty of Veterinary Science, University of Pretoria, South Africa) during the months July/August 2007.

3.2.2 Experimental animals

Twelve Tswana goat wethers obtained from the Northwest Province of South Africa formed the research flock. All the goats were housed individually in metabolic crates. Ambient temperature in the metabolic room was maintained at 23 °C. Their average body weight was 28.67 ± 4.48 kg. All the goats were about 15 months old. The metabolic crates were designed for easy collection of faeces and urine.

3.2.3 Experimental design

The goats were randomly allocated to form three groups of 4 animals in each group. These groups were exposed to the following treatments: water *ad libitum* (this served as control); 50 % of *ad libitum* water intake once in the morning; and 25 % of the *ad libitum* water intake in the morning and with another 25 % *ad libitum* water in the afternoon. The design can thus be regarded as a 3x3 Latin square where each group received treatment once only. Each treatment was only applied once per sampling period. This cross-over design removed the sequential effect of ‘time’ while sampling over a period exceeding 30 days.

The goats were adapted to the diet for 10 days. The sampling period was five days and the recovery or flush period (wash-out period) between treatments was also five days.

3.2.4 Experimental procedure

The *ad libitum* water intake of each goat was determined before the trial began. The 50 % volume was then calculated per animal and all treatments assigned per group of animals. *Eragrostis teff* with a composition of 94.4 % DM, 43.9 % ADF, 80.1 % NDF, and 7.1 % CP was fed *ad libitum*. After the initial adaptation period of 10 days, on day 0

of the first treatment, blood samples were taken from the jugular vein of all goats. This was repeated again during the last day of the treatment (day 5). Each blood sample was collected into EDTA tubes and analysed for total plasma proteins, haematocrit, osmolarity and blood urea. Body weights, heart and respiration rates, and rectal temperatures were also measured on days 0 and 5.

Feed and water intakes were measured daily before the morning feeding at 8 a.m. by weighing the hay which was left over (leftovers). Faeces were voided into bags while urine was collected in containers beneath the metabolic crates. Specific gravity of urine in g/l was determined daily using a urinometer. Total volumes were measured and a 50ml sample collected and frozen. After the collection period all the daily samples were pooled per goat and a 50 ml sample collected and frozen. Grab samples of feed offered and faeces collected from bags were stored in sealed plastic bags for later analysis. Suitable subsamples (10 % of the total) of feed, faeces and urine were taken and stored at -20 °C for later analysis.

Initial and final body weights were measured on an electronic scale to one decimal place. The percent body weight loss was also calculated per treatment at the end of the experiment. Rectal temperature was measured by carefully inserting a clinical thermometer into the rectum of each restrained experimental animal for 1 minute. The thermometer was cleaned between animals using cotton wool soaked in methylated spirit. Respiratory rate was obtained by counting the movements (per minute) of the thoracic cage of the experimental animals. Heart rate was obtained with the aid of a stethoscope.

3.2.5 Analysis

3.2.5.1 Blood

The total plasma protein concentration in g/100ml was estimated using a hand-held refractometer. The haematocrit in percent was obtained using a microhaematocrit centrifuge and MSE microhaematocrit reader. Plasma osmolality in mOsm/l was estimated using the freezing point depression method with the aid of a micro osmometer (Hermann Roebling, Messtechnik, Berlin). Blood urea concentrations were measured

using the urease method with the Ace Alera Alfa Wassermann analyser (Siemens Medical Solutions, South Africa).

3.2.5.2 Feed and faeces

Dry matter content of both feed and faeces was determined by accurately weighing a sample and drying it at 70 °C to constant weight. Both dry matter and percent moisture were calculated. Crude protein was determined by the Dumas combustion method (AOAC, 2006). Nitrogen was then calculated by dividing the crude protein by 6.25. Acid and Neutral detergent fibre content were analysed according to standard procedures (Van Soest et al., 1991).

3.2.5.3 Urine

Urinary urea concentrations were measured using the urease method with the Ace Alera Alfa Wassermann analyser (Siemens Medical Solutions, South Africa). Protein in urine was determined by the Dumas combustion method (AOAC, 2006).

3.2.5.4 Calculations

Insensible water loss was taken as the difference between total intake (water drunk + feed water) and water lost via the faeces and urine (Van der Walt *et al.*, 1999). Digestibility of the feed was calculated as the proportion of the ingested feed components that was not recovered in the faeces. Nitrogen retention was calculated as the amount ingested less the amount excreted in the faeces and urine (Ebong, 1995).

3.2.5.5 Statistical analysis

Data were subjected to the statistical analyses using the Generalized Linear Model Procedures (GLM) of SAS (2003). The model included the effects of treatment (water restriction), animal (goat) and phase. All initial values (data prior to the onset of treatments), were used as covariates. Treatment mean differences were compared using the Tukey Procedure. Values are presented as least square means \pm standard error of the mean (LSM \pm s. e.).

3.3 Results

3.3.1 Body weight change and blood parameters

The final body weight of the *ad libitum* water group was significantly greater ($p < 0.05$) than that of treatment groups. However there was no difference in final body weights between water restriction groups. For the *ad libitum* water group the final body weight was 28.05 kg, while the half and quarter *ad libitum* water groups weighed 26.9 and 26.4 \pm 0.17 kg respectively. Rectal temperature values were not affected by water restriction ($p > 0.05$). Values remained constant at 38 °C among the *ad libitum* water and water restriction groups. Heart and respiration rates were reduced in the treatment groups; however, the values were not significant (Table 3.1).

Table 3.1: Least square means (\pm s. e.) of final body weights, temperature, heart rate (HR), and respiration rates (RR) of goats offered *Eragrostis teff* hay and subjected to half *ad lib* of their average daily water intake

	<i>Ad lib</i> n = 12	Half <i>ad lib</i> n = 12	Quarter <i>ad lib</i> n = 12	s. e.
Bodyweight (kg)				
Initial:	28.67	28.41	28.64	1.35
Final:	28.05 ^a	26.90 ^b	26.40 ^b	1.35
Temperature (°C)	38.32 ^a	38.13 ^a	38.18 ^a	0.07
HR (beats/minute)	73.31 ^a	65.88 ^a	68.72 ^a	2.37
RR (breaths/minute)	61.65 ^a	58.46 ^a	56.31 ^a	2.34

^{ab}Means in the same row having different superscripts are significantly different ($p < 0.05$).

The haematocrit was not affected by water restriction. The average haematocrit (PCV) was 29.12, 29.2, and 29.69 \pm 0.28 % for the *ad libitum* water, half *ad lib* and quarter *ad libitum* water groups respectively. The total plasma protein (TPP) concentrations were

6.9, 7.0, and 7.2 ± 0.13 g/100ml for the *ad libitum* water, half *ad lib* and quarter *ad libitum* water groups respectively. These results showed that water restriction did not have any effect on TPP values. Plasma osmolality values were significantly lower in the control compared to treatment groups. For the *ad libitum* water group, plasma osmolality was 312.2 ± 1.34 mOsmol/l and 318.3 ± 1.32 for half *ad libitum* water and 323.0 ± 1.29 mOsmol/l for quarter *ad libitum* water treatments. Blood urea concentrations rose from 3.38 ± 0.18 mMol/l for the control to 4.94 ± 0.18 and 5.45 ± 0.18 mMol/l for half *ad libitum* water and quarter *ad libitum* water groups respectively ($p < 0.05$). There was however no difference between the water restriction groups (Table 3. 2).

Table 3.2: Least square means (\pm s.e.) of haematocrit (PCV) , total plasma proteins (TPP), osmolality and blood urea of goats offered *Eragrostis teff* hay and subjected to half *ad lib* of their average daily water intake

	<i>Ad lib</i> n=12	Half <i>ad lib</i> n=12	Quarter <i>ad lib</i> n=12
Haematocrit (%)	29.12 ± 0.28	29.20 ± 0.29	29.69 ± 0.28
TPP (g/100ml)	6.9 ± 0.13	7.0 ± 0.13	7.2 ± 0.13
Osmolarity (mOsmol/l)	312.2 ± 1.34^a	318.3 ± 1.32^b	323.0 ± 1.29^c
Blood urea (mMol/l)	3.38 ± 0.18^a	5.45 ± 0.18^b	4.94 ± 0.18^b

^{ab}Means in the same row having different superscripts are significantly different ($p < 0.05$).

3.3. 2 Feed intake and water balance

The *ad lib* group consumed more water and the restricted groups taking in about half (Tables 3.3 and 3.4). Feed intake was significantly ($p < 0.05$) reduced by water restriction from 899.69 g/d for the *ad libitum* water to 784.06 and 787.08 ± 28.28 g/d for the half and quarter *ad lib* groups respectively. Dry matter intake followed the same pattern. The

water to dry matter intake ratio was higher ($p < 0.05$) at 1.47 for the *ad libitum* water group compared to 0.79 ± 0.067 for the water restriction groups (Table 3.3).

Table 3.3: Least square means of water and feed intake of Tswana goats offered *Eragrostis teff* hay and water either *ad lib*, half *ad lib* or quarter *ad lib* in the morning and afternoon

	<i>Ad lib</i> n=12	Half <i>ad lib</i> n=12	Quarter <i>ad lib</i> n=12	s. e.
Water (ml)	1249.47 ^a	587.77 ^b	590.83 ^b	66.31
Feed intake (g)	899.69 ^a	784.06 ^b	787.08 ^b	28.28
DMI (g)	848.69 ^a	740.16 ^b	743.00 ^b	26.70
Water : DMI	1.47 ^a	0.79 ^b	0.79 ^b	0.07

^{ab}Means in the same row having different superscripts are significantly different ($p < 0.05$).

Faecal water for the *ad libitum* water group was 428.38, and 387.16 and 358.79 ± 39.58 g/d for the half and quarter *ad libitum* water groups respectively. There was no significant difference between the *ad lib* and water restriction groups with regard to faecal water. Volume of urine voided was significantly ($p < 0.05$) reduced from 321.72 ml for the *ad libitum* water group to 245.00 and 255.17 ± 17.49 ml/d for the half *ad libitum* and quarter *ad libitum* water groups respectively. Insensible water loss was ($p < 0.05$) reduced by water restriction from 549.7 to 20.96 and -0.49 ± 42.54 ml/d for the quarter *ad lib* and half *ad libitum* water groups respectively. No significant difference was found between water restriction groups (Table 3.4).



Table 3.4: Least square means of water balance of Tswana goats offered *Eragrostis teff* hay and water either *ad libitum*, half *ad libitum* or quarter *ad libitum* in the morning and afternoon

Water Intake	<i>Ad lib</i> n=12	Half <i>ad lib</i> n=12	Quarter <i>ad lib</i> n=12	s. e.
Free water(ml)	1249.47 ^a	587.77 ^b	590.83 ^b	66.31
% Free water	95.9 ^a	92.8 ^b	92.9 ^b	0.36
Feed water (g)	50.35 ^a	43.91 ^b	44.08 ^b	1.58
% Feed water	4.1 ^a	7.2 ^b	7.1 ^b	0.36
Total intake (ml)	1299.81^a	631.67^b	634.91^b	67.21
Water Output				
Faecal water (g)	428.38 ^a	387.16 ^a	358.79 ^a	39.58
% Faecal water	33.3 ^a	61.7 ^b	57.6 ^b	3.24
Urine (ml)	321.72 ^a	245.00 ^b	255.17 ^b	17.49
% Urine	25.9 ^a	40.6 ^b	41.2 ^b	2.66
Insensible loss (ml)	549.7 ^a	- 0.49 ^b	20.96 ^b	42.54
% Insensible	40.8 ^a	-2.3 ^b	1.2 ^b	4.66
Total intake(ml)	1299.81^a	631.67^b	634.91^b	67.21

^{ab}Means in the same row with different superscripts are different at $p < 0.05$. Percentage for each variable is as a percentage of total water intake.

Water consumption was significantly ($p < 0.05$) reduced from 1.38 ml/kg feed to 0.75 ± 0.06 ml/kg feed for the water restriction groups. Water use efficiency (ml free water per metabolic weight) was higher ($p < 0.05$) for the *ad libitum* water group at 102.97 ml/kg

BW^{0.75} than the 49.79 and 50.84 ± 5.43 ml/kg BW^{0.75} for the half *ad lib* and quarter *ad libitum* water groups respectively (Table 3.5).

Table 3.5: Least square means of water use efficiency (ml/kg BW^{0.75}) and feed intake of Tswana goats offered *Eragrostis teff* hay and water either *ad lib*, half *ad lib* or quarter *ad lib* in the morning and afternoon

	<i>Ad lib</i> (n = 12)	Half <i>ad lib</i> (n=12)	Quarter <i>ad lib</i> (n=12)	s. e.
Body weight (kg)				
Initial body weight (kg)	28.67	28.41	28.64	1.35
Final body weight (kg)	28.05 ^a	26.90 ^b	26.40 ^b	1.35
Free Water (ml)	1249.47 ^a	587.77 ^b	590.83 ^b	66.31
Water Consumption (ml/kg feed)	1.38 ^a	0.75 ^b	0.75 ^b	0.06
Water use efficiency (ml/kgBW ^{0.75})	102.97 ^a	49.79 ^b	50.84 ^b	5.43

^{ab}Means in the same row with different superscripts are different at p< 0.05.

Faecal dry matter was 334.18 g/d for the *ad lib* and 316.31 and 325.44 g/d for half and quarter *ad lib* water restriction groups respectively. There was no significant difference in faecal dry matter among the groups (p>0.05). The digestibility coefficients for DM, N, ADF and NDF, tended to be higher for the control group compared to treatment groups. However, only those for nitrogen reached significant levels. Between water restriction groups, there was no difference as the coefficients remained at 44 % (Table 3.6).

Table 3.6: Least square means of dry matter intake (g), faecal DM (g), and apparent digestibility of *Eragrostis teff* hay when fed to Tswana goats receiving water either *ad libitum*, half *ad libitum* or quarter *ad libitum* in the morning and afternoon

	<i>Ad lib</i> n = 12	<i>Half ad lib</i> n = 12	<i>Quarter ad lib</i> n=12	s. e.
DMI (g)	848.69 ^a	740.16 ^b	743.00 ^b	27.00
Faecal DM (g)	334.18	316.31	325.44	18.15
Apparent digestibility (%)				
DM	60.64	57.50	56.35	1.28
N	50.71 ^a	44.45 ^b	43.83 ^b	1.60
ADF	67.49 ^a	64.02 ^{ab}	62.70 ^b	1.18
NDF	66.75	64.35	63.14	1.41

^{ab}Means in the same row with different superscripts are different at $p < 0.05$.

The specific gravity of the urine for the treatment groups was 1.07 g/l and higher than the 1.06 ± 0.02 g/l for the *ad lib* group. Urine urea output was 46.51 mmol/d for the *ad libitum* water group and 39 ± 4.24 mmol/d for the water restriction groups, but there was no significant difference between the groups. Urea concentration was high at 158 mmol/l for the water restriction groups and 147 ± 14.47 mmol/l for the *ad libitum* water group. The difference between groups was not significant (Table 3.7).

Table 3.7: Least square means of urine specific gravity, urea output and urea concentration of Tswana goats fed *Eragrostis teff* hay and offered water either *ad lib*, half *ad libitum* or quarter *ad libitum* in the morning and afternoon

	<i>Ad lib</i> n=12	Half <i>ad lib</i> n = 12	Quarter <i>ad lib</i> n = 12	s. e.
Specific gravity (g/l)	1.06 ^a	1.07 ^b	1.07 ^b	0.002
Urea output (mmol/d)	46.51	38.79	39.43	4.239
Urea conc.(mmol/l)	147.32	158.09	158.37	14.469

^{ab}Means in the same row with different superscripts are different at $p < 0.05$.

Water restriction significantly ($p < 0.05$) decreased nitrogen consumed from 9.68 to 8.44 and 8.47 ± 0.30 g/d for the half *ad libitum* and quarter *ad libitum* water groups respectively. Faecal nitrogen was not affected by water restriction as it remained at 4.78, 4.70, and 4.76 ± 0.25 g/d for the *ad libitum* water, half *ad libitum*, and quarter *ad libitum* water groups respectively. Urinary nitrogen was not affected by water restriction. All the groups were in negative nitrogen balance (-2.88 ; -3.89 ; and -3.99 ± 0.58 g/d for *ad libitum* water, half *ad libitum*, and quarter *ad libitum* water groups respectively) (Table 3.8).



Table 3.8: Least square means of nitrogen consumption, excretion and retention in Tswana goats fed *Eragrostis teff* hay and receiving water either *ad lib*, half *ad lib* or quarter *ad lib* in the morning and afternoon

	<i>Ad lib</i> n = 12	<i>Half ad lib</i> n = 12	<i>Quarter ad lib</i> n = 12	s. e.
Intake				
N consumed (g)	9.68 ^a	8.44 ^b	8.47 ^b	0.30
Excretion				
Faecal N (g)	4.78	4.70	4.76	0.25
% Faecal N	49.29 ^a	55.55 ^b	56.17 ^b	1.60
Urinary N (g)	7.78	7.62	7.69	0.58
% Urinary N	80.21	89.80	91.11	5.35
N Retention				
N retained (g)	- 2.88	-3.89	-3.99	0.58
% N retained	-29.50	-45.32	-47.28	6.01

^{ab}Means in the same row with different superscripts are different at $p < 0.05$.

3.4 Discussion

The Dumas combustion method was used to determine N because the method does not cause environmental damage and gives accurate and faster results, unlike the standard Kjeldahl method to determine total N (Sader et al., 2004). A drop in body weight is one of the more common effects seen when water intake is restricted. Low final body weights

associated with water restriction can be ascribed to a reduction in both feed and water intake, together with a loss in total body water. Most of the body weight losses during water restriction in sheep and goats were caused by body water loss (El-Hadi, 1986; Degen & Kam, 1992; Parker *et al.*, 2003; Jaber *et al.*, 2004; Alamer, 2006).

The normal respiration rate in goats is 10 – 20 breaths per minute. Young and old goats have slightly higher respiration rates than normal. Normal heart rate ranges from 60 – 80 beats per minute while normal temperature ranges from 38.0 to 40.5 °C (Peacock, 1996). While restricting water intake, the heart rate, respiration rate and temperature of the experimental animals are usually monitored in order to check their health status. In agreement with the findings of this study, daily measurements of heart rate and rectal temperature of dairy cows restricted to 60 % of their daily water intake showed that the health of the cows was not affected by the magnitude of this restriction (Balch *et al.*, 1953). Degen (1977), working with Awassi male lambs reported that even during dehydration, sheep remained thermostable. When goats were given a high and a low protein diet and water restricted to 50 % of their *ad libitum* water intake, heart rate and rectal temperature were not affected (Qinisa & Boomker, 1999). Similar results were also obtained in Awassi sheep (Jaber *et al.*, 2004; Hamaden *et al.*, 2006). A noticeable reduction in respiratory activity during water deprivation has been reported in sheep (Abdelatif & Ahmed, 1994); and goats (Hassan, 1989; Adogla-Bessa & Aganga (2000). Other researchers have obtained results similar to those in this experiment where no significant change in the respiration rates of goats could be detected (Singh *et al.*, 1982; Baker, 1989). According to Alamer (2006), the change in respiration rate may be related to increased environmental temperature imposed on animals during water restriction. The higher ambient temperature could presumably prevent any reduction in respiration rate. In goats, the excessive heat load as a result of solar radiation exposure during water restriction resulted in a 50 % increase in respiration rate (Dm'iel, 1986). Goats restricted to 40 % of their daily *ad libitum* water intake in a hot, dry climate with average maximum and minimum temperatures of 43.4 ± 0.3 °C and 23.3 ± 0.1 °C also had increased respiration rates (Ahmed & El Kheir, 2004). Aganga *et al.*, (1990), reported that respiration rates decreased with increased water deprivation and this was thought to be as

a result of the reduction in metabolic activity of water-deprived ewes. Decreased respiration could be an adaptive mechanism to survive water deficiency, as evaporation of water from respiratory membranes would thus be decreased.

The normal PCV values range from 22 to 38 % and TPP normal values are 6.0 to 7.5 g/dl (Duncan & Prasse, 1986). PCV results showed no significant variation in Yankasa sheep deprived of water for up to 5 days (Aganga *et al.*, 1989; Igbokwe, 1993). Jaber *et al.*, (2004), found no variation in PCV and haemoglobin in Awassi sheep where 2 days and 4 days water restriction were imposed. Similar results were obtained in goats restricted to 50 % and 30 % of their daily *ad libitum* water intake (Ajibola, 2000). The PCV and TPP values of the goats in this study are therefore regarded as being within the normal range.

The recorded increase in plasma osmolality following water restriction has also been reported in other studies on goats and sheep. Plasma osmolality increased linearly throughout the 3-day dehydration period in Baladi, Anglo-Nubian and crossbred goats (Hassan, 1989). Meintjies and Engelbrecht (1994) observed rising plasma osmolality values in water restricted South African Mutton Merino wethers from 299 to 331 mOsmol/kg and these returning to their control values by the second day of rehydration. The increase in plasma osmolality was likely caused by an increase in plasma sodium. The rise in plasma osmolality during water restriction contributes to the maintenance of the plasma volume by inducing water movement into the vascular system (Alamer, 2006; Mengistu *et al.* 2007). The observed rise in plasma urea levels in this study is in agreement with that seen in other studies during water restriction in goats and sheep (Laden *et al.* 1987; Abdelatif & Ahmed, 1994; Ahmed & Abdelatif, 1995; Qinisa & Boomker, 1999). The rise may also be related to a drop in urinary total nitrogen and urea output, which results in an increase in nitrogen retention (More, 1982; Mousa *et al.*, 1983; Brosh *et al.*, 1987; Jaber *et al.*, 2004).

Water restriction has often been shown to reduce food intake in ruminants. Water and DM intake (DMI) are linearly related (Macfarlane & Howard, 1972; Silanikove, 1987). Other results have been similar to those of this study. Food intake was reduced from 19

and 22 g/kg, prior to dehydration, to 14 and 18 g/kg per metabolic weight in Sudanese sheep and goats respectively (El Hadi, 1986). In Saudi Arabian lactating goats daily dry matter intake was reduced during water restriction periods by 18 and 12 % in 50 and 25 % water restriction regimes respectively (Alamer, 2009). On the contrary Mengistu *et al.*, (2004) in Ethiopian goats, Ajibola (2000) in Pedi goats of South Africa and Casamassima *et al.* (2008) in sheep, did not find significant effects of water restriction on feed intake, because ruminants are able to accumulate water, according to a reservoir system, and use it in periods of scarce water supply. Effect of water restriction on DMI can be variable depending upon species, age of animals, nature of diets, environmental temperature, humidity (Misra & Singh, 2002) and also possibly due to the short duration of the digestion study (Adogla-Bessa & Aganga, 2000).

Water restriction reduced DMI by 12 % in both water restriction treatments in this study. This is 38 % less than the degree of water restriction at 50 %. More *et al.*, (1983), reduced the water intake of sheep and goats fed a diet of oaten chaff (1.7 % N) by 50 % and their feed intake was reduced by 25 %, which was half the percentage of water restriction. In steers when water was restricted, the water-to-feed ratios were reduced from 2.9 l/kg on water free choice, to 2.4 l/kg and 2.2 l/kg, on 80 % of free choice and 60 % of free choice respectively (Utley *et al.*, 1970). With drinking water restricted to 50 % of usual intake in dairy cows, Burgos *et al.* (2001) found that the total water water-to-feed ratio decreased from 5.6 ± 0.2 (mean \pm SE) in the baseline period to 4.3 ± 0.1 (mean \pm SE) in the water restriction period. Ajibola (2006) reported that when water was restricted in goats, the water to feed ratio was reduced from 1.88 on free choice to 1.02 and 0.61, on 50 % of free choice and 30 % of free choice, respectively. In this study, water to DMI ratio was reduced from 1.47 to 0.79. This smaller reduction in the water to feed ratio emphasizes the ability of the Tswana goats to utilize water well when it is scarce.

Regardless of the treatment, more water was lost as faecal water than urine. This seems to suggest that the Tswana goats conserve water through the kidneys and that faeces can be a route through which to get rid of excess water. This is also shown by the lower urine



output in the water restriction groups. When faecal water and urine were expressed as a percentage of total water intakes, the goats on water restriction regimes excreted more water through both the faeces and urine. Faecal water was 32.96 % of the total intake for the *ad lib* and 61.29 and 56.51 % for the half and quarter *ad lib* groups, respectively. Urine was 24.75 % for the *ad lib* and 38.79 and 40.19 % for the half *ad lib* and quarter *ad lib* groups, respectively (Table 3.4). These results are in agreement to those of Ajibola (2006) where Pedi goats were restricted to 30 and 50 % of their *ad libitum* water intake. On the other hand, Utley *et al.*, (1970) and More & Sahni (1981) reported that in ruminants, water restriction will lead to conservation of water through the excretory routes. Water restriction reduced insensible water loss from 1487 to 969 g/d in sheep restricted to half *ad lib* water (Van der Walt *et al.*, 1999). In steers, the insensible water loss for the control was 7.2 l/d, 6.2 and 4.7 l/d for the 80 % and 60 % of free choice water (Utley *et al.*, 1970). In this study, there were large differences between the *ad lib* and water restricted groups. For the *ad lib* group, the insensible water loss was 549.7 ml/d, but - 0.49 and 20.96 ml/d for the half *ad lib* and quarter *ad lib* groups, respectively. Further research should be conducted on insensible water loss in water restricted animals in order to find an answer which could explain this large difference.

The water used by animals is related to the metabolic weight of the animals. In order of efficiency the half *ad lib* and quarter *ad lib* groups had a significantly higher water use efficiency at $50 \text{ ml/kg BW}^{0.75}$ compared to the *ad lib* group at $102.97 \text{ ml/kg BW}^{0.75}$ demonstrating better water utilization by the goats when water is in short supply.

Water restriction reduced digestibility coefficients for DM, N, ADF and NDF. Only coefficients for Nitrogen digestion were significantly different to those of animals receiving water *ad lib*. Imposing a reduction of up to 40 % in voluntary feed intake of a forage diet at near maintenance in sheep, goats and cattle resulted in only small changes in particulate matter retention time in the rumen, with no appreciable effect on the apparent digestibility of the diet (Silanikove *et al.*, 1980; & Varga & Prigge, 1982). As reported by Silanikove (1992), a 10 – 30 % reduction in feed intake by ruminants is not expected to affect digestion or passage rate to any great extent. In a comparative study

by Freudenberger & Hume (1993), where goats were water restricted to 57 % of their *ad libitum* water intake and offered a low nitrogen (1.3 %) diet, apparent dry matter and fibre digestibilities were unaffected by the water restriction. The water restriction reduced dry matter intake by 20.8 % which is higher than the 12 % obtained in this study. More *et al.*, (1983), reduced the water intake of sheep and goats fed a diet of oaten chaff (1.7 % N) by 50 % and this water restriction reduced the feed intake by 25 %. There was no significant change in dry matter digestibility between treatments. The percent reduction in dry matter intake seemed to be the important factor in improving digestibility coefficients of water restricted goats. The water restriction has to reduce DMI by more than 40 % to show a significant difference in digestibility and nitrogen retention.

The reduced DMI which accompanied water restriction resulted in a decrease in nitrogen consumption by the treatment groups 8.44 g/d for the half *ad lib* and 8,47 g/d for the quarter *ad lib* compared to 9.68 g/d for the *ad lib* group. This is a reflection of the higher DMI, as the main source of nitrogen to the goats via the feed. Faecal nitrogen was unaffected by water restriction. All the goats lost about 4.7 g/d nitrogen through the faeces. When faecal nitrogen was expressed as a percentage of nitrogen consumed , the water restriction groups lost 56 % nitrogen compared to 49 % nitrogen for the *ad lib* group. Similarly, urinary nitrogen excretion followed the same pattern.

When expressed as a percent of nitrogen consumed, more urinary nitrogen was excreted by the water restriction group (90 %) compared to the 80 % for the *ad lib* group (Table 3.8). The significant reduction in urine volume (Table 3.4) was off-set by an increase in urinary nitrogen concentration as shown by the high urea concentration (Table 3.8) of the water restricted groups at 158 mmol/l compared to the 147 mmol/l for the *ad lib* group leading to the higher specific gravity of the water restricted group compared to the *ad lib* group (Table 3.8). All the groups were in negative nitrogen balance, the nitrogen deficit being more in the water restricted groups. These results are not in agreement with earlier reports that water restriction improves nutrient digestibility and nitrogen retention (English (1966); Topps & Elliot (1967); Thornton & Yates (1969), Asplund & Pfandes (1972); Van der Walt *et al.*, (1999) and Ajibola (2000)). Osman & Fadlalla (1974), in



Sudanese sheep observed a negative nitrogen balance. They concluded that low feed intake due to water restriction reduces nitrogen intake, and this lead to a greater endogenous nitrogen excretion.

Most temperate grasses utilize the C₃ photosynthetic pathway and most tropical grasses use the C₄ photosynthetic pathway. C₃ plants tend to have higher nitrogen and lower cell wall concentrations than their C₄ counterparts (Wilson & Haydock, 1971; Caswell *et al.*, 1973). C₃ and C₄ grasses may have similar nitrogen content and cell wall concentrations, they might be nutritionally different because C₄ plants concentrate protein in highly-vascularized bundle sheath cells which have been shown to be indigestible to insect granivores (Caswell & Reed, 1976) and resistant to bacterial degradation *in vitro* (Akin *et al.*, 1983; Wilson & Hattersley, 1983). On the contrary, protein is dispersed more evenly throughout the highly-digestible mesophyll of C₃ plants. C₄ grasses are predicted to have lower dry matter digestibility and apparent nitrogen digestibility than the C₃ grasses (Caswell *et al.*, 1973; Ehleringer & Monson, 1993).

Eragrostis teff grass, used in this study, is also classified as a C₄ grass. The dry matter digestibility was depressed by water restriction though the difference was not significant while the reduced apparent nitrogen digestibility was significant. It may be that the unavailable nitrogen in C₄ grasses is made more unavailable during times of water scarcity hence a negative nitrogen balance in all the Tswana goats in this study.

3.5 Conclusion

Tswana goats tolerated the 50 % water restriction well as shown by the minimal changes in haematocrit, total plasma proteins, plasma osmolarity, heart rate and rectal temperature. Water restriction improved neither the nutrient digestibility nor the nitrogen balance of the Tswana goats. There seems to be no difference whether the 50 % water is given once, or split into two 25 % morning and afternoon sessions. More research is needed with more stringent water restrictions (< 50 % of their *ad libitum* water intake) and possibly for a longer duration than was used in this study.

Since water restriction did not bring about an improvement on nutrient digestibility and nitrogen retention when Tswana goats were offered a low nitrogen diet, there was therefore a need to investigate their response to water restriction on a high nitrogen diet. Furthermore, it was of interest to investigate whether there were breed differences when water was restricted. Tswana goats were then compared to Boer goats in the second experiment.



PART II

EFFECT OF WATER RESTRICTION ON ASPECTS OF DIGESTION IN TSWANA AND BOER GOATS OFFERED *ERAGROSTIS TEFF* AND LUCERNE HAY

CHAPTER 4

PHYSIOLOGICAL RESPONSES OF WATER-RESTRICTED TSWANA AND BOER GOATS

4.1 Introduction

The productivity of goats in the arid and semi-arid region is limited by a number of environmental constraints. The chronic scarcity of water and the sparse vegetation of poor quality that also fluctuates with season are among the major constraints (King, 1983). Rainfall is erratic and seasonal, thus drinking water for livestock is scarce even during the rainy season. The water scarcity is persistent and much more severe during the dry season. As a result, animals must travel long distances in search of feed and water and they may spend several days without being watered (Mengistu, 2007). Desert breeds of goats and sheep are known for their adaptability to water shortages (Singh *et al.*, 1976; Brosh *et al.*, 1987; Silanikove, 1984). Unfortunately, little is known about the water economy of our South African indigenous Tswana and Boer goat breeds (Qinisa & Boomker, 1999). It is therefore important to understand how goats respond to water scarcity when offered high and poor quality feeds. An attempt has therefore been made to investigate the blood parameters' status of water restricted indigenous Tswana and Boer goats when fed teff and lucerne hay.

4.2 Material and Methods

4.2.1 Study site

This study was conducted at Onderstepoort (Faculty of Veterinary Science, University of Pretoria, South Africa) during the months September to November 2007.



4.2.2 Experimental animals

Twelve (12) Tswana and Boer goat wethers (six of each breed) obtained from the Northwest Province of South Africa formed the research flock. All the goats were housed individually in metabolic crates. Ambient temperature in the metabolic room was maintained at 23 °C. The goats had an initial body weight of 24.7 ± 2.45 kg. All the goats were about 15 months old. The metabolic crates were designed for easy collection of faeces and urine.

4.2.3 Experimental procedure

The goats were randomly allocated to form two groups of 6 goats, comprising of 3 goats of each breed. One group was adapted to teff (*Eragrostis teff*) for 10 days while the other was adapted to Lucerne (*Medicago sativa*).

During this period each goat was given 5 litres of clean drinking water daily. The daily feed intake and water consumption of each goat was measured and recorded. During the last day of the adaptation period (which served as day 0), blood was withdrawn from the jugular vein, and then again on day 4 and the last day (day 7). The collected blood was analysed for total plasma proteins, haematocrit, osmolarity and blood urea.

The body temperature, heart and respiration rates were also measured on the last adaptation day (day 0) and again during the last day of the experiment (day 7). Rectal temperature was measured in degrees Celsius by carefully inserting a clinical thermometer into the rectum of each restrained experimental animal for 1 minute. The thermometer was cleaned between animals using cotton wool soaked in methylated spirits. Respiratory rate was obtained by counting the movements (per minute) of the thoracic cage of the experimental animals. Heart rate was obtained with the aid of a stethoscope. Body weights were measured on the last day of the adaptation period (day 0), last day of the experiment (day 7) and a day (24 hours) thereafter (day 8). After the adaptation period, the goats continued receiving feed *ad libitum* but their water intake was restricted to 50 % of their average daily intake (calculated for each animal from the adaptation data). Once the first trial period was completed, the trial was repeated by

changing the diets of each group. The group that had been on teff was then fed lucerne and vice versa.

4.2.4 Blood analysis

The total plasma protein concentration in g/100ml was estimated using a hand refractometer. The haematocrit, in percent, was obtained using a microhaematocrit centrifuge and MSE microhaematocrit reader. Plasma osmolality in mOsm/l was estimated using the freezing point depression method with the aid of a micro osmometer (Hermann Roebling, Messtechnik, Berlin). Blood urea concentrations in mMol/l were measured using the urease method with the Ace Alera Alfa Wassermann analyser (Siemens Medical Solutions, South Africa).

4.3 Statistical analysis

Data were subjected to statistical analysis using the Generalized Linear Model Procedures (GLM) of SAS (2003). The model included the effects of treatment (water restriction), day, breed and diet. All initial values (data prior to the onset of treatments) were used as covariates (control values). Difference among treatment means were compared by Least Significant Difference (LSD).

4.4 Results

The chemical composition of teff and lucerne is presented in Table 4.1. The nutritive value of lucerne was higher than that of teff as reflected by the higher crude protein concentration and low fibre content.

Table 4.1: Means of proximate analysis of *Eragrostis teff* and *Medicago sativa* on a dry matter basis

	<i>Eragrostis teff</i>	<i>Medicago sativa</i>
DM (g/kg)	944	936
ADF (g/kg)	439	313
NDF (g/kg)	801	475
CP (g/kg)	71	207

4.4.1 Body weight variation

All the animals in this trial lost weight by the end of the water restriction period. This weight was regained after a day of rehydration (i.e. day 8) (Table 4.2). In the Boer goats, the body weight loss was only significant at day 7 on lucerne. In the Tswana goats, there was no significant difference between the treatment weights and control values for both lucerne and teff. Both breeds lost 10 % of their body weight when offered lucerne while water-restricted and then regained 13 -14 % of their dehydrated body weight.

Boer goats lost 2.44 kg (23.08 - 20.64 kg) on average and Tswana goats lost 2.6 kg on average (25.55 – 22.95 kg). After a day of rehydration, Boer goats regained 2.91 kg (23.55 – 20.64 kg) while the Tswana goats regained 2.98 kg (25.93 – 22.95 kg). On teff, they lost 7-9 % of their body weight when water restricted and regained 10 % of their dehydrated body weight when rehydrated. Boer goats lost 2.17 kg (24.23 – 22.06 kg) and Tswana goats lost 1.85 kg (25.75 – 23.90 kg). After a day of rehydration, Boer-goats regained 2.14 kg (24.20 – 22.06) while the Tswana goats regained 2.27 kg (26.17 – 23.90) while eating teff.



Table 4.2: Effect of 50% water restriction on body weights (kg) of Boer goats (n = 6) and Tswana goats (n = 6) fed *Eragrostis teff* and *Medicago sativa* hay

Feed type	Goat breed	Day 0	Day 7	Day 8	LSD
Lucerne	Boer	23.08 ^{ab}	20.64 ^b	23.55 ^a	2.66
	Tswana	25.55 ^a	22.95 ^a	25.93 ^a	3.69
Teff	Boer	24.23 ^a	22.06 ^a	24.20 ^a	3.07
	Tswana	25.75 ^a	23.90 ^a	26.17 ^a	4.55

^{a,b} Means within same row with different superscript are significantly different at $p < 0.05$.
LSD = Least Significant Difference

4.4.2 Dehydration and health status

For both the Boer and Tswana goats, the haematocrit and total plasma proteins were not affected by water restriction. Heart rate and rectal temperature values were also not affected by water restriction. Temperature values tended to be higher in goats fed on lucerne hay. Respiration rate increased in both breeds during water restriction (Table 4.3).

Table 4.3: Effect of 50% water restriction on blood parameters, heart and respiration rates, and rectal temperature in Boer goats (n=6) and Tswana goats (n=6) fed *Eragrostis teff* and *Medicago sativa* hay

Feed	Breed	DAY	HT	TPP	OSM(P)	UREA	HR	RR	TEMP
	Boer	0	23.17 ^a	6.34 ^a	316.25 ^a	9.37 ^b	80.25 ^b	56.33 ^a	39.00 ^b
	Tswana		25.50 ^a	6.88 ^b	318.17 ^a	9.15 ^b	74.33 ^a	56.42 ^{ab}	38.85 ^b
	Boer		27.17 ^b	6.83 ^{ab}	334.50 ^b	9.98 ^b	-	-	-
	Tswana	4	27.42 ^b	7.39 ^{bc}	330.33 ^b	10.33 ^b	-	-	-
Lucerne	Boer		26.75 ^a	7.13 ^b	339.42 ^b	11.53 ^b	86.75 ^c	60.75 ^b	39.00 ^b
	Tswana	7	27.58 ^b	7.73 ^c	333.00 ^b	10.60 ^b	81.75 ^{bc}	62.42 ^b	38.94 ^b
	Boer	0	26.58 ^a	6.23 ^a	312.58 ^a	5.48 ^a	71.75 ^a	52.91 ^a	38.40 ^b
	Tswana		27.92 ^b	6.87 ^b	316.17 ^a	4.78 ^a	76.17 ^{ab}	53.83 ^a	38.20 ^a
Teff	Boer		27.67 ^b	6.90 ^b	327.67 ^b	6.73 ^b	-	-	-
	Tswana	4	27.92 ^b	7.58 ^c	327.00 ^b	6.19 ^a	-	-	-
	Boer		26.92 ^a	6.76 ^a	325.33 ^b	7.28 ^b	74.25 ^a	62.83 ^b	38.58 ^b
	Tswana	7	29.08 ^b	7.61 ^c	325.50 ^b	6.61 ^{ab}	70.17 ^a	61.33 ^b	38.16 ^a
S. E.			1.32	0.22	2.15	0.55	2.71	2.35	0.05

^{abc} Means within same column with different superscript are significantly different at $p < 0.05$.

HT = haematocrit in percent; TPP = total plasma protein in g/100ml
OSM (P) = Plasma osmolarity in mOsmol/l; UREA = Blood urea in mMol/l
HR = heart rate in beat/minute; RR = respiration rate in breaths/minute
TEMP = rectal temperature in °C.

When fed lucerne, the urine: plasma osmolar ratio stayed at 7.2:1 at day 4 and 7 of water restriction in both Boer and Tswana goats. On teff, the urine: plasma osmolar ratio of rose from 6.6:1 and 5.9:1 on day 4 to 7.8:1 and 7.4:1 on the last day of water restriction for Boer and Tswana goats respectively. On average, the urine: plasma osmolar ratio for both breeds is about 7:1 (Table 4.4).



Table 4.4: The urine: plasma osmolar ratio of water restricted Boer goats (n=6) and Tswana goats (n=6) fed either *Eragrostis teff* or *Medicago sativa* hay

Feed	Breed	DAY	OSM(U)	OSM(P)	U/P _{osmol}
Lucerne	Boer	4	2416.00 ^a	334.50	7.2 : 1 ^b
	Tswana		2369.00 ^b	330.33	7.2 : 1 ^b
	Boer	7	2454.83 ^{ab}	339.42	7.2: 1 ^b
	Tswana		2476.17 ^b	333.00	7.4: 1 ^b
Teff	Boer	4	2163.17 ^a	327.67	6.6: 1 ^a
	Tswana		1926.00 ^a	327.00	5.9 : 1 ^a
	Boer	7	2539.83 ^b	325.33	7.8: 1 ^c
	Tswana		2409.50 ^b	325.50	7.4: 1 ^c
S. E.			113.49	2.15	0.35

^{abc} Means within same column with different superscript are significantly different at $p < 0.05$.

4.5 Discussion

Loss of body weight during water restriction trials is usually a result of loss of water content from the gastro-intestinal tract (rumen) and other body water. This is highlighted by the almost instant return to normal body weight during rehydration after such trials. Body weight losses were regained within 24 hrs in Saudi Arabia indigenous goats deprived of water for 3 days. The goats were able to consume a volume of water accounting for 23.5 % of their dehydrated body weights (Alamer, 2006). El-Nouty *et al.*, (1990), reported similar findings where Aardi goats regained 20 % of their dehydrated body weights after being deprived of water for 4 days. Water – deprived Bedouin goats’ body weight loss was fully compensated for during one short drinking bout (Brosh *et al.*,

1987; Choshniak & Shkolnik, 1978). The black Bedouin goats are also able to gulp an amount of water that exceeded the losses in their body weights (Maltz *et al.*, 1984).

Some of the goats in this study regained more than their original body weight. Tswana and Boer goats have the capacity of rapid rehydration which can match that of the Bedouin goats as illustrated by their ability to regain the lost body weights within 24 hrs of rehydration. Moderate water restriction seems to lead mainly to loss of body water and not tissue mass, and this has no deleterious effects on the production or growth of the goats.

The hydration status of an animal can be monitored using the PCV, which should increase when dehydration is significant. PCV results showed no significant variation in Yankasa sheep deprived of water for up to 5 days (Aganga *et al.*, 1989; Igbokwe, 1993). In goats, Ajibola (2000), found no significant variation in PCV values of goats which were restricted to 50 % and 30 % of their free choice water intake. In this study PCV and TPP values did not deviate from the 22 – 38 % and 6.0 to 7.5 g/dl respectively (Duncan & Prasse, 1986). In both breeds, PCV and TPP values were therefore not affected by water restriction in this study.

The normal plasma osmolarity ranges from 280 – 300 mOsmol/l. Values above 300 mOsmol/l indicate hypertonicity (dehydration) while those below 260 mOsmol/l indicate hypotonicity (overhydration) (Blood & Radostis, 1989). The recorded increase in plasma osmolarity following water restriction in this study has also been reported in other studies on goats (Hassan, 1989; El –Nouty *et al.*, 1990) and sheep (Igbokwe, 1993; Meintjies & Engelbrecht, 1994). The rise in plasma osmolarity was likely to have been caused by an increase in plasma sodium. The rise in plasma osmolarity during water restriction contributes largely to the maintenance of the plasma volume, by inducing water movement into the vascular system (Alamer, 2006; Mengistu *et al.*, 2007). The increase in blood urea is due to the greater water uptake from the kidneys and to the decreased blood flow towards the urinary apparatus that causes a reduction of urine and the increase of blood urea concentration (Casamassima, 2008). Water restriction may cause a

reduction in urinary nitrogen excretion (Brosh *et al.*, 1986) as a result of a reduced filtration in the glomerulus of the kidney (Wittenberg *et al.*, 1986).

When checking the health status of an animal the most commonly used measurements are that of heart and respiration rate as well as rectal temperature. Daily measurement of heart rate and rectal temperature of dairy cows restricted to 60 % of their daily water intake showed that the health of cows was not affected by the magnitude of the restriction (Balch *et al.*, 1953). Degen (1977), working with Awassi male lambs found that even during dehydration, sheep remained thermostable. Similar results were also obtained in Awassi sheep (Jaber *et al.*, 2004; Hamaden *et al.*, 2006). Both Boer and Tswana goats remained thermostable and showed no significant changes in heart rate during this trial. In goats, the excessive solar heat load due to solar radiation exposure during water restriction resulted in a 50 % increase in respiration rate (Dmi'el, 1986). Goats restricted to 40 % of their daily *ad libitum* water intake showed increased respiration rates (Ahmed & El Kheir, 2004). In this study respiration rates were also elevated by water restriction. However, the contrary was shown by Aganga *et al.*, (1990), who reported that respiration rates decreased with increased water deprivation - possibly as a result of a reduction in metabolic activities of the water-deprived ewes. This is also an adaptive mechanism to survive water deficiency by limiting evaporation from the respiratory surfaces.

Concentration of the urine during water deprivation helps to keep plasma fluid levels stable. This results in changes in the ratio of solutes in the urine to that in the plasma. The maximum urinary: plasma osmolar ratio achievable by cattle is about 4:1. Goats and sheep have the ability to achieve urinary: plasma osmolar ratios (U/P_{osm}) in the range of 6:1 to 8:1 (Maloiy, 1973b, cited by Wilson (1989)). Owen (1975) found significantly greater U/P_{osm} ratios in sheep during dehydration when fed a high, rather than a low, protein diet. There seems to be no major difference in the U/P_{osm} ratios when both Boer and Tswana goats were fed either eragrostis teff or lucerne hay. The ratio (average of 7:1) obtained in this study when compared with those in desert-adapted ruminants after periods of dehydration i.e. 8:1 for the camel (Maloiy, 1972), 7: 1 for the Bedouin goat (Maloiy *et al.*, 1979), and 11: 1 for the dik-dik (Maloy, 1973), illustrate that the Boer and

Tswana goats are normally capable of a high degree of urine concentration and are, in this respect, also well adapted to living in arid regions.

4.6 Conclusion

Tswana and Boer goats could be classified as rapid recoverers as they were able to regain the lost body weight within a very short space of time (24hrs), after rehydration. Restricting the water intake of goats to 50 % of their average daily water intake did not tax their maximum physiological capabilities as shown by lack of change in their heart rate and rectal temperature. The urine: plasma osmolar ratios indicated that these goats can easily survive under arid conditions.



CHAPTER 5

WATER UTILIZATION AND APPARENT DIGESTIBILITY OF FEED BY WATER RESTRICTED TSWANA AND BOER GOATS FED ERAGROSTIS AND LUCERNE HAY

5.1 Introduction

Water is often overlooked as an important component in diets of livestock (Adams & Sharpe, 1995). Water is needed for the normal rumen fermentation and metabolism, proper flow of feed through the digestive tract, good nutrient absorption, normal blood volume and tissue requirements. The lack of an adequate supply of water can be a very serious limiting factor with regard to animal performance.

In many arid and semi-arid areas of the world the demand for water increases in the dry season, which is often the season at which ambient temperatures are highest. The water content of available forage, as well as its nutritional value, tends to be very low during this period and there is also depletion in surface water resources. All these factors may cause the goat to walk further, and the additional muscular activity still further increases the animal's need for water. The resulting physiological stress emphasises the need for ensuring the goat's water supply, particularly during the dry season. With the advent of rainfall, the availability of water, both as surface water and in forages, becomes high, and the animal can readily meet its requirement (Devendra & Burns, 1970).

The ratio of dry matter to free water intake has been shown to be important in ruminants where an inadequate supply of water reduces also the intake of dry matter, and this restriction has been shown to be severe at higher ambient temperatures (Bianca *et al.*, 1965). Furthermore, the low nutritive value of available herbage in the drier parts of the tropics (French, 1957; Payne, 1966) may further affect the animal by decreasing voluntary food intake (Crampton, 1957; Blaxter *et al.*, 1961; Minson, 1967). The combined effect of these factors on voluntary food intake can lead to severely lowered productivity (Devendra & Burns, 1983). There have been conflicting reports on the

effect of water intake on the digestibility of nutrients. Some researchers have reported an increase in digestibility (Asplund & Pfandes, 1972) when ruminants are water restricted while others observed no improvement in digestibility (Hadjigeorgiou *et al.*, 2000).

Where there is a shortage of water, those animals capable of using it as efficiently as possible will maximise production. Goats are adapted to water shortages and are efficient users of water (Devendra (1980); Narjisse (1991); Tisserand *et al.* (1991)). The efficiency of water usage and of digestibility will be affected by water intake, quality of the diet and the breed of goat. Information available on the water use efficiency and the digestibility of feed by Boer and Tswana goats is limited. The present study was therefore initiated to investigate the water use efficiency of Boer and Tswana goats when water restricted and offered teff and lucerne as feeds.

5.2 Material and Methods

5.2.1 Animals

Twenty-four goats (12 Boer and 12 Tswana goat wethers) were used in this experiment. The experiment was conducted at the Faculty of Veterinary Science, University of Pretoria (Onderstepoort) in August-November 2007. The goats were 12 -15 months old and had a mean initial live weight of 24.7 ± 4.35 kg.

5.2.2 Feeds

Two types of feeds were used, teff (*Eragrostis teff*) and Lucerne (*Medicago sativa*). Chemical composition of the feeds is as presented in Table 5.1

Table 5:1: Proximate analysis of *Eragrostis teff* and *Medicago sativa* hay on a dry matter basis

	<i>Eragrostis teff</i>	<i>Medicago sativa</i>
DM (g/kg)	944	936
ADF (g/kg)	439	313
NDF (g/kg)	801	475
CP (g/kg)	71	207



5.2.3 Experimental procedure

The goats were randomly allocated to form 4 groups of 6 goats. In each group, there were 3 Boer and 3 Tswana goat wethers. These were employed into a 4 x 4 Latin square design with the following treatments:

- (1) Water *ad libitum* and *Eragrostis teff ad libitum*,
- (2) 50 % of their average daily water intake (calculated for each goat) and *Eragrostis teff ad libitum*,
- (3) Water *ad libitum* and lucerne (*Medicago sativa*) *ad libitum*, and
- (4) 50 % of their average daily water intake (calculated for each goat) and lucerne (*Medicago sativa*) *ad libitum*.

The experimental design was developed in conjunction with Biostatiticians that specialize in biological experiments. The design was specifically selected in order to ensure accurate statistical analyses. The goats were weighed at the beginning and at the end of each treatment period. The goats were then adapted to their respective diets for 10 days after which samples were collected for seven days. There was a 10 days flushing off (wash out) period between treatments. All the goats were fitted with faecal bags and placed in individual metabolic crates specially designed for easy collection of urine and measurements of water and feed intake. Faeces were collected everyday in the morning from faeces bags and urine from cooled containers underneath the metabolic crates.

5.2.4 Feed and water intake

Feed and water was offered at 08h00 in the morning. The feed was weighed in a single balance scale and water measured using a graduated cylinder. The feed and water remaining from the previous day were measured in order to determine actual consumption. The daily water intake was determined after subtracting the measured daily evaporation losses that occurred from a container similar to those provided for the goats.

5.2.5 Chemical and statistical analyses

Feed and faeces were dried to a constant weight in an oven at 70 °C in order to determine dry matter. In brief, dry matter content was determined by accurately weighing a sample and drying it at 70 °C to constant weight. Both dry matter and percent moisture

were calculated. Crude protein was determined by the Dumas combustion method (AOAC, 2006). Nitrogen was then calculated by dividing the crude protein by 6.25. Acid and neutral detergent fibre contents were analysed according to the procedures of Van Soest *et al.*, (1991).

Data were subjected to the statistical analyses using the Generalized Linear Model Procedures (GLM) of SAS (2003). The model included the effects of treatment (water restriction), breed (goat) and breed x treatment. All initial values (data prior to the onset of treatments), were used as covariates. Treatment mean differences were compared using the Tukey Procedure. Values are presented as least square means \pm standard error of the mean (LSM \pm s. e.).

5.3 Results

5.3.1 Water and feed intake

Regardless of the treatment, the Boer goats drank more water compared to the Tswana goats though the difference was not significant. There was no difference in feed intake between the breeds. The water to dry matter ratio was statistically not different (Table 5.2).

Table 5.2: Least square means of water and feed intake (g \pm s. e.) of Boer and Tswana goats

	BOER	TSWANA	S.E
Free water (g)	1306.7	1271.5	41.71
Feed intake (g)	843.4	844.4	17.59
DMI (g)	792.4	793.3	16.51
W: DMI	1.6	1.5	0.95

^{ab} Means in the same row with different superscripts are different at $p < 0.05$.

DMI = dry matter intake, W: DMI = water to dry matter ratio

Regardless of the breed, the water intake of goats reflected the treatments imposed with *ad libitum* groups on both feeds drinking more water than the restricted groups. The water intake of goats on lucerne was higher than those groups offered teff. On teff there

was significant difference in feed intake between the *ad lib* and half *ad lib* water groups while on lucerne the *ad lib* group's feed intake was significantly higher at 1002.7 g/d compared to 808.0 ± 24.88 g/d. Water restriction reduced water to dry matter ratio from 1.7 to 0.8 on teff and from 2.3 to 1.3 ± 0.06 on lucerne (Table 5.3).

Table 5.3: Least square means of water and feed intake (g ± s.e.) of goats offered *Eragrostis teff* and *Medicago sativa* hay, and water either *ad libitum*, or half of their average daily *ad libitum* water intake (means)

Water In	ERAGROSITS TEFF (n=24)		MEDICAGO SATIVA (n= 24)		s. e.
	<i>Ad lib</i>	Half <i>ad lib</i>	<i>Ad lib</i>	Half <i>ad lib</i>	
Free (ml/d)	1264.1 ^a	544.2 ^b	2372.4 ^c	975.8 ^d	58.99
Feed intake (g)	783.0 ^{ab}	691.9 ^a	1092.7 ^c	808.0 ^b	24.88
DMI (g)	739.2 ^a	653.1 ^b	1022.8 ^c	756.3 ^b	23.34
W:DMI	1.7 ^a	0.8 ^b	2.3 ^c	1.3 ^d	0.06

^{ab} Means in the same row with different superscripts are different at p< 0.05.

On teff, there was no significant difference between the breeds within treatment regarding water, feed and dry matter intake. However, even between treatments feed and dry matter intake was not significantly different. The water to dry matter ratio was also not significantly different between the breeds within the treatments. On lucerne the difference was also not between breeds within treatments but only between treatments (Table 5.4). Both breeds had higher values for water and feed intake as well as water to dry matter ratio when they were on *ad libitum* water intake and offered lucerne.

Table 5.4: Least square means of water and feed intake (g ± s.e.) of Boer (n=12) and Tswana (n=12) goats offered *Eragrostis teff* and *Medicago sativa* hay and water either *ad libitum* or half of their average *ad libitum* water intake (means)

Trt	Breed	Water (g/d)	Feed (g/d)	DMI(g/d)	W:DMI
1	Boer	1213.9 ^b	783.9 ^a	740.0 ^a	1.6 ^{bc}
	Tswana	1314.2 ^b	782.1 ^{ab}	738.3 ^a	1.8 ^c
2	Boer	530.8 ^a	696.3 ^a	657.3 ^a	0.8 ^a
	Tswana	557.5 ^a	687.4 ^a	648.9 ^a	0.9 ^a
3	Boer	2515.5 ^c	1086.3 ^c	1016.8 ^b	2.5 ^d
	Tswana	2229.2 ^c	1099.1 ^c	1028.8 ^b	2.2 ^d
4	Boer	966.7 ^b	807.2 ^b	755.5 ^a	1.3 ^b
	Tswana	985.0 ^b	808.8 ^b	757.0 ^a	1.3 ^b
	S.E.	83.42	35.18	33.01	0.09

^{ab} Means in the same column with different superscripts are different at $p < 0.05$.

Treatment 1 = Water *ad lib*, *Eragrostis ad lib*;

Treatment 2= Half *ad lib* water, *Eragrostis ad lib*,

Treatment 3 = Water *ad lib*, *Lucerne ad lib*

Treatment 4= Half *ad lib* water, *Lucerne ad lib*,

DMI = dry matter intake, W: DMI = water to dry matter ratio

The Boer goats produced significantly ($p < 0.05$) more faecal water (g/d) compared to Tswana goats (484.7 ± 17.78 versus 422.9 ± 17.78 for Boer and Tswana respectively). There was no significant difference ($p < 0.05$) between the volume of urine (ml/d) produced (467.9 ± 21.17 and 480.4 ± 21.17) and insensible water lost (405.2 ± 29.08 and 419.4 ± 29.08 ml/d) between the Boer and the Tswana goats respectively (Table 5.5).



Table 5.5: Least square means of water balance (ml and %) of Boer and Tswana goats (means)

	BOER (n=12)	TSWANA (n=12)	S.E
Water balance			
Water intake			
Free water (ml/d)	1306.7	1271.5	41.71
% Free water	95.4	95.4	0.12
Feed water (g/d)	51.0	51.1	1.09
% Feed water	4.6	4.6	0.12
Total intake	1357.7	1322.6	42.27
Water output			
Faeces (g/d)	484.7 ^a	422.9 ^b	17.78
% Faeces	40.5 ^a	37.1 ^b	1.59
Urine (ml/d)	467.9	480.4	21.17
% Urine	35.9	36.7	1.31
Insensible loss (ml/d)	405.2	419.4	29.08
% Insensible loss	23.6	26.2	1.87
Total output (ml/d)	1357.7	1322.6	42.27

^{ab} Means in the same row with different superscripts are different at $p < 0.05$. Percentage of variables is as a percentage of total water intake.

Regardless of the breed (Table 5.6), the *ad lib* water treatment groups drank more water compared to water restricted groups. The lucerne *ad lib* water group drank nearly twice as much as the teff *ad lib* water group. The water restricted groups followed the same trend with the group on teff drinking about half that on lucerne. There was no significant difference ($p > 0.05$) in faecal water between *ad lib* and half *ad lib* water groups when teff was on offer. However, on lucerne the goats produced more faecal water ($p < 0.05$)

on *ad lib* water compared to all the other groups. Water restriction did not affect the volume of urine produced when the goats were on teff. However on lucerne, the volume of urine was reduced from 879.4 to 523.9 ± 29.97 ml/d. Overall urine produced on teff was less than that from feeding lucerne.

On teff, when excretion of water (water out) is expressed as a percent of water intake, more water was lost as faecal water than as urine (33.7 % faecal water versus 21.4 ± 1.85 % urine; 56.0 % faecal water versus 36.0 ± 1.85 % urine (between the 2 treatments)). On lucerne, when water out is expressed as a percent of water intake, more water was excreted as urine (36.2 ± 1.85 % urine versus 28.4 ± 2.25 % faecal water ; 51.6 ± 1.85 % urine v/s 37.2 ± 2.25 % faecal water (between the 2 treatments) than was lost via the faeces.

Water restriction reduced ($p < 0.05$) insensible water loss from 586.9 to 52.6 ± 41.13 ml/d when goats were fed teff while on lucerne insensible water loss was significantly reduced from 881.7 to 127.9 ± 41.13 ml/d. There was, however, no significant difference between the water restricted groups. Except for the insensible water loss, the highest percentage of water excreted on both feeds, was from the water restricted groups.



Table 5.6: Least square means of water balance (ml/d and %) of goats offered *Eragrostis teff* and *Medicago sativa* hay, and water either *ad libitum*, or half of their average daily *ad libitum* water intake (means)

	ERAGROSITS TEFF (n=24)		MEDICAGO SATIVA (n= 24)		
Water balance					
Water In	<i>Ad lib</i>	Half <i>ad lib</i>	<i>Ad lib</i>	Half <i>ad lib</i>	s. e.
Free (ml/d)	1264.1 ^a	544.2 ^b	2372.4 ^c	975.8 ^d	58.99
% Free water	96.5 ^a	93.1 ^b	97.1 ^a	94.9 ^c	0.17
Feed (g/d)	43.9 ^a	38.8 ^a	69.9 ^b	51.7 ^c	1.54
% Feed water	3.5 ^a	6.9 ^b	2.9 ^a	5.1 ^c	0.17
Total intake	1307.9 ^a	582.9 ^b	2442.3 ^c	1027.6 ^d	59.77
Water out					
Faeces (g/d)	436.1 ^a	322.1 ^a	681.2 ^b	375.8 ^a	25.15
% Faeces	33.7 ^a	56.0 ^b	28.4 ^a	37.2 ^a	2.25
Urine (ml/d)	285.0 ^a	208.2 ^a	879.4 ^b	523.9 ^c	29.96
% Urine	21.4 ^a	36.0 ^b	36.2 ^b	51.6 ^c	1.85
Insensible(ml/d)	586.9 ^a	52.6 ^b	881.7 ^c	127.9 ^{bd}	41.13
% Insensible	44.9 ^b	8.1 ^a	35.5 ^b	11.2 ^a	2.64
Total	1307.9 ^a	582.9 ^b	2442.3 ^c	1027.6 ^d	59.77

^{abcd} Means in the same row with different superscripts are different at $p < 0.05$.

On teff (Table 5.7), when offered both *ad lib* and half *ad lib* water, Boer goats had a lower water intake than Tswana goats (1257.8 versus 1358.0ml/d (*ad lib*) and 569.8 versus 596.0 ml/d (half *ad lib*) for Boer and Tswana goats respectively) but values did not reach significant levels. Faecal water, urine and insensible water loss followed the same trend (higher values for Tswana goats but no significant difference between the breeds). For faecal water and urine produced, there was no significant difference

between the breeds and between treatments. However, the insensible water loss was high for the *ad lib* water treatments when compared to water restriction treatments. On lucerne, the *ad lib* groups regardless of the breed produced more water through the faeces, as urine and insensible water loss. The only significant loss in faecal water on *ad lib* water was where the Boer goats produced 781.8 to 580.5 ± 35.57 ml/d of the Tswana goats. However, when the faecal water was expressed as a percentage of total water intake, the difference was not significant. On the other hand, the half *ad lib* water lucerne group (regardless of the breed) lost more water as urine when urine was expressed as a percent of water intake (Table 5.7).

Table 5.7: Least square means of water balance (ml and %) of Boer (n=12) and Tswana (n=12) goats offered *Eragrostis teff* and *Medicago sativa* hay and water either *ad libitum* or half of their average *ad libitum* water intake (means)

Water	Eragrostis teff		Medicago sativa				S.E.		
	Ad lib (n=12)		Half ad lib (n=12)		Ad lib (n=12)			Half ad lib (n=12)	
Breed	Boer	Tswana	Boer	Tswana	Boer	Tswana	Boer	Tswana	
Freewater (ml)	1213.9 ^b	1314.2 ^b	530.8 ^a	557.5 ^a	2515.5 ^c	2229.2 ^c	966.7 ^b	985.0 ^b	83.42
% Free water	96.4 ^b	96.6 ^b	93.1 ^a	93.2 ^a	97.3 ^c	96.9 ^c	94.8 ^b	94.9 ^b	0.24
Feed water (g)	43.9 ^{ab}	43.8 ^a	39.0 ^a	38.5 ^a	69.5 ^c	70.3 ^c	51.7 ^c	51.8 ^c	2.18
% Feed water	3.6 ^a	3.4 ^a	6.9 ^c	6.8 ^c	2.7 ^a	3.1 ^a	5.2 ^b	5.1 ^b	0.24
Faeces (g)	457.0 ^{ab}	415.1 ^a	330.9 ^a	313.2 ^a	781.8 ^c	580.5 ^b	369.0 ^a	382.6 ^a	35.57
%	35.2 ^{ab}	32.2 ^a	58.1 ^c	53.8 ^c	31.1 ^a	25.6 ^a	37.5 ^{bc}	37.0 ^b	3.19
Urine (ml)	263.3 ^a	306.6 ^a	200.8 ^a	215.7 ^a	875.4 ^c	883.7 ^c	531.9 ^b	515.8 ^b	42.34
%	20.9 ^a	21.9 ^a	35.1 ^b	36.9 ^b	33.8 ^b	38.5 ^{bc}	53.6 ^d	49.6 ^c	2.611
Insensible (ml)	537.5 ^b	636.3 ^{bc}	38.1 ^a	67.1 ^a	927.8 ^d	835.7 ^{cd}	117.3 ^a	138.4 ^a	58.17
%	43.9 ^b	45.9 ^b	6.7 ^a	9.4 ^a	35.1 ^b	35.9 ^b	8.9 ^a	13.5 ^a	3.74

^{abcd} Means in the same column with different superscripts are different at $p < 0.05$.

The final body weights (kg) of the Tswana goats were higher ($p < 0.05$) compared to that of Boer goats (24.9 ± 0.54 to 23.0 ± 0.54 kg). Regardless of the treatment, there was no significant difference in the water use efficiency of Boer and Tswana goats (Table 5.8).

Table 5.8 Least square means of water use efficiency (ml/kg BW^{0.75}) of Boer and Tswana goats (means)

	BOER	TSWANA	S.E.
Initial weight (kg)	24.0 ^a	25.9 ^b	0.55
Final weight (kg)	23.0 ^a	24.9 ^b	0.54
Free water (ml/d)	1306.7	1271.5	41.71
Water efficiency (ml/kg ^{0.75})	122.8	113.2	3.71

^{ab} Means in the same row with different superscripts are different at $p < 0.05$.

On teff, there was no difference in final body weight between the *ad lib* and half *ad lib* water groups. When lucerne was offered the *ad lib* water group had a higher final body weight than the half *ad lib* water group. Water use efficiency values were lower in water restricted group and about half those of the *ad lib* water groups (Table 5.9).

Table 5.9 Least square means of water use efficiency (ml/kg BW^{0.75}) of goats offered *Eragrostis teff* and *Medicago sativa* hay and water either *ad libitum* or half of their average *ad libitum* water intake (means)

Water	Eragrostis teff (n=24)		Medicago sativa (n=24)		S. E.
	<i>Ad lib</i>	Half <i>ad lib</i>	<i>Ad lib</i>	Half <i>ad lib</i>	
Initial weight (kg)	25.6	25.0	24.9	24.3	0.77
Final weight (kg)	25.6 ^b	23.0 ^{ab}	25.4 ^b	21.8 ^a	0.76
Free water (ml/d)	1264.1 ^a	544.2 ^b	2372.4 ^c	975.8 ^d	58.99
Water efficiency (ml/kg)	111.0 ^b	52.1 ^a	211.2 ^c	97.6 ^b	5.25

^{abcd} Means in the same row with different superscripts are different at $p < 0.05$.

On teff, final body weights were not significantly different between the Boer and Tswana goats within treatments. Similarly water use efficiency followed the same trend.

Both breeds had lower final weights and water use efficiency values when water restricted (treatment 2). On lucerne when offered water *ad libitum* Tswana had significantly higher final body weights than Boer goats (26.2 versus 24.5 kg). The water use efficiency value was significantly lower in Tswana goats than in Boer goats (193.9 versus 228.5 ml/ kg^{0.75}). When water restricted no significant differences were observed between the breeds in final body weights and water use efficiency.

Table 5.10: Least square means of water use efficiency (ml/kg^{0.75}) of Boer and Tswana goats offered low and high nitrogen diets and water either *ad libitum* or 50% of their average *ad libitum* water intake (means)

Trt	Breed	Initial weight	Final weight (kg)	Free water(ml/d)	Water efficiency
1	Boer	24.9 ^{ab}	24.8 ^{ab}	1213.9 ^b	109.8 ^b
	Tswana	26.3 ^b	26.5 ^b	1314.2 ^b	112.3 ^b
2	Boer	24.2 ^{ab}	22.1 ^a	530.8 ^a	52.6 ^a
	Tswana	25.8 ^{ab}	23.9 ^a	557.5 ^a	51.6 ^a
3	Boer	23.9 ^{ab}	24.5 ^a	2515.5 ^c	228.5 ^d
	Tswana	25.9 ^{ab}	26.2 ^b	2229.2 ^c	193.9 ^c
4	Boer	23.1 ^a	20.6 ^a	966.7 ^b	100.2 ^b
	Tswana	25.6 ^{ab}	23.0 ^a	985.0 ^b	95.1 ^b
	S.E.	1.09	1.07	83.42	7.43

^{abc} Means in the same column with different superscripts are different at $p < 0.05$.

5.3.2 Dry matter intake and apparent digestibility

Regardless of the treatments, there was no difference in dry matter intake and apparent digestibility coefficients between the Boer and the Tswana goats. For both breeds the dry matter intake stood at about 793 ± 16.51 g/d and faecal dry matter at 338 ± 0.95 g/d. The ratio of water to dry matter intake stayed at 1.6 ± 0.04 . The apparent digestibility coefficient for DM was 57 ± 0.81 % and for nitrogen 56 ± 1.13 %. ADF and NDF apparent digestibility coefficients were 53 ± 1.12 and 57 ± 0.99 % respectively (Table 5.11).



Table 5.11 Least square means of dry matter (g) and apparent digestibility (%) for Boer and Tswana goats offered *Eragrostis teff* and *Medicago sativa* hay and water either *ad libitum* or half their average daily *ad libitum* water intake (means)

	BOER (n =12)	TSWANA (n =12)	S. E.
DMI (g/d)	792.41	793.25	16.51
Faecal DM (g/d)	337.63	338.26	0.95
Apparent digestibility (%)			
DM	56.52	56.49	0.81
N	55.44	56.72	1.13
ADF	52.57	54.29	1.12
NDF	57.06	57.86	0.99

^{ab} Means in the same row with different superscripts are different at P< 0.05.

DMI = dry matter intake; DM = dry matter: N = nitrogen: ADF = acid detergent fibre: NDF = neutral detergent fibre.

In Table 5.12, there was no significant difference in dry matter intake between goats given *ad lib* and half *ad lib* water when offered teff but a significant difference was observed between the 2 groups when lucerne was fed. The dry matter intake (DMI) for the *ad lib* water group was higher at 1022.8 g/d compared to 756.3 ± 23.34 g/d for the half *ad lib* water lucerne fed groups. On the teff diet, faecal DM was significantly reduced by water restriction, from 360.2 to 315.2 ± 9.78 g/d, while when lucerne was offered faecal DM dropped from 384.3 to 292.1 ± 9.78 g/d. The digestibility coefficients for DM, N, ADF and NDF did not differ significantly between the *ad lib* and half *ad lib* water groups when they were fed either teff or lucerne. However, digestibility coefficients for DM and N were significantly higher when the groups were fed lucerne rather than teff. ADF and NDF digestibility coefficients remained significantly higher

when teff was offered. When fed lucerne, the digestibility coefficients for nitrogen were almost double those found when the goats were fed teff.

Table 5.12 Least square means of dry matter(g) and apparent digestibility coefficients (%) for goats offered *Eragrostis teff* and *Medicago sativa* hay and water either *ad libitum* or half of their average *ad libitum* water intake (means)

Water	ERAGROSTIS TEFF (n=24)		MEDICAGO SATIVA (n=24)		S. E.
	<i>Ad lib</i>	<i>Half ad lib</i>	<i>Ad lib</i>	<i>Half ad lib</i>	
DMI (g)	739.17 ^{ab}	653.12 ^a	1022.75 ^c	756.28 ^b	23.34
Faecal DM (g)	360.15 ^b	315.16 ^a	384.33 ^b	292.15 ^a	9.78
Apparent digestibility (%)					
DM	51.45 ^a	51.41 ^a	62.21 ^b	60.96 ^b	1.14
N	38.60 ^a	36.61 ^a	75.29 ^b	73.82 ^b	1.59
ADF	59.54 ^a	60.32 ^a	49.07 ^b	44.77 ^b	1.58
NDF	60.70 ^a	61.20 ^a	55.31 ^b	52.63 ^b	1.40

^{abcd} Means in the same row with different superscripts are different at $p < 0.05$.

DMI = dry matter intake; DM = dry matter: N = nitrogen: ADF = acid detergent fibre;
NDF = neutral detergent fibre.

No significant difference was observed between the breeds (Boer and Tswana) within and between treatments for dry matter (intake and output) or for digestibility coefficients for DM, N, ADF and ADF when teff (treatment 1 & 2) was offered. With lucerne feeding (treatment 3 & 4), there was no significant difference within the treatment between the Boer and Tswana goats for digestibility of nutrients but the *ad lib* water groups had significantly higher values for DMI and DM output than the half *ad lib* water groups (Table 5.13).

Table 5.13 Least square means of dry matter intake(g) and apparent digestibility coefficients (%) for Boer (n = 12) and Tswana (n=12) goats offered offered *Eragrostis teff* and *Medicago sativa* hay, and water either *ad libitum* or half of their average *ad libitum* water intake (means)

Trt	Breed	Dry matter (g/d)		Apparent digestibility (%)			
		DMI	Output	DM	N	ADF	NDF
1	Boer	740.03 ^a	355.09 ^b	52.38 ^a	38.90 ^a	60.41 ^b	61.28 ^a
	Tswana	738.34 ^a	365.22 ^{bc}	50.51 ^a	38.32 ^a	58.66 ^b	60.12 ^a
2	Boer	657.34 ^a	315.79 ^{ab}	51.59 ^a	36.28 ^a	59.56 ^b	61.19 ^a
	Tswana	648.91 ^a	314.53 ^a	51.24 ^a	36.93 ^a	61.08 ^b	61.21 ^a
3	Boer	1016.75 ^b	387.47 ^c	61.39 ^b	74.70 ^b	47.07 ^a	53.33 ^a
	Tswana	1028.76 ^b	381.19 ^c	63.04 ^b	75.88 ^b	51.07 ^{ab}	57.29 ^a
4	Boer	755.52 ^a	292.18 ^a	60.73 ^b	71.89 ^b	43.22 ^a	52.44 ^a
	Tswana	757.03 ^a	292.11 ^a	61.19 ^b	75.75 ^b	46.33 ^a	52.81 ^a
	S. E.	33.01	13.83	1.61	2.25	2.23	1.98

^{abc} Means in the same column with different superscripts are different at P< 0.05.

Treatment 1 = Water *ad lib*, Eragrostis; Treatment 2= Half *ad lib* water; Eragrostis,

Treatment 3 = Water *ad lib*, Lucerne; Treatment 4= Half *ad lib* water, Lucerne;

DM = dry matter; N = nitrogen; ADF = acid detergent fibre; NDF = neutral detergent fibre

5.4 Discussion

The lower water content of faeces excreted by the Tswana goats seems to suggest that they conserve more water through the digestive system, while the Boer goat uses both available excretory routes (digestive and renal systems). This water saving mechanism

tends to be supported by a slightly better utilization of water by the Tswana goat (122.77 versus 113.19 ml/kg BW^{0.75}/day for Boer and Tswana goat respectively). The insensible water loss was reduced during water restriction when fed both teff and lucerne. A similar observation was made by Van der Walt *et al.* (1999) in sheep offered low and high nitrogen diets and water restricted to 50 % of their *ad libitum* water intake. In all cases, as in this study, the quantity of insensible water lost was higher than that lost via the faeces and urine. Forbes (1995) attributed this high insensible water loss to the rise in heat production caused by the increase in food intake, leading to greater evaporative heat losses. Goats subjected to 30 and 60 % feed restrictions had lower insensible water losses compared to the 0 % feed restriction (Teixeira *et al.*, 2006). The efficiency of water use when consumed by the goats may be calculated as ml/kg BW^{0.75}/day. The values are 111.0, 52.1, 211.2, 97.6 for the *ad lib* and half *ad lib* water groups when fed teff and lucerne respectively. The goats with the lower values (water restricted) were found to utilize water better than the *ad lib* water groups. Similar observations were also made by Ajibola (2006) where the water efficiency of goats was 55.5 ± 15.8 ml/kg BW^{0.75}/d for water restricted animals and 112.0 ± 31.0 ml/kg BW^{0.75}/d for goats receiving water *ad lib*. Mengistu (2007), also obtained lower water use efficiency values of 86.1 ± 4.3 and 127.7 ± 3.9 ml/kg BW^{0.75}/d for both the water restricted and control groups respectively.

The lack of change in DMI in response to water restriction in this study is comparable to other studies in desert sheep and goats where water was restricted to 50 % of *ad libitum* water intake (Ali *et al.*, 1982; Mousa *et al.*, 1983; El Hadi, 1986; Muna & Ammar, 2001) as well as Yankasa sheep with the same quantity of water (Umunna *et al.*, 1981) and steers water restricted to 60 % of their *ad libitum* water intake (Utley *et al.*, 1970).

Reduction in DMI differs according to the feed on offer. When the goats were offered teff, water restriction reduced feed intake by 11.6 % while on lucerne the reduction was 26.1 %. These percent reductions differ from those of Muna & Ammar (2001), who restricted goats to 40 % of *ad lib* water intake and then observed an 18.8 % reduction when legume hay was offered and a 21.21 % reduction in feed intake with grass hay. In

desert sheep DMI intake was reduced by 8 % on lucerne hay and 34.17 % on grass hay (Osman & Fadlalla, 1974). In pygmy goats with free access to concentrate food and hay, dehydration reduced concentrate intake sooner and to a greater extent than the intake of hay (Langhans *et al.*, 1989). Similarly, in lactating cows, water deprivation for 2 days reduced the intake of corn pellets by about 50 % and the intake of grass by only 20 % (Brosh *et al.*, 1988). In this study it would seem the percent feed reduction was lower for teff because its water content was higher than that of lucerne so the goats continued to eat it as a strategy to obtain at least some water (Senn *et al.*, 1996).

A 57 % reduction in water intake in this study when goats were on teff decreased the water to dry matter intake ratio by 51 % while on lucerne a 59 % reduction in water intake dropped the water to dry matter ratio by 44 %. A lesser reduction of 31 % was observed in sheep fed lucerne and restricted to 65 % of their *ad libitum* water intake (Hadjigeorgiou *et al.*, 2000). In goats a similar percent (30 %) reduction to this ratio was reported when their water intake was restricted to 50 % and fed oaten chaff (More *et al.*, 1983). Aardi goats restricted to 50 % of their *ad libitum* water intake and fed alfalfa hay, reduced the water to dry matter intake ratio to an average of 40 % (Alamer, 2009) which is comparable to the reduction in this study when goats were on lucerne feeding. It would thus appear that the reduction in dry matter intake is coupled not only to the type of animal being studied, but also to the type of feed being consumed when available water is reduced.

A watery medium is needed for both the physical softening and the biochemical digestion of feed. An adequate supply of water could therefore aid the breakdown of feed and thereby facilitate the fermentation and digestion processes (Adogla-Bessa & Aganga, 2000). This could account for the higher digestibility observed when goats were offered lucerne compared to teff. The lack of significance between the *ad lib* and water restricted groups in digestibility of DM, N, ADF and NDF has also been reported by other researchers. Digestibility coefficients for DM and ADF were not affected when goats were restricted to 57 % of their voluntary water intake (Freudenberger & Hume, 1993). In a comparative study by Qinisa (1999), where goats were fed low and high

nitrogen diets, a 50 % water restriction did not affect digestibility coefficients for DM, OM, ADF, NDF, and N.

Imposing a reduction of up to 40 % in voluntary feed intake of a forage diet at near maintenance in sheep, goats and cattle resulted in only small changes in particulate matter retention time in the rumen, with no appreciable effect on the apparent digestibility of the diet (Silanikove *et al.*, 1980; Varga & Prigge, 1982). According to Silanikove (1992), a 10 - 30 % reduction in feed intake is not expected to significantly affect digestion or passage rate. Silanikove *et al.*, (1980) also showed that reducing voluntary feed consumption to 60 - 65 % of the *ad lib* intake did not influence the digestibility in either the Bedouin or Saanen breeds of goat. Similarly in this study there was no difference in digestibility coefficients between the Boer and Tswana goats when water was restricted while they were eating teff or lucerne hay.

5.5 Conclusion

Both Boer and Tswana goats were equally efficient in water utilization when water restricted. Water restriction did not improve digestibility in either breed when teff or lucerne was fed. The relatively high digestibility coefficients for ADF and NDF in the goats when teff was offered, suggest that the goats are efficient in digesting high fibre diets.



CHAPTER 6

NITROGEN RETENTION IN WATER RESTRICTED BOER AND TSWANA

GOATS

6.1 Introduction

There have been conflicting reports on the effect of water restriction on the improvement of nitrogen retention in ruminants. Some researchers observed an improvement in nitrogen retention in response to water restriction (More & Sahni, 1981; Van der Walt *et al.*, 1999; Ajibola, 2006). Bohra & Ghosh (1977) reported no improvement in nitrogen retention in Marwari sheep which were water restricted to 50 % of *ad libitum* water intake. Instead, both groups of animals, and particularly the water restricted group, remained in negative nitrogen balance. In an experiment using goats, despite a 50 % water restriction, there was also no improvement in nitrogen balance (Freudenberger & Hume, 1993).

The quality of the diet has also been shown to have an influence on nitrogen retention when ruminants are dehydrated. Van der Walt *et al.*, (1999), reported an improvement in nitrogen balance when sheep were fed low nitrogen (5.4 % CP) diet, but not when fed a medium nitrogen (10.3 % CP) diet – this experiment compared the effect of different protein levels on nitrogen balance. Ajibola (2006) observed improved nitrogen retention in goats fed a medium diet containing 10.5 % crude protein and water restricted to 50 and 30 % of their *ad libitum* water intake.

Breed-related differences in nitrogen metabolism have also been found in different ruminants. Warwick and Cobb (1976) stated that *Bos indicus* breeds exhibit higher digestibility of low quality diets when compared to *Bos Taurus* breeds. However, where nitrogen balance and blood and urinary nitrogen metabolites were monitored to determine changes in metabolic status due to changes in dietary N intake, Coleman and Frahman (1987) found that Brahman-cross steers excreted more urinary N and retained less N during repletion (given an 18 % protein diet compared to 7.5 % protein) than Angus x Hereford crosses. Sahlu *et al.*, (1993), indicated that there was no apparent

breed difference between Nubian, Alpine and Angora goats with regard to nitrogen utilization when the goats were fed a pelleted diet containing 9 to 21 % crude protein. Information about South African indigenous goat breeds' ability to retain nitrogen when exposed to water restriction, while offered low and high nitrogen diets, is lacking. This study was therefore designed to investigate the effect of water restriction on nitrogen retention of Boer and Tswana goats fed teff and lucerne hay.

6.2 Material and Methods

6.2.1 Animals

Twentyfour goats (12 Boer and 12 Tswana goat wethers) were used in this experiment. The experiment was conducted at the Faculty of Veterinary Science, University of Pretoria (Onderstepoort) in August-November 2007. The goats were 12 -15 months old and had a mean initial live weight of 24.7 ± 4.35 kg.

6.2.2 Feeds

Two types of feeds were used, teff (*Eragrostis teff*) and Lucerne (*Medicago sativa*). The chemical composition of the feeds is presented in Table 6.1

Table 6:1: Proximate analysis of *Eragrostis teff* and *Medicago sativa* hay on a dry matter basis

	Eragrostis teff	Medicago sativa
DM (g/kg)	944	936
ADF (g/kg)	439	313
NDF (g/kg)	801	475
CP (g/kg)	71	207



6.2.3 Experimental procedure

The goats were randomly allocated to form 4 groups of 6 goats. In each group, there were 3 Boer and 3 Tswana goat wethers. These were used into a 4 x 4 Latin square design with the following treatments:

- 1) Water *ad libitum* and *Eragrostis teff ad libitum*,
- 2) 50 % of their average daily water intake (calculated for each goat) and *Eragrostis teff ad libitum*,
- 3) Water *ad libitum* and lucerne (*Medicago sativa*) *ad libitum*,
- 4) 50 % of their average daily water intake (calculated for each goat) and lucerne (*Medicago sativa*) *ad libitum*.

Each treatment was only applied once per sampling period. The design removed the “sequential effect of time” while sampling over a period exceeding 30 days. The goats were then adapted to their respective diets for 10 days, after which samples were collected for seven days. All the goats were fitted with faecal bags and placed in the individual metabolic crates specially designed for easy collection of faeces and urine and measurements of water and feed intake. Faeces were collected from the faeces bags every day in the morning, and urine from cooled containers underneath the metabolic crates. There was a 10 days recovery or flush period (wash-out period) between treatments. The goats were weighed at the beginning and at the end of each treatment.

6.2.4 Feed and water intake

Feed and water were offered at 08h00 in the morning. The feed was weighed in a single balance scale and water measured using a graduated cylinder. Before giving the daily ration, the feed and water from the previous day were removed and measured in order to determine actual consumption. The daily water intake was determined after subtracting daily evaporation losses measured from a container similar to those provided for the goats.

6.2.5 Laboratory procedures: Chemical and statistical analyses

Feed and faeces were dried in a forced-draught oven to determine dry matter. In brief, dry matter content was determined by accurately weighing a sample and then drying it at 70

°C to constant weight. Both dry matter and percent moisture were calculated. Crude protein was determined by the Dumas combustion method (AOAC, 2006). Nitrogen was then calculated by dividing the crude protein by 6.25. Acid and neutral detergent fibre contents were analysed according to the procedures of Van Soest *et al.*, (1991).

Urinary urea concentrations were measured using the urease method with the Ace Alera Alfa Wassermann analyser (Siemens Medical Solutions, South Africa). Protein in urine was determined by the Dumas combustion method (AOAC, 2006).

Data were subjected to the statistical analyses using the Generalized Linear Model Procedures (GLM) of SAS (2003). The model included the effects of treatment (water restriction), breed (goat) and breed x treatment. All initial values (data prior to the onset of treatments) were used as covariates. Treatment mean differences were compared using the Tukey Procedure. Values are presented as least square means \pm standard error of the mean (LSM \pm s. e.).

6.3 Results

Regardless of the treatment, there was no significant difference ($p > 0.05$) in the volume of urine produced by the two breeds. The urine specific gravity was found to be 1.06 ± 0.002 g/l for both breeds. The urea output and the urea concentration did not differ significantly (Table 6.2).

Table 6.2: Least square means of urine output (ml), urea output (mmol/d) and urea concentration (mmol/l), as well as specific gravity (g/l) of urine produced by Boer and Tswana goats during all treatments (means)

	BOER (n=12)	TSWANA(n=12)	S. E.
Urine output (ml/d)	467.89	480.35	21.168
Specific gravity (g/l)	1.06	1.06	0.002
Urea output (mmol/d)	113.99	117.26	5.461
Urea conc.(mmol/l)	253.21	243.50	8.519

^{ab} Means in the same row with different superscripts are different at $p < 0.05$

Regardless of the breed, when teff was offered, and water restricted to 50 % of the *ad libitum* intake, the volume of urine produced was reduced from 284.95 ml/d to 208.24 ml/d. This difference was not significant. Similarly there was no significant difference ($p > 0.05$) between breeds in specific gravity, urea output and urea concentration of the urine produced during the trials. When lucerne was offered, water restriction significantly ($p < 0.05$) reduced volume of urine voided from 879.49 ml/d to 523.88 ± 29.94 ml/d. The specific gravity of the urine for the water restricted group increased ($p < 0.05$) to 1.07 g/l when compared to 1.05 ± 0.03 g/l for the urine of the *ad lib* group (water offered *ad libitum*). There was no significant difference between urea outputs but urea concentration of the urine was high ($p < 0.05$), at 305.22 mmol/l, for the water restricted group compared to the 227.40 ± 12.05 mmol/l of the *ad lib* group. The volume of urine voided from goats on lucerne was higher ($p < 0.05$) than that from goats on teff. The specific gravity of urine was the highest ($p < 0.05$) for the lucerne-fed water restricted group. Goats on teff excreted less urea compared to when they were offered lucerne. The concentration of urea was significantly the highest ($p < 0.05$) in the urine of the lucerne-fed water restricted group (Table 6.3).

Table 6.3: Least square means for urine output(ml), urea output(mmol/d), urea concentration(mmol/l), and specific gravity(g/l) of urine from goats offered *Eragrostis teff* and *Medicago sativa* hay and given water either *ad libitum* or half of their average *ad libitum* daily water intake

Water	Eragrostis Teff (n=24)		Medicago Sativa (n=24)		s. e.
	<i>Ad lib</i>	Half <i>ad lib</i>	<i>Ad lib</i>	Half <i>ad lib</i>	
Urine output	284.95 ^a	208.24 ^a	879.49 ^b	523.88 ^c	29.936
S.G.	1.06 ^a	1.06 ^{ac}	1.05 ^b	1.07 ^c	0.003
Urea output	57.47 ^a	53.66 ^a	196.16 ^b	155.21 ^b	7.722
Urea conc.	213.70 ^a	247.11 ^a	227.40 ^a	305.22 ^b	12.049

^{abc} Means in the same row with different superscripts are different at $p < 0.05$.
S.G. = Specific gravity of urine; Urea conc. = urea concentration



No significant difference was observed in urine output, specific gravity, urea output and urea concentration between breeds, when teff was fed. On *ad libitum* water, Boer goats produced 263.33 ± 42.335 ml/d with a specific gravity of 1.06 ± 0.004 g/l and 62.22 ± 10.921 mmol/d with a concentration of 242.58 ± 17.039 mmol/l. The Tswana goats produced 306.56 ± 42.335 ml/d of urine with a specific gravity of 1.05 ± 0.004 g/l and 52.72 ± 10.921 mmol/d of urea with a concentration of 184.82 ± 17.039 mmol/l. On half *ad libitum* water intake, Boer goats voided 200.82 ± 42.335 ml/d of urine with a specific gravity of $1.07 \pm$ and 55.80 ± 10.921 mmol/d at a concentration of 263.08 ± 17.039 . On the otherhand, Tswana goats produced 215.67 ± 42.335 ml/d with a specific gravity of 1.06 ± 0.004 and 51.52 ± 10.921 mmol/d urea at a concentration of 231.13 ± 17.039 mmol/l.

There was no significant difference observed between the breeds within the treatment when lucerne was offered. On *ad libitum* water, Boer goats produced 815.43 ± 42.335 ml/d of urine with a specific gravity of 1.05 ± 0.004 g/l and 85.34 ± 10.921 mmol/d of urea at a concentration of 214.08 ± 17.039 mmol/l. Tswana goats produced 883.37 ± 42.335 ml/d of urine with the same specific gravity as the Boer goats and 206.98 ± 10.921 mmol/d urea at a concentration of 240.72 ± 17.039 mmol/l. On half *ad libitum* water, Boer goats produced 531.98 ± 42.335 ml/d of urine with a specific gravity of 1.07 ± 0.004 g/l and 152.60 ± 10.921 mmol/d urea at a concentration of 293.10 ± 17.039 mmol/l. Tswana goats produced 515.79 ± 42.335 ml/d of urine with a specific gravity of 1.06 ± 0.004 g/l and 157.83 ± 17.039 mmol/d urea at a concentration of 317.33 ± 42.335 mmol/l (Table 6.4).



Table 6.4: Least square means of urine output(ml), urea output(mmol/d), urea concentration (mmol/l), and specific gravity(g/l) of urine from Boer (n=12) and Tswana (n=12) goats offered *Eragrostis teff* and *Medicago sativa* hay and water either *ad libitum* or half of their average *ad libitum* daily water intake

Trt	Breed	Urine(ml/d)	S. g.(g/l)	Urea(mmol/d)	Urea (mmol/l)
1	Boer	263.33 ^a	1.06 ^{ab}	62.22 ^a	242.58 ^{ab}
	Tswana	306.56 ^a	1.05 ^a	52.72 ^a	184.82 ^a
2	Boer	200.82 ^a	1.07 ^{bc}	55.80 ^a	263.08 ^b
	Tswana	215.67 ^a	1.06 ^b	51.52 ^a	231.13 ^a
3	Boer	815.43 ^c	1.05 ^a	185.34 ^{bc}	214.08 ^a
	Tswana	883.37 ^c	1.05 ^a	206.98 ^c	240.72 ^a
4	Boer	531.98 ^b	1.07 ^c	152.60 ^b	293.10 ^b
	Tswana	515.79 ^b	1.06 ^b	157.83 ^b	317.33 ^b
	S.E.	42.335	0.004	10.921	17.039

^{abc} Means in the same column with different superscripts are different at $p < 0.05$.

Treatment 1 = Water *ad lib*, *Eragrostis teff*; Treatment 2 = Half *ad lib* water, *Eragrostis teff*; Treatment 3 = Water *ad lib*, Lucerne; Treatment 4 = Half *ad lib* water intake, Lucerne; S.G. = specific gravity, urea conc = urea concentration

Regardless of treatment, nitrogen consumed, faecal nitrogen, urinary nitrogen and nitrogen retained were not significantly different between Boer and Tswana goats (Table 6.5). Nitrogen consumed by each breed was about 19 g/d (18.65 versus 18.73 ± 0.47 g/d for Boer and Tswana goats respectively) while faecal nitrogen was about 6 g/d (6.42 versus 6.03 ± 0.23 g/d for Boer and Tswana goats respectively). Urinary nitrogen was 6.36 and 7.12 ± 0.39 g/d for Boer and Tswana goats respectively. Boer goats retained 5.86 compared to 5.54 ± 0.36 g/d of nitrogen for Tswana goats.

Table 6.5: Least square means for nitrogen consumption and excretion, and nitrogen retention (g) in Boer and Tswana goats (means)

	BOER (n = 12)	TSWANA (n =12)	S. E.
Intake			
N consumed (g)	18.65	18.73	0.47
Excretion			
Faecal N (g)	6.42	6.03	0.23
% Faecal N	34.4	32.2	1.13
Urinary N (g)	6.36	7.12	0.39
% Urinary N	34.1	38.2	1.70
Retention (Intake – Excretion)			
N retained (g)	5.86	5.54	0.36
% N retained	31.4	29.6	1.99

^{ab} Means in the same row with different superscripts are different at $p < 0.05$. Percentage of variable is as a percentage of N consumed.

Regardless of the breed, when offered teff, water restriction reduced nitrogen consumed, faecal and urinary nitrogen and nitrogen retained by the goats but all these values did not reach significant levels. Water restriction reduced nitrogen consumed from 8.43 to 7.45 ± 0.67 g/d while faecal nitrogen decreased from 5.22 to 4.69 ± 0.33 g/d. Urinary nitrogen dropped from 2.98 to 2.69 ± 0.54 g/d and nitrogen retained fell from 0.22 to 0.06 ± 0.51 . When lucerne was on offer, water restriction reduced ($p < 0.05$) nitrogen intake from 33.85 to 25.03 ± 0.67 g/d. Faecal nitrogen dropped from 8.37 to 6.63 ± 0.33 g/d while urinary nitrogen decreased from 12.09 to 9.27 ± 0.54 g/d ($p < 0.05$). Nitrogen retained also fell from 13.38 to 9.13 ± 0.51 g/d ($p < 0.05$) (Table 6.6).

Table 6.6: Least square means of nitrogen consumption and excretion, and nitrogen retention (g) for goats offered *Eragrostis teff* and *Medicago sativa* hay, and water given either *ad libitum* or half of their average *ad libitum* daily water intake (means)

Water	TEFF (n=24)		LUCERNE (n=24)		S. E.
	<i>Ad lib</i>	Half <i>ad lib</i>	<i>Ad lib</i>	Half <i>ad lib</i>	
Intake					
N consumed(g)	8.43 ^a	7.45 ^a	33.85 ^c	25.03 ^b	0.67
Excretion					
Faecal N (g)	5.22 ^a	4.69 ^a	8.37 ^c	6.63 ^b	0.33
% Faecal N	61.9 ^a	63.0 ^a	24.7 ^c	26.5 ^b	1.59
Urine N (g)	2.98 ^a	2.69 ^a	12.09 ^c	9.27 ^b	0.54
% Urine N	35.4	36.1	35.7	37.0	2.40
Retention (Intake -excretion)					
N retained (g)	0.22 ^a	0.06 ^a	13.38 ^c	9.13 ^b	0.51
% N retained	2.6 ^a	0.81 ^a	39.5 ^c	36.5 ^b	2.82

^{abc} Means in the same row with different superscripts are different at $p < 0.05$.

Percentage of variables is as a percentage of N consumed.

Nitrogen intake, faecal and urinary nitrogen and nitrogen retained did not differ significantly ($p > 0.05$) between the breeds both on *ad libitum* and half *ad libitum* water regimes when teff was offered. For each breed the nitrogen intake was 8.4 ± 0.95 g/d when water was offered *ad libitum* compared to 7.5 ± 0.95 g/d when they received half *ad libitum* water. Faecal nitrogen was 5.2 ± 0.47 g/d when Boer and Tswana goats had free access to water and 4.7 ± 0.47 g/d when their water was restricted to half of *ad libitum* water intake. Urinary nitrogen was about 3.0 ± 0.77 g/d when both breeds were on *ad libitum* and half of *ad libitum* water regimes. Nitrogen retained was 0.4 and 0.1 ± 0.72 g/d on *ad libitum* water and -0.2 and 0.3 ± 0.72 g/d on half *ad libitum* water for Boer and Tswana goats respectively. On lucerne, there was also no breed effect but those

on *ad lib* water had significantly higher values compared to the half *ad lib* group (Table 6.7).

Table 6.7: Least square means of nitrogen consumption and excretion, and nitrogen retention (g) of Boer (n=12) and Tswana (n=12) goats offered *Eragrostis teff* and *Medicago sativa* hay and water either *ad libitum* or half of their average *ad libitum* daily water intake (means)

Water	ERAGROSTIS TEFF (n =12)				MEDICAGO SATIVA (n = 12)				S. E.
	<i>Ad lib</i>		<i>Half ad lib</i>		<i>Ad lib</i>		<i>Half ad lib</i>		
Breed	Boer	Tswana	Boer	Tswana	Boer	Tswana	Boer	Tswana	
N in (g)	8.4 ^a	8.4 ^a	7.5 ^a	7.4 ^a	33.7 ^c	34.1 ^c	25.0 ^b	25.1 ^b	0.95
Faecal N(g)	5.2 ^a	5.2 ^a	4.7 ^a	4.7 ^a	8.5 ^c	8.2 ^c	7.2 ^{bc}	6.1 ^{ab}	0.47
% Faecal N	61.1 ^c	61.7 ^c	63.7 ^c	63.1 ^c	25.3 ^b	24.1 ^a	28.1 ^b	24.3 ^{ab}	2.25
Urine N (g)	2.8 ^a	3.1 ^a	3.0 ^a	2.4 ^a	11.2 ^{bc}	13.0 ^c	8.5 ^b	10.1 ^b	0.77
% Urine N	31.0	35.0	38.4	31.4	32.6	38.1	34.2	39.4	3.40
N retained (g)	0.4 ^a	0.1 ^a	- 0.2 ^a	0.3 ^a	14.0 ^c	12.8 ^c	9.3 ^b	9.0 ^b	0.72
% N	7.8 ^a	3.4 ^a	-2.1 ^a	5.6 ^a	42.0 ^b	37.8 ^b	37.7 ^b	36.3 ^b	3.99

^{abc} Means in the same column with different superscripts are significantly different at $p < 0.05$. Percentage of variables is as a percentage of N intake.

6.4 Discussion

Throughout the trials the Tswana goats produced slightly more urine than the Boer goats resulting in a higher urea output, but also leading to a lower urea concentration when compared to Boer goats. The urea concentration of the urine produced by Boer goats was higher than that found in the urine of Tswana goats though not significantly so.

The specific gravity of urine is a measurement of the relative amount of solids in solution and is an indication of the degree of tubular reabsorption, or concentration, by the kidney. Under conditions of normal renal function and normal metabolism, the specific gravity varies inversely with the volume of urine excreted. If large volumes of urine are voided, the specific gravity is low, whereas if small quantities are being eliminated, the specific gravity is generally high.

In this study, when teff was fed, lack of a significant difference in urine output, resulted in the same specific gravity of 1.06 g/l both in the *ad lib* and water restricted group. However, on lucerne, the water restricted group with lower urine output had a significantly higher specific gravity of 1.07 compared to the 1.05 of the *ad lib* group. This indicates greater water retention or reabsorption by the kidneys resulting in a more concentrated urine. The normal specific gravity values for sheep and goats range from 1.015 to 1.045 with an average of about 1.030 (Radostis, *et al.*, 2000). Utley *et al.*, (1970) also observed that the urine had a higher specific gravity (1.044 g/l) when steers were water restricted on a low nitrogen (60g N) diet, than on a high nitrogen (80g N) diet where the urine SG was 1.025 g/l. Urea output and urea concentration were positively related both on teff and lucerne (Table 6.3).

On teff, water restriction reduced nitrogen consumed by the same per cent (11.6 %) as the reduction in dry matter intake. Similarly, with lucerne nitrogen consumed was reduced by the same 26.1 % as the reduction in dry matter intake (Chapter 5). This shows that dry matter intake was the main source of nitrogen consumed. Excretion of nitrogen in the faeces and urine was reduced by only 10 % in response to water restriction when teff was fed whilst when fed lucerne the reduction was 20.8 % and 23.3 % for faecal and urinary nitrogen respectively.

On teff, when expressed as a percent of N consumed, most of the nitrogen was lost through the faeces (61.9 % for *ad lib* and 63 % for half *ad lib*) compared to the 35.4 and 36.1 % of urinary N for *ad lib* and half *ad lib* groups respectively. Ajibola (2006) observed similar results and he attributed higher faecal losses of nitrogen to a reflection

of feed consumption and faecal output resulting in a high feed intake producing a high faecal loss of nitrogen. On lucerne, more nitrogen was lost as urinary N (35.7 and 37 %) compared to faecal N (24.7 and 26.5 %) for *ad lib* and half *ad lib* groups respectively. Higher urinary nitrogen as a percentage of nitrogen intake indicates high protein or inorganic nitrogen intake and rapid ruminal digestion, resulting in ammonia production in excess of normal microbial needs (Van Soest 1994; Merkel *et al.*, 1999). This may be a reflection of higher water intakes by the goats which led to more urine being produced when fed lucerne compared to teff.

Ajibola (2006) found that water restriction reduced urine N by 66.7 % in goats which were restricted to 50 % of their *ad libitum* water intake, thus bringing about an improvement of 85.6 % in nitrogen retention. In the current trials, faecal nitrogen was reduced, due to water restriction, by about 10.9 %. Therefore, in this study on teff (Table 6.6), the reduction in urinary nitrogen excretion was offset by the high nitrogen lost through the faeces. The reverse was true for lucerne. Less nitrogen was lost through the faeces but that was offset by more nitrogen excreted through urine. On teff, nitrogen retention was reduced by 72.7 % compared to the 31.8 % when lucerne was fed. When nitrogen retention was expressed as a percent of intake, on teff 3 and 1 % was retained while on lucerne the retention was 39.5 and 36.5 % for *ad lib* and half *ad lib* water groups respectively. Therefore both on teff and lucerne restricting water did not improve nitrogen retention. Similar results were also obtained in sheep restricted to 50 % of their *ad libitum* water intake and offered *Cenchrus ciliaris* with 3.09 % CP. Throughout the experimental period, sheep in both groups remained in negative nitrogen balance, this being more pronounced in the water-restricted group (Bohra & Ghosh, 1977). Nitrogen balance or retention in desert goats fed lucerne (19.65 % CP) or sorghum (5.33 % CP) hay and given *ad libitum* food and water, *ad libitum* food and restricted water or *ad libitum* water and restricted food, was not improved by water restriction of 40 %. Instead goats on sorghum were in negative nitrogen balance (Muna & Ammar, 2001). This is similar to the Boer goats, in this study, that were in negative nitrogen balance (though not statistically significant) when fed teff and water restricted to 50 % of their *ad libitum* water intake.

Negative retention of nitrogen by small ruminants on poor quality diets was observed in castrated Beetal goats (Singh & Mudgal, 1991) and also observed in this study (see Chapter 3) where Tswana goats were offered teff and water intake was restricted. Water deprivation had no significant effect on the nitrogen balance of goats on *ad libitum* water, when they were watered once every day at 15 hrs and once at 15hrs after 48 hrs (Misra & Singh, 2002).

A difference was observed between the breeds Bedouin and Saanen goats as far as the ability for economising their nitrogen metabolism is concerned. Bedouin goats, in contrast to the Saanen goats, were able to balance their nitrogen economy when consuming poor quality food such as wheat straw. The higher efficiency of the Bedouin goat in terms of economising its nitrogen metabolism by recycling urea was not demonstrated when all animals were being fed alfalfa hay containing 16 % CP (Silanikove, 1986). The Bedouin goat only retained more nitrogen on a low nitrogen diet (wheat straw).

In this study, when faecal N was expressed as percent of N intake, both Boer and Tswana goats, when on the teff diet, regardless of whether they were water restricted or not, lost about 62 % of what had been taken in; while on lucerne, faecal N as a percent of intake stood at 25 %. Nitrogen retained by both Boer and Tswana goats on teff did not differ significantly within and between treatments. However, when nitrogen retained was expressed as a percentage of intake, Tswana goat retained 0.7 % compared to 4.6 % of the Boer goats when on *ad lib* water. When water was restricted, Tswana goats retained 4.3 % nitrogen while the Boer goats were in a negative nitrogen balance of -2.5 %. This seems to suggest that Tswana goats may well utilise their nitrogen better when there is a shortage of water and protein, than Boer goats do under the same conditions.

On lucerne, no breed difference was statistically observed when examining N retained. However, N retained was expressed as a % of N intake, thus Boer goats retained about 42 % when compared to about 38 % retained by Tswana goats on *ad lib* water, while when water was restricted the percent N was almost the same (37.2 and 35.8 % for Boer

and Tswana goats respectively). The seemingly lower N retention by the Tswana goats may be ascribed to their higher urinary nitrogen excretion (33.2 versus 38.2 % for Boer and Tswana) when on *ad lib* water, while when water was restricted urinary nitrogen excretion was 34 and 40 % for Boer and Tswana goats respectively. Both breeds retained more when on *ad lib* water than when water was restricted and lucerne was being fed.

Grasses can be classified by the photosynthetic pathway they use. In C₃ plants, the first photosynthetic products have 3-carbon structures, while the first products of C₄ plants have 4-carbon structures. C₄ grasses are found in all tropical grasslands and are dominant in warm-season temperate grasslands. C₄ forage has thinner leaves, more bundle sheaths and smaller inter-veinal distances (Heckathorn *et al.*, 1999). According to Minson (1971), this is equivalent to a higher cellulose and a higher lignin content, and as a result, a decrease in digestibility compared to C₃ grasses. C₄ grasses are expected to have a lower N availability because they concentrate protein in highly vascularised bundle sheath cells, which have proven to be a deterrent to insectivorous and bacterial degradation (Caswell & Reed, 1976; Heckathorn *et al.*, 1999). *Eragrostis teff* is also classified as a C₄ grass (Hunter, 2008). The protein concentration in the C₄ grasses is in the range of 6 to 8 % (Reid *et al.*, 1990) as is the teff in this study. According to Robinson *et al.*, (2006), C₄ N is well protected and unavailable. The unavailability of nitrogen in C₄ grasses could be worsened by the lack of water available for use by the rumen microbes. This could be a reason for the low nitrogen digestibility and nitrogen retention in this study.

Nitrogen intake (g/d) increases with CP level in the diet. Faecal N and urine N, absorbed N and retained N were all directly related to dietary N levels in Angora goats fed a high (21 % CP), medium (15 % CP) and low (9 % CP) N diet (Sahlu *et al.*, 1993). It would thus seem that for an improvement in nitrogen retention to occur, the availability of nitrogen is key, and this will be determined by the dry matter intake as the main source of nitrogen intake.

6.5 Conclusion

Water restriction had no effect on nitrogen retention when goats were fed teff. When fed lucerne, water restriction reduced the nitrogen retained by the goats. There was no breed difference in nitrogen retention in response to water restriction when Tswana and Boer goats were offered teff and lucerne. The results seem to suggest that shortage of water may be more limiting than breed characteristics where goats are concerned when they are offered low nitrogen diets. This would need to be well managed in terms of range animals when low quality feed must be utilized during times of drought.



CHAPTER 7

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

7.1 Effect of water restriction on aspects of digestion in water restricted Tswana goats

It was expected that Tswana goats would perform better when water restricted and offered teff (a low nitrogen diet) as they seem to be well adapted to the semi-arid North West Province seen by their large numbers. Their performance was also expected to be affected by the frequency of watering/drinking especially when water is in short supply.

The Tswana goats in terms of their body weight loss and blood parameters' results tolerated the 50 % water restriction well. The final body weight of the water restricted goats was 5 % less than the ones on *ad libitum* water. The 5 % body weight loss is accepted as not severe in water restriction studies as the animals cannot be allowed to lose more than 10 % of their body weight. This tolerance was in turn shown by the low water use efficiency values when the goats were water restricted.

The Tswana goats remained in negative nitrogen balance and this was more pronounced in the water restricted groups. Tswana goats could not effectively utilise the N in teff when water-restricted as it was unavailable. The unavailability of N in teff due to the inherent structure of the grass seems to have been worsened by the shortage of water necessary for its degradation. This may also be supported by the higher digestibility of N on *ad libitum* water when compared to the water restricted groups.

It is proven in this study that the frequency of watering has no influence on digestion; rather the quantity of water available during the restriction period plays an important role in digestion. Dividing the 50 % restriction into equal portions of 25/25 % in the morning and afternoon had no influence at all. When there is inadequate water, it does not matter whether the goats are given what little water there is all once, or twice a day, in smaller amounts. This practice may only be beneficial once range goats are used to getting water

at the homestead in the afternoon, because then the owner does not have to go and fetch the goats. They will just come in on their own to quench their thirst.

7.2 Effect of water restriction on aspects of digestion in Boer and Tswana goats offered *Eragrostis teff* and Lucerne hay

Water restriction did not affect blood and physiological parameters of Tswana and Boer goats differently. The only difference occurred because of the difference in diets. In most cases although the difference was significant between the diets, it was within the normal range for such parameters.

Goats, regardless of treatment, utilized water better when water restricted. There was no difference between Tswana and Boer goats in water utilization except that on teff both breeds had lower water use efficiency values. This may mean that goats, regardless of the breed, are more efficient in the utilization of water when it is in short supply and when offered low quality (nitrogen) diets.

There was no difference between the *ad lib* and water restricted goats in terms of dry matter intake and digestibility coefficients for DM, N, ADF, and NDF, when they were offered teff. However, the DMI was higher on *ad lib* than half *ad lib* water intake when lucerne was offered. There was no difference between Tswana and Boer goats when on *ad lib* and half *ad lib* water intake treatments in terms of DMI, and the digestibility coefficients for DM, N, ADF, and NDF also did not differ significantly between breeds. On lucerne, there was no difference between the breeds within the treatments, but differences are noticeable between treatments.

Water restriction did not improve nitrogen retention in either Boer or Tswana goats when offered teff. However, on a lucerne diet, nitrogen retention was reduced by restricting water intake. Tswana goats appeared to have retained slightly more nitrogen when water was restricted and they were offered teff, although the difference was not significant.

7.3 Recommendations

More research with more stringent water restrictions and possibly of a longer duration than this study should be carried out. Particular attention should be paid to the following factors:

(i) The age of the goats

Better digestion is to be expected from mature adults than young growing goats.

(ii) Type of grass

Grasses can be divided into C₃ and C₄ according to their photosynthetic pathways. The nitrogen in the C₄ grasses is unavailable. Thus two grasses of the same protein content can give varying results when goats are subjected to water restriction due to the unavailability of nitrogen. It would be interesting to study different grasses with regard to estimating the availability of nitrogen and then compare their effects in the goats when water is restricted.

(iii) Mixed diets v/s single diets

Comparison of diets based on their protein content can also give different responses based on whether diets are mixed or fed solely. The methods used to mix and/or pellet diets can also influence digestibility and water usage.

(iv) Level of water restriction

Comparison based on the level of water restriction (e.g. 50 % water restriction) compared to where goats were given water once in 2 days or once in three days seems to be inaccurate and any conclusion unfair because in one case there is a quantity of water involved while on the other hand the actual frequency of drinking is examined. Goats are still able to take in enough water to last for 2 or 3 days. This cannot be accomplished by those goats given their 50 % share, because they are limited to 50 % of their normal intake and there is no more available to store.

(v) Low, Medium and High quality diets

The ranges should be surveyed to determine the limits for all three quality diet classes. At the moment it is not clear where these different classes occur and exactly what factors limits the different classes.

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