Performance of the Ethiopian Somali Goat during different Watering Regimes

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Abstract

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Water is scarce in the semi-arid regions of Ethiopia and therefore goats are watered intermittently. This can result in dehydration and decreased animal performance. The aims of these studies were to investigate the mechanisms employed by the Ethiopian Somali goat to endure water scarcity and to generate information on milk yield and kid growth. All studies were conducted at the Errer Valley research station, eastern Ethiopia.

The first study evaluated the effects of watering male goats once daily and every 2nd, 3rd and 4th day for 72 days at indoor conditions. The goats were fed hay *ad libitum* and were given 200 g of concentrates daily. In the second study, 14 does and their kids were studied 3 to 4 months after parturition in the hot dry season. They were randomly distributed to once daily or once every 4th day watering. The kids followed the does out on pasture. Every evening, the does were each given 300 g concentrates. The kids were offered 100 g of concentrate per head and day in-group. The third experiment evaluated drinking pattern and milk production of 12 goats during a rainy period. The does were randomly assigned to two feeding treatments starting 11 to 17 days after parturition and continuing for 72 days. Six goats were each given 250 g concentrates every evening and six goats were only grazing. The kids suckled morning and evening. One udder half was hand milked in the mornings.

Plasma osmolality and vasopressin concentration increased to high levels on the 4th day of water deprivation in the males and initially in late lactating does. It shows that four days of water deprivation challenged water balance. The osmolality in every 4th day watered does increased less as the cycles continued, indicating that the goats economized on water. Intermittently watered does and kids spent more time in the shade and browsed watery plants. Rectal temperature increased daily by about 3.5°C in all does and by 2.5°C and 3.2°C in kids watered daily and every 4th day, respectively, during the hot dry period. Milk yield was about 22 % lower than in the group given water daily. Kids watered once every 4th day did not gain body weight as fast as those watered daily. Goats did not always drink when offered water during a rainy period. The milk yield was less than half a litre per day although good forage was available. Concentrate supplementation increased milk yield by 13%, but reduced fat percentage. Both does and kids increased their body weight during the rainy period.

In conclusion, the Ethiopian Somali goat rapidly adjusts to water shortage and starts to economize on water when subjected to a prolonged period of intermittent watering. It is important that this unique adaptability is considered in breeding programs aimed at increasing the comparatively moderate milk production. Nevertheless, more than three days interval between watering during the hot dry season is not recommended since it may jeopardize animal performance and welfare.

Keywords: body weight, dehydration, feed intake, goat, milk, pasture, plasma osmolality, rainy period, temperature regulation, vasopressin, water intake

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Contents

Appendix

The present thesis is based on four papers listed below, which will be referred to by their Roman numerals.

I. Mengistu, U., Dahlborn, K. & Olsson, K. 2007. Effects of intermittent watering on water balance and feed intake in male Ethiopian Somali goats. *Small Ruminant Research* 67, 45-54.

II. Mengistu, U., Dahlborn, K. & Olsson, K. 2006. Effects of intermittent watering on growth, thermoregulation and behaviour of Ethiopian Somali goat kids. *Small Ruminant Reseach* (2006), doi: 10.1016/j.smallrumres.2006.10.012. *In press.*

III. Mengistu, U., Dahlborn, K. & Olsson, K. 2006. Water intake, thermoregulation and behaviour in lactating Ethiopian Somali goats during repeated cycles of intermittent watering. *Submitted.*

IV. Mengistu, U., Dahlborn, K. & Olsson, K. 2006. Drinking pattern and milk production in grazing Ethiopian Somali goats during the rainy period. *Manuscript.*

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List of abbreviations

CP	crude protein
DM	dry matter
H	hour(s)
ha	hectare
Lsmeans	least square means
mo	month(s)
RIA	radioimmunoassay
rpm	rotation per minute
s.e/SEM	standared error of means
s.d.	standard deviation
SG	supplemented group
TPP	total plasma protein concentration
Tr	rectal temperature
UG	unsupplemented group
W1	watered once every day
W2	watered once every two days
W3	watered once every three days
W4	watered once every four days

Introduction

Ethiopia is endowed with abundant livestock resources of varied and diversified genetic pools with specific adaptations to its wide range of agro-ecologies (Janke, 1982). Farm animals as a whole are an integral part of the country's agricultural system and are raised both in the highland and lowland areas. In the highland areas, animals are used for land cultivation (mainly oxen), in mitigating risk during crop failure and as a source of milk, milk products and meat for family consumption, property security and monetary saving and investment. In the lowland areas, where crop production is not a feature of the pastoral system, livestock is the major source of food and cash income to the pastoral populations (FDRE, 1996; Baars, 2000; Habtemariam, 2003; IBC, 2004; Markos, 2006).

In many tropical countries, goats make a valuable contribution especially to the poor in rural areas. This is due mainly to their efficiency in terms of meat and milk production, low cost of maintenance, a great adaptive feature to the harsh environment and their inherent suitability for small-scale production (Silanikove, 2000; Misra & Singh, 2002; Degen, 2007)**.** The number of goats in Ethiopia is estimated at about 15 million heads (CSA, 2005) that are classified into 13 distinct major breeds and four additional sub-types (Workneh, 1992; Alemayehu, 1993; Nigatu, 1994; FARM-Africa, 1996; Getinet, 2001; IBC, 2004).

The habitats of the indigenous goat breeds extend from the arid lowlands to the humid highlands covering even the extreme tsetse-infested areas of the country (Workneh, 1992). The goats are mainly kept under the smallholder mixed farming systems in the highlands and the pastoral and agro-pastoral production system in the lowlands. No commercial scale intensive goat production system has yet been reported. In the mixed crop-livestock and agro-pastoral farming systems, goat production is based on day grazing, sometimes supplemented with crop residues, and the animals are penned at night. In the pastoral system, the goats are reared often under extreme harsh conditions on marginal rangelands during the day with almost no supplementation and returned to thorn enclosures at night (FARM-Africa, 1996).

In the regions consisting of large areas of arid and semi-arid environments (such as Somale and Afar), goats are more numerous than other livestock species (CSA, 2005). A survey result in eastern Ethiopia has showed that a pastoral household on the average owns more goats than camel and cattle (Baars, 2000). In these areas, goats are the most important species for milk next to camels. The daily milk offtake from goat and sheep in eastern Ethiopia's pastoral production system was estimated at about 0.24 and 0.40 kg/day in the dry and wet seasons, respectively, and the family usually consumes it fresh. It was also reported that goats are the most common animals sold by pastoral households for immediate cash income such as for purchase of food items. Also, goats are the major species slaughtered at home to be consumed by the family (FARM-Africa, 1996; Baars, 2000). This shows the important role that goats play in the household nutrition and food security of the pastoral society.

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 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. For example, it was reported that the Afar and the Somali pastoralists water their goats every 3 to 4 days (Afar goat) and every 5 to 8 days (Short-eared Ethiopian Somali goat) during the dry season. In some highland areas, intermittent watering of goats at intervals of 2 to 3 days is also common (FARM-Africa, 1996). This shows that intermittent watering, particularly under the pastoral production system, is employed as a management tool for livestock watering. By doing so, they economize on the scarce water resource and cover large grazing area so animals can maximize the utilization of the available forage.

Coupled with the excessive heat in these environments, long watering intervals impose a considerable degree of dehydration and physiological stress on the animals. The available data on the interval of the watering frequency employed in the region are based on questionnaire survey results (FARM-Africa, 1996) and have not been substantiated by controlled experiments.

Background

This section will briefly present an overview of the incitement for the studies of the Ethiopian Somali goat.

Thermoregulation

In the hot environment of the arid and semi-arid areas, the high air temperature combined with intense solar radiation produces conditions in which environmental temperature substantially exceeds body temperature. When the total heat load exceeds the level that cannot be dissipated by non-evaporative means, the only effective mechanism employed by mammals to maintain body temperature within tolerable limits is evaporative cooling by panting and sweating. However, panting and sweating depletes body water and cause dehydration in animals that do not have frequent access to water. Thus, animals subjected to infrequent watering possibilities require a compromise between temperature regulation and other physiological systems (Jessen, Dmi'el & Choshniak, 1998; Walsberg, 2000).

Many animal species indigenous to the arid environment allow their body temperature to increase during the hot portion of the day, which is an important mechanism in the water economy of the animals. A rise in body temperature allows the animal to store a corresponding amount of heat in the body. It also decreases heat gain from the environment by reducing the thermal gradient driving heat into the animals' body (Schmidt-Nielson *et al.*, 1957). The heat stored during the hottest hours of the day is dissipated during the cool night when the ambient temperature falls below the body temperature. In this manner the animals minimize evaporative cooling during the day (Schmidt-Nielson *et al.*, 1957; Taylor, 1969; Taylor, 1970a; Ostrowski, Williams & Ismael, 2003).

Fluctuations in body temperature of 4 to 7 °C have been recorded in captive ungulates (such as camels, gazelle and oryx) deprived of drinking water at high ambient temperature. When hydrated, these animals change their body temperature by only 1 to 2 °C, suggesting that hydration state influences the use of heterothermy (Schmidt-Nielson *et al.*, 1957; Taylor, 1970a, b). Free-ranging Arabian oryx varied its body temperature by about 4 °C during the course of the day in the summer when the heat load was high and water availability was limited. The change in body temperature during the course of the day was only 1.5 °C during the winter (Ostrowski, Williams & Ismael, 2003).

The ability of Ethiopian Somali goats to use thermoregulation to save water in their environment has not been investigated earlier. We studied diurnal variation in rectal temperature to investigate if the Ethiopian Somali goats also use heterothermy to reduce water loss (Papers **II** and **III**) during the hot dry period. This was compared with diurnal changes in rectal temperature in male goats kept indoors (Paper **I**). We also studied changes in rectal temperature in lactating goats during the rainy period when they were not dehydrated (Paper **IV**).

Efficient water use

Following water deprivation, arid-adapted ruminants drink large volumes of water when it is accessible and retain the water within the body, mainly in the rumen. The importance of the rumen and rumen-like forestomach for storing water in ruminants and in camels, respectively, were highlighted in previous reports (Macfarlane, Morris & Howard, 1963; Hoppe, Kay & Maloiy, 1975; Benlamlih *et al.*, 1992). As summarized in the review by Silanikove (1994), many findings show that the water stored in the rumen is used during the subsequent days of dehydration and the animals can survive the first few days of water deprivation without altering water balance in the body proper.

Animals also reduce the amount of water lost in faeces and urine during the periods of scarcity (Ahmed & Abdelatif, 1994; Hossaini-Hilali, Benlamlih & Dahlborn, 1994; Meintjes & Engelbrecht, 1994). Reduction in faecal moisture content of up to 50 % has been reported in sheep water deprived for two days (Meintjes & Engelbrecht, 1994). A reduction in sweat rate following restricted water intake has also been observed in goats as a strategy to conserve water (Robertshaw & Dmi'el, 1983; Baker, 1989).

Water balance is controlled primarily by vasopressin and by the thirst mechanism. As animals become dehydrated, plasma osmolality increases. This acts on osmorecepters in the hypothalamus to cause thirst and release of vasopressin from the pituitary gland (Anderson, 1978). Vasopressin activates the formation of aquaporin-II, which increases the water permeability of the collecting duct in the kidney and water then leaves the renal tubules by osmosis (Nielsen *et al.*, 2002; Nielsen *et al.*, 2007). Hypovolemia can also stimulate thirst and vasopressin release but this mechanism is less sensitive than the osmotic stimulus. In this thesis total plasma protein concentration was used as an indirect measure of changes in plasma volume.

The rate of elevation in plasma osmolality and vasopressin concentration during water deprivation seems to be an indication of how efficient the water is saved and utilized within the body. We measured plasma osmolality, vasopressin and total plasma protein concentrations to study how they changed during repeated cycles of different intermittent watering regiems (Papers **I** and **III**).

Behaviour

Behaviours such as timing of daily activities and use of cooler microhabitats reduce heat loads and minimize evaporative water loss. Use of shaded, lower temperature microhabitats are common in animals adapted to a hot environment. During the hottest hours of the day and dry periods, desert adapted animals are less active and tend to avoid the heat of the sun by resting in the shade. They become active and spend more time moving and consuming feed during the cooler periods of the day (Taylor & Lyman, 1967; Lewis, 1977, 1978; Brosh, Sneh & Shkolnik, 1983; Alderman, Krausman & Leopold, 1989; Ostrowski, Williams & Ismael, 2003). The use of a cooler microclimate, such as shade of trees, reduces heat loads and helps to maintain a temperature gradient between the body and the environment without using evaporative cooling mechanisms (Cain III *et al.*, 2006). Furthermore, the general behaviour of foraging on succulent plants and browse species with higher water content provides a means to reduce the amount of drinking water needed to maintain water balance (Taylor, 1969; Kay, 1997).

To study the changes in behavioural pattern in Ethiopian Somali goats in relation to intermittent watering and high environmental heat load, we followed the behaviour of lactating goats and their kids while they were out on pasture during a hot dry period (Papers **II** and **III**).

Milk yield and composition

Milk yield of most Ethiopian indigenous breeds of goats in their natural habitat is about half a litre per day (MOA, 1999). These animals thrive in a harsh environment where food and water are scarce during most periods of the year. Besides the high environmental temperature in their natural habitat, lactation puts an additional strain on the water balance of the animal. As a result, the lactating does are confronted with two challenging physiological processes – the need for conservation of water for themselves and milk production to promote kid growth and survival. The majority of the available literature shows that desert adapted lactating goats tolerate a short duration of water deprivation and continue to produce milk for the young. Some breeds of goats and sheep have a better capacity and maintain their milk yield during the first few days of water deprivation, *e.g.* the Bedouin goat.

Long intervals of water deprivation reduce feed intake to a varying extent. Milk yield falls with prolonged periods of water deprivation due to both the loss of water and decreased feed intake (Little *et al.*, 1976; Maltz & Shkolnik, 1980; Ali & Mirghani, 1983). However, there is no direct mechanism involved in regulating the water phase of milk during water deprivation. Instead, milk osmolality increase in parallel to the rise in plasma osmolality.

In one experiment, the black Bedouin goats produced about 700 ml/day of milk when they were watered once daily. They maintained the milk yield at this level during the first two days of water deprivation, but it dropped to 53 and 35 % of the initial yield when they were watered once every third and fourth days, respectively, (Maltz & Shkolnik, 1984). Similar to the black Bedouin goats, the Sudanese Nubian goats maintained the initial 390 ml/day milk production during the first and second day of water deprivation. During the third and fourth days of water deprivation, the milk yield was reduced to 91 and 66 % of the initial value, respectively (Ali & Mirghani, 1983). The Moroccan goat produced about 700 ml/day of milk during a pre-dehydration period. The milk yield immediately dropped to 86 and 72 % of the pre-dehydration value after one and two days of water deprivation, respectively (Hossaini-Hilali, Benlamlih & Dahlborn, 1994). The milk yield of Yankasa sheep, when watered once daily, was about 135 ml/day. After two and three days of water deprivation, they produced only 73 and 45 %, respectively, of the amount they produced when they were watered daily (Aganga *et al.*, 1990).

Milking potential of the Ethiopian Somali goat in their natural environment has not been investigated earlier. We had the opportunity to study milk production in early lactation during the long rainy period and thus we could clarify the milking capacity in the Ethiopian Somali goats during favourable conditions (Paper **IV**). We were also interested in investigating changes in milk yield during water deprivation in the hot dry period (paper **III)**.

Feed intake

It has been reported that goats well adapted to a hot environment demonstrate a greater capability to endure the stressful effects induced by intermittent watering and thereby maintain higher feed intake. This ability is particularly important for lactating and growing animals. However, there is fairly good agreement in the literature that voluntary feed intake generally, although not always, declines stepwise on each of the subsequent days during water deprivation.

The voluntary feed intake of adult male Sirohi, Marwari and Kutchi goat breeds of India that were housed in a semi-open shade and watered once every two days was not different from that measured when they were allowed to drink water once daily (Misra & Singh, 2002). On three days of water deprivation, adult Nubian bucks housed in unshaded pens maintained 82 % of their pre-water deprivation feed intake (El-Hadi, 1986). During the fourth day of water deprivation, 17-month old male Barmer goats fed in a metabolic cage and in the shade maintained 60 % of their pre-dehydration period feed intake (Khan, Ghosh & Sasidharan, 1978). The Egyptian male Baladi goats of 9 to 12 months of age maintained only about

35 % of the control period feed intake when they were kept in a semi-open shade and when watered once every third day (Hassan, 1989). In the Saudi Arabia indigenous goats (Hipsi, Aardi and Zumri) kept in a shaded pen, feed intake was sharply reduced starting from the first day of water deprivation and only 15 % of their voluntary intake was maintained on the third day of water deprivation (Alamer, 2006).

The conditions under which the experiments were conducted vary among the studies presented above. However, the large variation between the different genotypes in the ability to maintain feed intake, even when they were watered at the same interval indicates a variation among goat breeds adapted to the hot environment. Thus, we investigated the dry matter intake in the intermittently watered male goats of 10 to 12 months of age at the start of the experiment during the 72 days of intermittent watering when they were kept indoors and fed hay and concentrates diet (Paper **I**).

Growth and body weight change

Most welfare concerns have led to recommendations that animals should have free access to water. However, this is not always possible for livestock living under the traditional husbandry system in the arid and semi-arid environments. Experiments show that it is not certain that daily watering is the best method when the quality of feed is low, but rather that intermittent watering may even be beneficial because it improves feed digestion and energy metabolism when animals are maintained on low quality roughage (Brosh, Shkolnik & Choshniak, 1986; Brosh *et al.*, 1986; Brosh, Shkolnik & Choshniak, 1987). Animals in arid and semi-arid environments are entirely dependent on grazing, which is poor in its nitrogen content throughout most of the year. Furthermore, on a low nitrogen diet, a frequent water intake leads to higher urinary excretion so that urea is less available for re-use in protein synthesis and to facilitate digestion of crude fibre (King, 1983).

The Barmer goat fed hay *ad libitum* lost only 6 % of its body weight at the end of four days of water deprivation (Khan, Ghosh & Sasidharan, 1978). El-Hadi (1986) reported a loss in body weight of 14 % and 18 % in desert-adapted ram and Nubian bucks, respectively, on the third day of water deprivation and when they were fed hay. The body weight loss in the Saudi Arabia indigenous goats following three days of water deprivation was about 20 % and the body weight was regained within 24 h of rehydration (Alamer, 2006). Dorper rams fed on wheat straw lost 16 % of initial body weight after four days of water deprivation. Of this loss, 94 % and 6 % was found to be water and body solids, respectively (Degen & Kam, 1992). When Yankasa sheep of different physiological states (dry, pregnant or lactating) were watered once every 24, 48 or 72 h for 50 days, the weight gains were positive regardless of the status of the animal and level of water deprivation. However, the daily weight gain was reduced with increasing water deprivation and mostly in the lactating goats (Aganga *et al.*, 1990). Since most of the lost weight is regained after periods of water deprivation, the body weight loss in goats and sheep during water deprivation is mainly due to body water loss rather than a loss in body solids.

The majority of studies conducted on water deprivation have been in adult animals and available data on young desert-adapted kids and lambs are few. The available data on young animals suggest that intermittent watering reduced average daily weight gain. Mousa & Elkalifa (1992) reported a 22 and 16 % reduction in body weight of growing kids and lambs kept in cages (6 to 9 mo of age), respectively, after five days of water deprivation. In the black head Ogaden lambs (6 to 9 mo of age), the group watered either once every third or fourth day did not grow as much as those watered daily at the end of 90 days of trial under confinement (Zewdu, 1991). More & Sahni (1980) reported that three or four days of intermittent watering of both the dams and their suckling lambs did not affect the growth of Chokla lambs when they were weaned at three months of age. However, lambs watered once every second day between three and six months of age followed by every three days watering up to the age of nine months weighed 21 % less as compared to the daily watered group (More, Singh & Sahni, 1976).

We studied the effects of repeated cycles of intermittent watering on body weight gain in male goats of 10 to 12 months at the beginning of the study, in mature lactating dams and in suckling kids (3 to 4 mo of age) that accompanied their dams to pasture during the hot dry season (Papers **I, III** and **II**, respectively). We were also interested in investigating the growth rate of young suckling kids (from about 11 days after birth to 3 months of age) that were only allowed to suckle morning and evening and body weight of dams in early lactation during the rainy period (Paper **IV**).

Aims of the thesis

The general aim of this thesis was to investigate the physiological and behavioural mechanisms by which the Ethiopian Somali goat endures intermittent watering in its natural habitat and to generate baseline information on their milking capacity and kid growth.

The specific aims were:

- To investigate whether Ethiopian Somali goats employ thermoregulation as a mechanism to minimize water loss.
- To investigate how intermittent watering over prolonged periods affects fluid balance, feed intake and body weight gain in young male goats kept in confinement.
- To investigate how intermittent watering over prolonged periods affects fluid balance, feed intake and body weight in does and kids that were let out on pasture during the hot dry season
- To investigate if intermittently watered suckling kids and lactating dams employ behavioural adjustments at pasture as a mechanism to save water during the hot dry season.
- To study milk yield and milk composition of grazing/browsing does in early and late lactation.
- To study drinking pattern, milk production capacity of dams and kid growth during a rainy period when water and forage of good quality were available.
- To study the effect of supplementation during the rainy period on milk production and composition and growth rate of kids.

Materials and Methods

Experimental site and facilities

The studies were conducted at the Errer Valley research station, 37 km from Haramaya University (formerly Alemaya University), in eastern Ethiopia (Fig. 1). The Valley lies in a transitional zone between the intensive crop production system areas of the Hararghea plateau and the Jijiga plain at an altitude of 1300 to 1600 m above sea level. The typical climatic condition is semi-arid with yearly rainfalls ranging from 400 to 500 mm (Tamire, 1986). Usually, the long dry season covers a 5-months period between October to the end of February followed by the short rainy season during March and April. The main rainy season covers the period between July to early September during most years.

The Errer Valley Research Station campus covers about 3 ha of land that is surrounded by a barbed wire fence. At one of the corner in the larger fence, there are three enclosures and a well-ventilated experimental house made of corrugated sheet. Outside these enclosures is a grazing area with grasses and browsing plants available to the animals. One of the three enclosures is divided into four larger compartments (8 m × 4.5 m each). These four larger compartments are further divided into seven individual pens (2 m × 1.5 m) with a free space in the middle.

The resident farmers communally own the grazing area outside the research station and animals belonging to the research station are also allowed to graze there. Rocky hills, ravines and a variety of indigenous browse species and grasses characterize this grazing area. The livestock species owned by the farmers are cattle, camel, goat, sheep and a few donkeys.

Fig. 1. Errer Valley Reseach Station

Experimental animals

The short-eared Ethiopian Somali goat breed (local name Denghier or Deghiyer) was used in all the experiments (Papers **I** - **IV**). This goat breed is related to the goats in Somalia, which were introduced from Arabia. In Ethiopia, the goats of this breed are widely distributed in the eastern part of the country (Fig. 2). The medium size and a short smooth coat that is mainly white in colour characterize the breed. They are raised under a pastoral management system and thus adapted to the semi-arid agro-ecology of the region (FARM-Africa, 1996). Except the kids (Papers **II** and **IV**), which were born at the research station, all the goats were purchased from the markets in Jijiga area, where a large population of this breed is found and brought to the Errer Valley Research Station.

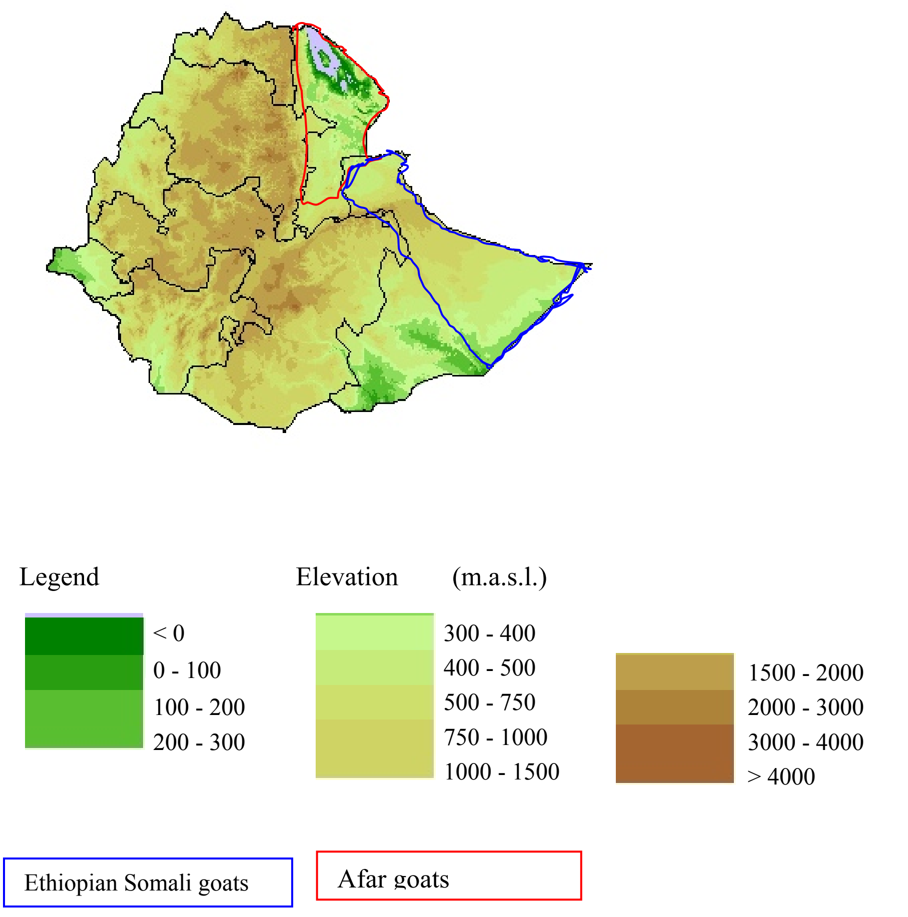

Fig. 2. Approximate distribution of Ethiopian Somali and Afar goats

Experimental procedures and animal management

This thesis is based on three separate experiments. The first experiment (Expt-1) evaluated four regimes of intermittent watering in intact male Ethiopian Somali goats (Paper **I**). The procedure we have followed in this experiment was more of a traditional approach used in many water balance studies where the animals were protected from the sun and fed a balanced diet of hay and concentrate. In experiments two and three (Expt-2 and Expt-3, respectively), we have simulated the small ruminant production system in the region. These animals were grazing during parts of the day, offered some concentrate supplement in the evening (except one group of dams used during Expt-3) and penned during the night. In Expt-2 we evaluated the effect of two watering regimes (once every day and once every fourth day) during late lactation in grazing does and their suckling kids. The results have been separated into two papers so that the effects on kids and does, respectively, could be described more clearly (Papers **II** and **III**). Expt-3 assessed water intake pattern and performance of lactating Ethiopian Somali goats and their kids during a long rainy period (Paper **IV**).

Expt-1 (Paper **I**) was conducted during the year 2003. In this experiment, 28 intact male goats of 10 to 12 months of age were randomly divided into four equal groups. Four watering regimes, once every day, once every two days, once every three days and once every four days were compared. The total duration of the experiment was 72 days divided into 6 periods of 12 days each. The animals were individually fed with grass hay *ad libitum* and were supplemented with 200 g concentrates every day. During the first four days of each period, each animal was put into an individual metabolic cage (1.2 m × 0.8 m). The cages were placed in the experimental house in four rows of seven cages each. During the adaptation period, we made a preliminary assessment for any variation in the temperature and draught between the different corners of the house and observed no systematic difference at any corner. We therefore decided to put animals belonging to the same treatment in the same row, so that management of animals and sampling would be easier and the procedures clear to all personnel involved in the experiment.

All results reported in Paper **I** are based on measurements taken during the first four days in each periods (when the animals were in their cages). Between the measurement sessions (eight days), each group of 7 goats was kept in the 4 enclosures outdoors. Within these enclosures, the goats were kept in the individual pens except from 0900 h to 1100 h in the mornings when they were released into the common area to interact with the other goats in the same group. The watering regimes and the feeding were the same as when they were in the cages.

During 2005, the year when Expt-2 (Papers **II** and **III**) and Expt-3 (Paper **IV**) were conducted, a total of 64 does' were kept at the Errer Valley Research Station. The flock was let out on to the communal grazing pasture every day. During the night, they were kept at the station in the outdoor enclosures (16 animals in each compartment), except during the rainy nights when they were moved into the experimental house made of corrugated sheet and kept together. Kids less than three months of age stayed at the research station and grazed inside the fenced area. The kids followed their dams to pasture after 3 months of age, which is the practice in pastoral area. These kids suckled in the morning and evening. During the evening when the does returned from grazing, concentrate (300 g/head and day) was fed in their respective compartments. The concentrate feed was distributed into four big containers made of metal sheet. The containers were welded onto four metal stands that raised it about 80 cm above the ground. Water was offered once every evening before concentrates were given.

In Expt-2 (Papers **II** and **III**), 14 lactating does that had given birth to one kid were selected among the does in late lactation (2.5 months) based on body weight and age of the dams and uniformity of their kids. The does were then separated from the flock and let out to pasture every day as before along with their kids. In the evening, the does were separated from kids and locked into individual outdoor pens and the kids were kept in two groups in separate pens. During the following fortnight, the personnel to be involved in a behaviour study followed the goats two days per week and were trained to record behaviours of a dam and her kid. Two days prior to the start of the actual experiment, the left udder half of the does were milked in the morning while the kids were suckling the right udder half. Based on these two days milk yield and individual goat body weight, the goats and their kids were randomly assigned to two watering treatments. One group of seven dams and their kids were watered once every day and the other seven dams and their kids were watered once every fourth day. The experiment period consisted of 32 days that were divided into four periods of eight days each. All measurements and samples of blood were taken during the first four days of each period followed by four days of no measurement before the next period commenced. At the start of the experiment, the kids were three months old.

During the experiment, the dams and the kids were let out to the grazing area outside the research station between 0900 h and 1215 h in the morning and between 1315 h and 1630 h in the afternoon. During the night, dams were kept in individual pens in the outdoor enclosure. They were individually offered concentrate supplement (300 g/head and day). Water was individually offered before feeding according to the treatment. The kids from both groups were mixed and kept in two groups in separate pens at the outdoor enclosure. We anticipated that placing kids individually would make them feel insecure. Thus, we decided to put the kids together. Three kids from one group and four kids from the other group were placed together in a pen according to their uniformity (similar physical condition) so that the weaker animals would not be prevented from eating concentrate. They were given concentrate per pen (100 g/head and day). The concentrate was distributed into three plastic containers so that all kids could have access to the feed at the same time. At watering, kids were taken out from the pen one at a time and individually offered water according to the treatment.

In Expt-3 (Paper **IV**), 12 does each with one kid were selected from the available does in early lactation. The does were selected according to stage of lactation. At the beginning of the experiment, the does were between 11 to 18 days of lactation. Two days prior to the start of the experiment, the left udder half was milked in the morning while the kids were suckling the right udder half. Based on the two days milk yield, the does were randomly assigned to two feeding treatments. One group of six does was supplemented with concentrate feed in the evening (250 g/head and day) and the other group of six goats was not given concentrate feed (unsupplemented group). The does were let out on pasture outside the station between 0900 h and 1215 h in the morning and between 1315 h and 1645 h in the afternoon. The kids stayed at the station and were allowed to graze between 0900 h and 1200 h in the morning and between 1430 h to 1615 h in the afternoon in the compound of the station. Concentrate (30 g/head and day) was distributed into four plastic containers and offered to the kids when they were in a group pen. During the night, the dams and the kids were kept in the experimental house in a separate pen of 2.5 m × 9 m and 2.5 m × 5 m, respectively.

The experimental period consisted of 72 days that was divided into six periods of 12 days each. The left udder half of the does was milked every day while the kids were suckling the right udder half. Milk yield was measured on all days throughout the experiment. Data on dams' water consumption, rectal temperature, body weight and the ambient temperature and humidity were taken during the first four days of the respective periods. Samples of blood and milk were also collected, but blood samples were not collected during period 6. Water was offered every day at midday both to the dams and the kids. The kids drank rarely water and the amount drunk was small and not measured.

Data collection and analysis

Rectal temperature (Tr) was measured by a digital rectal thermometer starting at 0830 h and 1530 h (Paper **I**), 0800 h and 1715 h (Papers **II** and **III**) and at 0800 h, 1230 h and 1700 h (Paper **IV**). Respiratory rate was measured by counting flank movement (Paper **I**).

Blood samples were collected from the jugular vein with vacutainers (Papers **I**, **III** and **IV**). In the male goats (Paper **I)**, blood samples were collected starting at 1100 h before new feed was offered and water was given according to the treatment. In the lactating goats used in Expt-2 (Paper **III**), we were interested to follow changes in osmolality twice daily, in the morning and afternoon. Therefore, milk samples were taken in the morning and blood samples were collected in the afternoon after the animals returned from grazing starting at 1715 h. In the does used in Expt-3 (Paper **IV**) both the blood and the milk samples were collected in the morning starting at 0805 h before the dams were let out for grazing.

For measurements of plasma osmolality, total plasma protein (Papers **I, III** and **IV**) and plasma concentrations of sodium and potassium (Paper **I**), 5 ml of blood was collected in a tube containing Li-heparin. For vasopressin (Papers **I** and **III**), glucose, insulin and cortisol analysis (Paper **IV**), 10 ml of blood was collected into tubes containing K_3-EDTA. The tubes were immediately transferred to an icebox in which they were kept cool and transported to the Haramaya University laboratory. After centrifugation, plasma in the heparinized tubes was transferred into two plastic tubes. Plasma osmolality and total plasma protein concentration were determined from one of the tubes on the same day. The other tube from the heparinized plasma and the plasma from K_3-EDTA tubes were stored at –20 °C and transported frozen to Sweden where they were stored at –70 °C until analysis.

The same experienced person milked the does during both experiments (Expt-2 and 3). To facilitate milk let down, the left udder half was milked while the kids were suckling the right udder half. This together with the experience of the person milking the goats' makes it possible to have a complete removal of the milk from the left udder half. The older kids in Expt-2 (Paper **II**) freely suckled both udder halves at grazing and until they were separated from the dams during the night. The younger kids in Expt-3 (Paper **IV**) were allowed to suckle both udder halves during the evening for about 1 hour after which they were separated until the next morning milking when they suckled only the right udder half. After milking, the milk yield of each animal was measured and samples of 10 ml were taken and analyzed for percentage milk fat, protein, lactose and total dry matter content. Total milk yield was calculated based on the amount of milk obtained from left udder half and morning milking (Papers **II** and **IV**).

Plasma and milk osmolality (Papers **III** and **IV**) were determined by freezing point depression on the same day. Plasma sodium and potassium concentrations (Papers **I**) were analyzed by flame photometry. Plasma total protein concentration (Papers **I**, **III** and **IV**) was measured on a TS refractometry. Vasopressin was analyzed by radioimmunoassay using a commercial vasopressin RIA kit validated for goat's plasma (Papers **I** and **III**). Plasma glucose concentration was determined by an enzymatic colorimeteric method without deproteinization. Plasma insulin was determined by the ultrasensitive bovine insulin ELISA kit after it had been evaluated and validated for goat plasma. Cortisol was analyzed using a commercial kit validated for goat plasma.

Behaviour

The behaviour of the kids and the dams were studied out on pasture at 5-minute intervals between 0930 h to 1200 h in the morning and 1400 h to 1630 h in the afternoon. In the kids, suckling pattern, feeding and location behaviours were recorded and the data was presented over the days of water deprivation (Paper **II**). Suckling pattern was registered as successful when it lasted for at least 5 s and as failed when the dam refused the suckling attempt. In the dams, feeding and location pattern were recorded and the data of the group watered once every fourth day were compared with those watered once every day (Paper **III**). During the four periods of the experiment, two dams and their kids from each treatment were randomly taken and monitored. Each animal was studied during only one of the periods. The ear tag numbers of the animals under observation were spray painted on both sides of the animal body so that the observer could easily identify them. Each one of the four trained persons was assigned to one of the dams and their kids and recorded the behaviours of the animals at 5-minute intervals. During most of the observation time, the dam and her kid followed each other. The few times they separated, two trained goat herders assisted in observing the kids and related the behaviour to the person taking notes.

Results

Rectal temperature

In the male goats (Paper **I**) and lactating does studied in Expt-3 (Paper **IV**), changes in rectal temperature over the course of the day were about 2 °C and 1.3 °C, respectively, in all the treatments. The male goats were kept indoors and the does were studied during the rainy period. Under both conditions, the heat load from the environment was relatively small.

The situation for the animals was different when they were out on pasture during the hot, dry season. In the grazing lactating does that were watered both once every day or once every fourth day, the rectal temperature increased on average by 3.5 °C over the course of the day (Paper **III**). Mean morning and afternoon rectal temperatures in those does watered once every fourth day was higher than every day-watered does on most of the days, but the differences were small except during the first period.

Rectal temperature in the suckling kids increased on the average by 2.5 and 3.2 °C in those watered once daily and once every fourth day, respectively, from morning to afternoon (Paper **II**). The kids that were watered once every fourth day had higher afternoon Tr on each day than those watered once every day. Mean morning rectal temperature was lower in the intermittently watered group, but the difference was significant only on the morning after the watering day. The temperature of the drinking water was about 25 °C. Thus, the lower rectal temperature after the days of watering could be due to the combined effect of the large volume of water ingested and the low night temperature.

Plasma and milk osmolality

During the rainy period, both milk and plasma osmolality in the grazing lactating goats were generally below 295 mosm/l, and it occasionally became even lower (Paper **IV**). The goats receiving concentrate supplementation had slightly higher plasma and milk osmolality than the unsupplemented goats.

In the male goats, plasma osmolality in the group watered once daily was between 303 and 305 mosm/l on all sampling days (Paper **I**). This was higher than that observed in the lactating goats during the rainy period, indicating that the male goats became slightly dehydrated during the 24 h-period without water. When the male goats were watered once every two days, the plasma osmolality significantly increased on the days of water deprivation and dropped on the day after watering. In the goats watered every third and fourth day, there was a steady increase in plasma osmolality over the days of water deprivation followed by a marked drop to below 300 mosm/l on the day after watering, which was significantly lower than in those goats watered once daily. The plasma sodium concentration followed the same trend as the plasma osmolality.

In the grazing lactating goats that were studied during the hot dry season and watered once daily, plasma osmolality was about 310 mosm/l on all sampling days (Paper **III**). Unlike the plasma osmolality, milk osmolality in these goats remained below 300 mosm/l. Milk was collected during the morning and blood during the evening. Since the goats had drunk during the preceding night, lower milk osmolality as compared to plasma osmolality was expected. The goats in this group were observed to graze in the sun during most of the time at pasture. Thus, they became dehydrated, which resulted in higher plasma osmolality than that recorded in the male goats watered once every evening indoors and in the lactating grazing goats during the rainy period. In the group offered water once every fourth day, the plasma osmolality during period 1 reached almost 340 mosm/l. During the second measuring period, the plasma osmolality only approached about 320 mosm/l and during the third period, the increase in plasma osmolality over the water deprivation days was even less. In period 4, starting 24 days after onset of the experiment, the plasma osmolality on the days of water deprivation was not significantly higher than in the goats watered once every day. However, on the day after watering, the plasma osmolality in the group watered once every fourth day fell below the value in the group watered once daily. It dropped more with repeated cycles and became as low as about 290 mosm/l during the last period. This indicates that the goats kept water in the extracellular fluid for a longer time as the water deprivation cycles continued. The milk osmolality in this group followed a similar trend as the plasma osmolality, but the values on each of the water deprivation days were higher for milk than for plasma osmolality, particularly during the last three periods. This could not be readily explained, but it may be that the goats adjusted their behaviour at pasture and saved water during the day and used more water during the night to digest the concentrate they consumed in the evening.

The plasma protein concentration in the male goats watered once every second day did not differ between the days of water deprivation. But, the concentration on day three in goats watered once every three days and on days three and four in the group watered once every fourth day was higher than that on day one in the respective groups (Paper **I**). The plasma protein concentration in the lactating goat watered once every fourth day increased over the days of water deprivation and its value on the third and fourth days of water deprivation during periods 1, 2 and 3 and on the fourth day during period three was significantly higher than that on the first day during the respective periods (Paper **III**). Total plasma protein concentration in the intermittently watered group did not differ from that in the once daily watered group except on day four during period 1, when the former group had higher plasma protein concentration.

Plasma vasopressin concentration

As shown above, the plasma osmolality increased in the intermittently watered goats, which resulted in increased plasma vasopressin concentration to decrease the urinary water loss (Papers **I** and **III**). In the once daily watered male goats (Paper **I**), plasma vasopressin concentration remained lower than 1 pmol/l on all days. In the group watered once every second day, plasma vasopressin concentration increased on each of the water deprivation days and returned to the basal level when the animals had access to water. During three days of water deprivation, the plasma vasopressin concentration increased steadily. When the goats had access to water after the third day, the plasma osmolality dropped to a value similar to that in the group watered once daily. Lengthening the water deprivation to once every fourth day caused a sharp increase of plasma vasopressin concentration (Paper **I**). Then, not only the plasma osmolality, but also the plasma protein concentration had increased indicating that both osmoreceptors and volume receptors had stimulated the vasopressin release during the fourth day of water deprivation.

In the lactating does (Paper **III**), plasma vasopressin concentration in the group offered water once daily was higher (about 2 pmol/l in this group) than that in the corresponding group of males. This is in agreement with the higher plasma osmolality in the does. During periods 1 and 2, the concentration in the group that was watered once every fourth day increased sharply and reached about 5-fold that in the does watered every day as should be expected for the change in plasma osmolality. During periods 3 and 4, the plasma vasopressin concentration on the fourth day of water deprivation reached only half of that during the first and second period, but it was higher compared to the group watered once daily.

Water consumption

Water deprivation caused dehydration of the Ethiopian Somali goats with lengthening of watering interval as shown by the increased plasma osmolality and vasopressin concentration even though they allowed the rectal temperature to rise. They replenished their water loss by rapidly consuming large volumes when they were given access to water (Papers **I** - **III**). However, they did not drink as much water as could be expected by a summation of the daily water intake in the group watered once daily.

The male goats watered once daily drank 1218 ± 47 ml/day (Paper **I**). When the amount of water drunk at each watering occasion was calculated over the days, the goats that were watered once every two, three and four days drank on the average 67, 67 and 63 % of the volume drank by the group watered once daily. In the grazing lactating does that were watered once every fourth day, the amount of water drunk at each watering occasion decreased over the periods, and the amount they drank during the fourth period was significantly lower than that during the preceding periods. The group watered once daily drank 1867 ± 98, 1689 ± 92, 2214 ± 100 and 1816 ± 96 ml/day during periods 1, 2, 3 and 4, respectively. By calculation, the intermittently watered does drank 65 % during periods 1 and 2 and 51 and 47 % during periods three and four, respectively, of the amount drank by the group watered every day during the respective periods. Yet, the plasma osmolality decreased with repeated cycles (Paper **III**). The kids watered once every day drank 392 ± 18 ml/day. By calculation, kids watered once every fourth day drank on the average 64 % of the amount drunk by the group watered once daily (Papers **II**).

Although drinking water was available once daily during the rainy period, the lactating does did not always drink (Paper **IV**). When the water intake was calculated, the supplemented does consumed relatively larger amounts of water each day than those only grazing (456 ± 34 *versus* 270 ± 36 ml/day).

Behaviour

The grazing and lactating does that were watered once every fourth day (Paper **III)** became less dehydrated as the water deprivation periods continued. During the last period, plasma osmolality and plasma vasopressin concentration did not increase more than the daily watered group. We believe that this situation would remain similar if the intermittent watering would have been continued for a longer period. One explanation could be that they changed their behaviour on pasture. Due to the fact that the does spread out at pasture and personnel was limited and needed to follow individual animals closely, only 2 does from each group were followed during each period. This did not allow us to do a statistical analysis. Thus, individual behavioural observations of the intermittently watered goats were evaluated against the overall mean of the daily watered group. Three standard deviation (3 s.d.) from the overall mean of the daily watered group was set as a reference point to decide whether a particular behaviour was affected by the four days of water deprivation.

During periods 1 and 2 of the study, one dam on the second day of water deprivation and both of the dams during days three and four reduced their feeding time as compared to the reference group. Those dams studied during periods 3 reduced their feeding time only on the fourth day of water deprivation. During period four, only one of the dams had dropped its feeding time during fourth day of water deprivation. All the intermittently watered dams studied during periods 1, 3 and 4 stayed in the sun for shorter times on the third and fourth days of water deprivation. Since they maintained their grazing time during periods 3 and 4, they must have continued eating in the shade.

The kids of these does (Paper **II**) spent less time grazing on day four of water deprivation as compared to those watered once every day. The water deprived kids remained longer in the shade and frequently suckled or attempted to suckle with prolonged intervals of water deprivation.

Milk production and composition

During the rainy period, vegetation of the grazing area was green and was of good quality and plentiful. The goats in early lactation that were only grazing during this experiment produced on the average 423 ± 7 ml of milk per day (Paper **IV**). The group that was offered concentrates produced 488 ± 7 ml of milk per day.

Concentrate supplementation during the rainy period to grazing goats increased the milk yield by about 13 %, reduced percentage milk fat and did not affect percentage protein and lactose.

The estimated average daily milk yield in late lactation (3 to 4 months after parturition) in the grazing and supplemented does watered once daily was 217 ± 8 ml/day (Paper **II**). Once every fourth day watering decreased milk yield on the average by 22 % as compared to the group watered once daily (Paper **III**). Four days of water deprivation increased average percentage milk fat, lactose and total dry matter, but did not affect protein content (Table 1).

Blood plasma glucose, insulin, cortisol and protein concentrations

In the does studied during the rainy period (Paper **IV**), the overall glucose, insulin and total plasma protein concentration were significantly higher in the supplemented group than the unsupplemented. Plasma glucose concentration during periods 1 and 2 in both groups was higher than that during periods 4 and 5. In both groups plasma insulin concentration was not significantly different over the periods, but its concentration during periods 4 and 5 in the supplemented goats tended to be higher than that during period 1. Plasma cortisol concentration values were not different between or within treatments.

Table 1. *Effect of intermittent watering on milk volume (ml) and composition (%) from one udder half milked each morning in late lactation. Means within the same row and heading with different superscript letters (a-c) differ. Means within the same column and under the same parameter with different numeric superscript (1-2) differ. W1D=Dams watered once every day; W4D=Dams watered once every fourth day. The kids suckled the other udder half at milking and both teats from 0830 to 1730 at pasture.*

	Days of water deprivation				
Items	D1	D2	D3	D4	Mean
Milk Volume					
W1D	67.2 ± 4.7^{1}	64.6 ± 4.7	69.3 ± 4.7^{1}	70.4 ± 4.7^{1}	67.9 ± 2.4^{1}
W4D	49.3 ± 4.8^{2}	61.1 ± 4.7	52.1 ± 4.7^{2}	47.7 ± 4.7^{2}	52.6 ± 2.4^{2}
Milk Composition					
Fat (%)					
W1D	6.7 ± 0.2	6.6 ± 0.2	6.5 ± 0.2	6.3 ± 0.2	6.5 ± 0.1^{2}
W4D	7.1 ± 0.2	6.9 ± 0.2	7.1 ± 0.2	6.6 ± 0.2	6.9 ± 0.1^{1}
Protein (%)					
W1D	4.9 ± 0.1^{a}	4.3 ± 0.1^{b}	3.9 ± 0.1^{c}	4.4 ± 0.1^{b}	4.4 ± 0.1
W4D	4.8 ± 0.1^{a}	4.4 ± 0.1^{b}	4.1 ± 0.1^{c}	4.5 ± 0.1^{ab}	4.4 ± 0.1
Lactose (%)					
W1D	4.0 ± 0.1^{b}	4.1 ± 0.1^{ab}	4.2 ± 0.1$^{a,\ 2}$	4.1 ± 0.1$^{ab,\ 2}$	4.1 ± 0.1^{2}
W4D	4.0 ± 0.1^{c}	4.2 ± 0.1^{b}	4.4 ± 0.1$^{a,\ 1}$	4.4 ± 0.1$^{a,\ 1}$	4.2 ± 0.1^{1}
Dry mater (%)					
W1D	16.4 ± 0.3^{a}	16.0 ± 0.2^{ab}	15.5 ± 0.2 $^{b,\ 2}$	15.7 ± 0.2$^{b,\ 2}$	15.9 ± 0.1^{2}
W4D	16.7 ± 0.3	16.4 ± 0.2	16.4 ± 0.2^{1}	16.4 ± 0.2^{1}	16.5 ± 0.2^{1}

Feed consumption, body weight change and growth

The supplemented lactating does studied during the rainy season (Paper **IV**) consumed the entire concentrate offered (250 g/day and animal) on all days. Despite the fact that they were at the early stage of lactation, both the supplemented and the unsupplemented groups gained weight, but the supplemented group gained more. The kids born to both dam groups consumed small amounts of concentrate at the beginning and ate more after they reached one months of age. Despite that the supplemented dams produced more milk, the kids had similar growth rates in both treatments.

In the male goats (Paper **I**) watered once every two days, hay dry matter intake on each of the water deprivation days was significantly lower than that in the group watered once daily or once every three days. Concentrate intake in the group watered once every four days started to decrease on the third day of water deprivation and the amount consumed on the fourth day was significantly lower than that consumed on the second and third days. In this group, hay dry matter intake on all days remained lower than that in the group watered once daily or every three days, but it was significantly lower only on the second and fourth days of water deprivation. Comparison between the overall averages of the treatments showed that the amount of concentrate dry matter intake consumed was similar between the treatments, but the groups watered once every two and four days had lower hay dry matter intake than the groups watered once daily or every three days. However, the reduction in feed intake in the two groups did not significantly affect average daily gain. The goats watered once every day, every two, three and four days gained 35, 29, 46 and 36 g/day, respectively.

The does that were studied during late lactation (Paper **III**) consumed the entire concentrate offered (300 g/day and animal) each evening. Since concentrate supplements were offered after the animals were given water according to the schedule, we are not certain that the group watered once every fourth day would have consumed all the concentrate on the 4th day of water deprivation if they had been given it before water was offered. The ability of these goats to consume the concentrates even during longer intervals of water deprivation might have contributed to the unchanged body weight at the end of the experimental period. Body weight of the dams watered once every fourth day temporarily decreased over the days of water deprivation. On average, the goats lost 13 % of their body weight by the end of the fourth day of water deprivation. However, the lost body weight was entirely regained upon drinking (Paper **III**).

The kids watered once every day and once every fourth day were kept together during the night (Paper **II**). The entire concentrate offered in-group (100 g/head per day) was consumed on all days. Since kids from both groups were kept together, the amount each group or individual animal ate was not quantified. Both kid groups gained weight during the experiment. The gain was significantly higher in kids watered once daily than those watered once every fourth day (53 ± 4 *versus* 33 ± 4 g/day).

General discussion

Four days of intermittent watering in confinement did not affect body weight of male goats, but it decreased feed intake and put a strain on the animals' fluid balance (Paper **I**). In the grazing lactating goats studied during the hot dry period, plasma osmolality and vasopressin concentration increased sharply during the first two periods of every four-day cycle of intermittent watering. With repeated cycles of intermittent watering, the does mobilized their defence mechanisms and plasma osmolality and vasopressin concentration increased less over the water deprivation days (Paper **III**). Repeated cycles of once every fourth day watering reduced milk yield and increased percentage milk fat, lactose and total dry matter. It reduced daily weight gain of suckling kids at ages 3 to 4 months as compared to those watered daily (Paper **II**). The Ethiopian Somali goats produced less than half a litre of milk per day during the rainy period when good quality and sufficient quantities of forage was available. Concentrate supplementation during the rainy period increased milk yield, but the growth rate of kids born to supplemented and unsupplemented dams was similar (Paper **IV**).

Do the Ethiopian Somali goats store water?

One of the mechanism by which desert adapted animals withstand scarcity of water deprivation is to drink large volumes of water when they have access and store it in the body fluid compartments. There are indications that the Ethiopian Somali goats store water. On the days after watering (24 h after drinking), the plasma osmolality in male goats watered once every third and fourth days was significantly lower than in goats watered once every day. Similarly, plasma and milk osmolality in the does watered once every fourth day fell after each watering day. The fall in plasma osmolality became more pronounced with repeated cycles of intermittent watering and increased slowly over the water deprivation days. The dip in the plasma osmolality after the watering days suggests that the goats stored the water consumed in their extracellular fluid and the rumen and used it during the forthcoming days of water deprivation. In this regard the Ethiopian Somali goats are similar to the black Bedouin goats (Chosniak *et al.*, 1984) and the lactating Moroccan goat (Hossaini-Hilali, Benlamlih & Dahlborn, 1994).

What are the strategies employed by the Ethiopian Somali goats to reduce water loss?

In the goat breed studied, rectal temperature increased over the course of the day. However, when the goats were protected from the sun (Paper **I)** and when they had good access to water (Paper **IV**), the goats showed a narrow range of diurnal variation in rectal temperature as compared to that observed in goats grazing out in their natural environment during the hot dry period.

The grazing dams and kids studied during the hot dry period increased their rectal temperature over the course of the day both when they were watered once daily and once every fourth day (Papers **II** and **III**). The difference in rectal temperature between the groups was small. The goats that were watered once daily had higher plasma osmolality than expected. It showed that the goats became dehydrated during daytime most likely due to the fact that they spent most of the time grazing in the sun unlike the water-deprived group. Thus, their rectal temperature increased almost in parallel to the group that was watered once every fourth day. The mechanism of rectal temperature regulation in this goat breed resembles that of the camel and oryx, which were able to increase their rectal temperature by 4 to 7 °C during periods of water scarcity (Schmidt-Nielsen *et al.*, 1957; Taylor, 1970a; Ostrowski, William & Ismael, 2003). A diurnal variation in body temperature of 2.4 °C was also reported in N'Dama cattle (Greig & McIntyre, 1979). By tolerating such variation in body temperature, the dependence on evaporative cooling, which would otherwise be needed to maintain lower body temperature is reduced and water is saved.

In the male goats, the diurnal variation in rectal temperature was about 2 °C and the respiratory rate remained low in both the daily watered and intermittently watered groups (Paper **I**). The goats were kept indoors protected from the sun and the environmental temperature rose only to about 30 °C. Nevertheless, the variation in rectal temperature while respiration was kept low shows that the goats saved water by employing diurnal variation of the rectal temperature. Judging from the plasma osmolality values, watering once daily instead of free access to water, involved some dehydration in the male goats fed hay and concentrates. However, lactating goats offered water once daily and grazing on high moisture vegetation during the rainy period had a more narrow range (1.3 °C) of diurnal variation in rectal temperature (Paper **IV**). It was reported that camels and oryx did not vary their body temperature by more than 1 to 2 °C over the course of the day when they were fully hydrated or during the winter (Schmidt-Nielsen *et al.*, 1957; Taylor, 1970a; Ostrowski, William & Ismael, 2003), which is in agreement with our observations. Taken together, the results of the present studies suggest that the Ethiopian Somali goats employed diurnal variation in rectal temperature as a mechanism to save water and this is most important during the dry season when the animals are out in their natural environment.

The grazing lactating does and their kids adjusted their behaviour at pasture (Papers **II** and **III**). The does and kids that were watered once every fourth day decreased the time they stayed in the sun with increasing days of water deprivation. The importance of such behavioural adjustment in the hot environment and during water scarcity was previously reported (Lewis, 1977, 1978; Alderman, Krausman & Leopold, 1989; Ostrowski, William & Ismael, 2003; Cain III *et al.*, 2006). Use of shade helps to maintain temperature gradient between the body and the environment and reduce evaporative water loss. However, we could not measure respiratory or sweating rate at pasture. It has been shown that goats can lose considerable amounts of fluid by sweating and panting during heat stress when they are fully hydrated, but that the sweat and panting rates decrease with dehydration (Baker, 1989, Robertshaw & Dmi'el, 1983). It remains to be shown to what extent the Ethiopian Somali goats use these mechanisms.

The increased plasma vasopressin concentration over the days of water deprivation meant that the animals concentrated urine to avoid water losses by that route. The initially high plasma vasopressin concentration in the intermittently watered lactating does was much higher than that needed to concentrate the urine maximally. However, even when the intermittently watered animals had changed their behaviour and achieved a smaller increase in plasma osmolality and vasopressin concentration similar to that in the once daily watered group, the values were still well above those needed to save water maximally via the kidneys. We did not measure the plasma vasopressin concentration in the mornings, when the plasma osmolality was very low after watering, and we did not take urine samples. However, the observation that the goats drank less water with repeated cycles indicates that they did not come into water diuresis.

In summary, the rise in rectal temperature during the course of the day, storing water in the rumen and extracellular fluid, change in behaviour at pasture and low urine flow are important mechanisms that enabled the goats to reduce water loss and endure intermittent watering.

What could be the possible optimal interval of intermittent watering considering animal performance and welfare?

The advantages of intermittent watering in tropical areas were discussed by many authors (*e.g.*, Musimba *et al.*, 1987; Nicholson, 1987). The results of these previous studies showed that the effects of intermittent watering on productive and reproductive traits were moderate and were compensated during periods of good pasture and water availability. In contrast, Aganga *et al.* (1990) recommended regular and frequent water supply to ewes of different physiological states for better productivity of the animals. However, owing to the scarcity of water and the need to exploit the scattered and meagre desert vegetation in the arid and semi-arid environment in Ethiopia, pastoral societies continue to employ intermittent watering as part of livestock management. Alternative livestock husbandry practices in these regions do not seem readily available. As a result, it is helpful to know the possible optimal watering regimes in these environments to balance the effect on animal productivity, animal welfare and the need to cover wider grazing areas.

The previous report of 5 to 8 days interval of watering for goats was based on survey results (FARM-Africa, 1996) and may not have considered the specific periods of the dry season (early, mid or late). Since the water content of the vegetation during the rainy period and for a short period during the early dry season is high, animals may then go without drinking for longer intervals. As the dry season proceeds, vegetation starts to dry and animals need to be watered at shorter intervals (King, 1983). The watering interval indicated above may therefore be too general and misleading. Thus, longer intervals of intermittent watering have been reported to cause irreversible circulatory failure, body weight loss and death of the animal (Macfarlane *et al.*, 1961; Etzion, Meyerstein & Yagil, 1984; Zewdu, 1991). For example, Zewdu (1991) reported death of desert-adapted black head Ogaden lambs kept indoors when they were watered at 6 or 7-

day intervals after they had lost about half of their initial body weight. This breed lives in the same area as the Ethiopian Somali goats.

The average daily weight gain recorded in all the groups of male goats in the present study fall within the range reported for this breed that were fed on similar concentrate diets and given water *ad libitum* under confinement (Simiret, 2005; Mekasha, Tegegne & Rodriguez-Martinez, 2007). However, the group that was watered once every third day maintained higher feed intake as compared to the other groups, whereas the group watered every fourth day decreased feed intake. The abrupt further rise in plasma vasopressin concentration after the third day of water deprivation in the male goats also showed that the fluid balance of the animal then became severely affected.

When the animals could find shade under trees and consume plants with a reasonable water content, four days without access to drinking water seemed to be endurable for mature grazing lactating goats after they had become accustomed to the repeated cycles of intermittent watering (Paper **III**). However, they decreased the overall milk yield and the kids occasionally seemed suckled in vain. Thus, suckling kids that were watered once every fourth day did not grow as much as their contemporaries that were watered once daily. This is attributed partly to the decreased milk yield of the dams and the decreased grazing time with increasing days of water deprivation. Partly the cause could be that at the age of 3–4 months, the kids no longer use milk as their only drinking source, but they also need to drink water. Thus, it is possible that more than four days of water deprivation can cause severe stress and further loss of animal productivity both in dams and kids.

In conclusion, two days of intermittent watering did not improve the performance of indoor fed male goats and four days stressed the animals. Four days of intermittent watering during the hot dry season reduced milk yield in dams and average daily weight gain of kids as compared to the group watered once daily. Although the physiological and behavioural changes at pasture allowed the goats to tolerate repeated cycles of every fourth day watering, access to shade and the availability of plants with high water content may be limited during the dry season. Thus, three days of water deprivation could be the maximal reasonable watering interval during the mid- and late-dry season in the natural environment of the Ethiopian Somali goats. More than four days of water deprivation could be a threat to productivity and welfare of the animals.

Is the Ethiopian Somali goat a good milk producer? Does removal of some milk affect kid growth?

Information on the milk production capacity of the Ethiopian Somali goat is scarce and there was no study conducted in the natural habitat of the breed. We registered the milk production in late and early lactation, first during the dry season under limited access to water and relatively low forage availability (Papers **II**) and then during the rainy period when forage quality was good and water was available (Paper **IV**).

Under indoor management and high levels of concentrate supplementation (400 g/day), the average milk yield obtained during late and early stages of lactation in the Ethiopian Somali goat was about 380 ml and 1000 ml per day, respectively (Workneh, 1997; Getenet, Alemu & Mekonnen, 2000). The milk yield obtained during the current studies was lower than that obtained under the indoor management. This could be attributed to the fact that the goats used in the indoor studies were obtained from the research flock and had been selected for better milk production. The Ethiopian Somali goats were shown to produce as much milk as the Moroccan goats fed on good quality feed (Hossaini-Hilali, Benlamlih & Dahlborn, 1993, 1994), but they are not as good as the Bedouin goats that can produce about 1000 ml milk per day even on low quality desert pasture (Maltz & Shkolnik, 1984).

Similar to that in the Moroccan goat (Hossaini-Hilali, Benlamlih & Dahlborn, 1994), milk production in the current goat dropped immediately after the first day of water deprivation. Unlike the Moroccan goat, in which milk yield continued to decrease with increasing days of water deprivation, the current goat maintained the milk yield at about the same level during every four days of water deprivation. Concentrate supplementation during the rainy period to grazing goats with daily access to drinking water increased milk yield and slightly prolonged persistency.

Body weight of the does increased and the supplemented group gained even more. In the supplemented group, the plasma glucose concentration was higher than in the unsupplemented group. Since the does gained weight, muscle tissue degradation should not have occurred, but the plasma protein concentration was high in both groups, and even more so in the supplemented does. The high plasma glucose and protein concentrations observed in the supplemented does could be due to concentrate supplementation.

Concentrate supplementation during the rainy period reduced the fat percent but did not affect milk protein and lactose percentages. The mean percentage fat and protein recorded during early lactation (up to 3 months of age) in the Ethiopian Somali goat is lower than the values reported for tropical goat breeds of West African dwarf and Red Sokoto that produce the same amount of milk (Mba, Boyo & Oyenuga, 1975; Akinsoyinu, Mba & Olubaja, 1977). During late lactation (3 to 4 months), the milk yield in the present breed was about half that during early lactation and the milk composition increased accordingly.

The average kid growth rate in the current study, when milk from one udder half was removed every morning after the kids had not suckled during the night, was similar to that reported for some goat breeds indigenous to the arid and semi-arid tropics. For example, the growth rate in the Afar goat breed from birth to 150 days of age under pastoral free ranging was reported to be 45 g/day. The average daily gain reported for Djallonke (birth to 90 days) and Massai (birth to 150 days) goat breeds under station management condition was 35 g/day and 49 g/day, respectively, (DAGRIS, 2007). Since milk is the major source of food among pastoral societies, the rate of kid growth under the conditions prevailing in the current study could be acceptable under traditional husbandry practices. With a large number of female goats in the pastoral flock (FARM-Africa, 1996), therefore, milking half of the udder for human consumption can provide a substantial amount of goat milk to the household. From the current observations, it may be concluded that the Ethiopian Somali goats have a milk production potential that can promote normal kid growth in their natural habitat and partial removal of milk during periods of reasonably good feed and water availability do not jeopardize normal kid growth.

Main conclusions

- The lactating Ethiopian Somali goat showed a mean diurnal variation of the rectal temperature of 3.5 °C during the hot dry season. Dehydrated does reached even higher temperatures.
- Lactating does watered daily stayed and grazed in the sun and showed pronounced increases in plasma osmolality and plasma vasopressin concentration. Dams watered once every fourth day initially showed much higher plasma osmolality and vasopressin concentration than the daily watered group. However, by spending more time in the shade, grazing more watery plants and keeping the ingested water in the rumen and extracellular fluid compartments, the does' degree of dehydration became less severe as the cycles of intermittent watering continued. This shows the adaptability of the breed and underlines the importance of shade to preserve the welfare and productivity of grazing goats during water scarcity in the hot, dry season.
- Once every fourth day repeated cycles of intermittent watering during the hot dry season decreased the overall milk production by 22 % as compared to once daily watering. The average daily weight gain of the suckling kids at 3 to 4 months of age, kept on the same watering schedule as the does, was lower compared with those watered once daily. This shows that young animals should be watered more often to exploit their growth potential.
- During periods of good forage and water availability, Ethiopian Somali goats have the capacity to produce enough milk to promote normal growth of kids even if some milk is removed for human consumption.
- Although water was offered every day during the rainy period, lactating goats did not always drink suggesting that daily watering during the rainy period in the semi-arid environment is not necessary at this productivity level.
- Concentrate supplementation during the rainy season increased milk yield and reduced the percentage of fat in the supplemented goats as compared to the unsupplemented group. The increased amount of milk with supplementation did not cover the cost of the concentrate or improve kid growth. Thus concentrate feeding during good forage availability at pasture is not economical. However, the dams increased their body weight, which could be an investment for the coming harsh periods.
- Three days of water deprivation had no detrimental effects on fluid balance and performance of male goats studied in confinement, but four days put strain on the fluid balance of the goats and reduced feed intake. This, together with the increased plasma osmolality, reduced plasma volume and markedly elevated plasma vasopressin concentration indicating that longer than four days of intermittent watering could be a threat to performance and welfare of goats kept in confinement on hay and concentrate.

Scope for future research

- Intermittently watered kids did not grow as fast as those watered daily. To get a clearer picture of the growth pattern of intermittently watered young animals in the arid and semi-arid environment, it is imperative to study if the reduced growth is compensated during a season of good water and access to forage.
- Effects of repeated cycles of intermittent watering on long-term rumen microorganisms, nutrient digestion and utilization in young goats need to be quantified.
- Milk production capacity and the lactation curve of the Ethiopian Somali goats in their natural environment should be further studied with a larger number of animals and different methods of milking.
- In the current experiment, total plasma protein concentrations were comparatively high. It was not possible to decide whether this was an adaptive mechanism or because of concentrate supplementation. This is an interesting area to investigate further.
- To design a future breeding strategy – identification of genes that contribute to the adaptability of this breed could be a first step. It is important that breeding programs that aim at improving the productivity of the animal take into due consideration the outstanding ability of these animals to thrive in their harsh environment.

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