Water Intake and Nutrient Balances of Holstein x Boran Cows Fed a Low-Quality Tropical Diet

*Andreas Jenet[1], Asfaw Yimegnuhal[*2], Azage Tegegne[2], Salvador Fernandez-Rivera[2] and Michael Kreuzer[1]*

[1] Swiss Federal Institute of Technology Zurich, Institute of Animal Science, CH-8092 Zurich, Switzerland

[2] International Livestock Research Institute (ILRI), P.O. Box 5689 Addis Ababa, Ethiopia

Abstract

A study was conducted to determine turnover of water, nitrogen and energy in lactating Holstein x Boran cows. Nine cows (Bos indicus × B. taurus) between their 42nd and 420th the days of lactation were selected for this study. The crossbred cows had ad libitum access to water and a dried maize stover/lablab mixture (3:1), and received 3.2 kg of concentrate (wheat bran, molasses, bone meal) and 3 kg of fresh Napier grass per day. After an adaptation period of 7 days, feed intake and excretion of faeces, urine and milk were quantitatively recorded and samples proportionate to excretion were taken. for seven days period. Data on milk and body weight were collected twice daily or every second week, respectively, throughout lactation. Milk yield decreased by 12 (±0.192) g·day^{-1} during the lactation period. Milk fat, protein and energy concentrations were 4.9 (±0.467) %, 3.2 (±0.064) %, 3.2 (±0.180) MJ·kg^{-1}, respectively. Dry matter digestibility was 57.6 (±7.84) % and the amount of faecal dry matter excreted was 4.1 (±0.821) kg ·day^{-1}. Energy and nitrogen balance were slightly positive, which was confirmed by the small weight gain. Crossbred cows consumed daily 52.6 (±4.33) kg water, including the water in feed. Water excreted with faeces, urine and milk was 23.8 (±3.68), 10.3 (±1.89), 5.7 (±1.56) kg·day^{-1}, respectively. Hence, the water balance of 15.8 (±2.29) kg day^{-1} was explained as water excreted by evapo-transpiration. Results indicate that with the quantity and quality of feed used in the study, variation in milk yield during the lactation does not affect the water consumption and total turn over of crossbred cows, although there is a shift from milk to faeces in water loss with advancing lactation.

Keywords: Crossbred cows, body weight changes, lactation, water intake, nitrogen balance, energy balance, milk yield.

Introduction

Water plays a key role in digestion, transport of metabolic products, excretion and in regulating body temperature through latent heat of vaporization. The water utilized by the animal's body is either ingested as drinking water or as a component of the feed or produced by catabolism (Woodford *et al*., 1984). Animals differ markedly on their ability to conserve water and to withstand water deprivation. Some desert animals such as the camel can tolerate a more severe dehydration without suffering an explosive heat rise (Schmidt-Nielson, 1962). Animals deprived of water refuse to consume feed already in early stages of dehydration and do not eat dry feed until after they are provided with drinking water (Steiger-Burgos *et al*., 2001).

The provision of adequate quantities of clean drinking water is a major prerequisite for satisfactory milk production, growth and animal health (Little and Shaw, 1978), but the minimum amount required is affected by various factors. Ambient temperature has a marked effect on water intake. Accordingly, *Bos taurus* cattle weighing 450 kg and eating

[*] Corresponding author

10 kg dry feed per day drank 28, 41 and 66 litres of water per day when the temperature was 4, 21, and 32°C, respectively (Maynard, *et al*., 1981). Lactating cows consume more water than dry cows of similar weight fed on maintenance level in order to use for milk excretion. Heavy temperate breed cows have a higher water intake (60 to 90 litres day^{-1}) than zebu cows (25 litres day^{-1}) (King, 1983). Also the type of feed plays a decisive role for water intake.

Nutrient balance experiments with cows are very rare in tropical countries. Extrapolation of data on nutrient balances from temperate climates and diets produces misleading results. The objective of this experiment was to investigate water consumption and turnover along with feed intake, milk yield, nitrogen as well as energy balance based on observation for seven days on lactating *Bos taurus x Bos indicus* crossbred cows fed a tropical diet.

Materials and Methods

Experimental site: The experiment was conducted at the Debre Zeit Research Station of the International Livestock Research Institute (ILRI) in Ethiopia at an altitude of about 1920 m above sea level. Minimum and maximum temperatures in the experimental barn were 16 °C and 29 °C, respectively. The experiment lasted for 2 weeks with the first week serving for adaptation to the urine collection apparatus and the second week for data collection and sampling.

Animal and feeding: Nine Holstein Friesian x Boran crossbred cows with either 50% or 75% Holstein blood of similar live weight of 392 (±21.7) kg but differing in stage of lactation were selected for this experiment. The cows were between 42 and 420 days of lactation. The stage of lactation was divided as early (42-140 days), medium (141-280 days) and late (281-420 days). The cows were penned and tethered individually in a ventilated barn with concrete floor. Each cow had *ad libitum* access to tap water, provided in buckets, and to a sun-dried mixture of maize stover and lablab (*Lablab purpureus*), with maize and lablab sown together on farm in a ratio of 3:1. Additionally, 3 kg of wheat bran and molasses mixture (5:1) together with 200 g bone meal was fed daily at 8:00 h. Three kg fresh Napier grass (*Penisetum purpureum*; equivalent to 0.4 kg dry matter) was also offered at 14:00 h. Table 1 gives the analysed composition of the feed ingredients.

Data collection and laboratory analyses: Cows were weighed in the morning after 12 h fasting at the start and end of the experiment. Quantities of water and feeds offered and refused were measured and recorded daily. Concentrate and Napier grass were consumed completely. The residual amounts of the roughage mix were weighed and samples were taken for analysis. Faeces and urine were separately collected over the same seven days collection period. For urine collection, each cow was shaved at the hips and between *tuber ischii* and *tuber coxia* using scalpel blade. Then Velcro® tapes were glued to the shaved skin around the vulva with special adhesive (CYANOLIT®, 3M, Rueschlikon, Switzerland). Cone shaped urine-collection-bag made of impregnated cloth with an oval opening on the inner side was then connected with the Velcro® tapes (Figure 1). A hard plastic (PVC) pipe (6 cm long, 2.5 cm wide and 0.5 cm thick) was inserted into the narrow part of the cone shaped bag and tied with a plastic string. The outlet was connected to a plastic pipe equipped with wire stabilizer and of a length of approximately 2 m. The plastic pipe was connected to a PVC pipe (20 cm long, 2.5 cm wide and 0.5 cm thick) and this was passed into 30-liter plastic containers to collect the urine (non-acidified). An outlet in the middle of the PVC pipe was connected to a smaller container that contained

50 ml concentrated sulphuric acid (49%) to avoid nitrogen loss. Faeces was collected as deficated from the floor and kept in a plastic container. The quantities of faeces and urine excreted were measured daily at 07:00h and 17:00h (Figure 1). Urine density was measured with Fisher Scientific Hydrometer. Faeces were thoroughly hand mixed, and the 10% and 5%, respectively, of the quantity of faeces and urine excreted was pooled for each cow over the collection period. Faeces and urine samples were stored at –20°C until being analysed. Cows were hand milked twice a day throughout the lactation. Total lactation milk yield was recorded and aliquot milk samples were taken during the experimental week for analysis. Current lactation body weights were taken from fortnightly body weight records.

Feed and faeces were analysed for dry matter (DM), organic matter (OM), ether extract (EE), gross energy (GE) and nitrogen following the procedure of AOAC (1990), as well as neutral detergent fibre (NDF) according to Van Soest and Robertson (1985). Nitrogen was determined in the acidified urine samples using Kjeldahl method. Milk samples were analyzed for protein by formaldehyde titration (milk N $\times$ 6.38) as suggested by AOAC (1990) and for fat (Gerber method).

Statistical analysis: Body nitrogen retention was computed as the balance between N intake and N excretion via faeces, urine and milk. The metabolizable energy intake (ME) was calculated as 0.81 of DE (MAFF, 1985). Net energy used for gain and lactation was calculated by subtracting the energy used for maintenance from the ME contained in feed (MAFF, 1985, Maynard *et al*., 1981). In order to be able to calculate water balance of the dairy cows, several variables had to be estimated. Milk water content was estimated on average to be 88% according to British Standard (1963). Urine dry matter was computed as the difference of the specific gravity of urine and pure water multiplied by a factor of 2.6 (French, 1956). Metabolically generated water, from feed as well as oxidation of protein, carbohydrates and fat during metabolic processes, was estimated to account for 0.40, 0.56, and 1.07 ml per g of nutrient, respectively (Maynard *et al*., 1981). Water turnover was calculated as the sum of drinking water, water intake directly through feed and metabolic water. The gross energy content of the milk ($MJ \cdot kg^{-1}$) was calculated using the following formula:

Gross energy = 3.86 $\times$ milk fat % + 2.05 $\times$ solid-non-fat % - 0.236 (MAFF, 1985).

Variables monitored during the observation period are summarized in Tables 2 to 6. Individual data on milk yield and body weight changes over the observation period were regressed over day of lactation (DL) using the General Linear Model (GLM) of the Statistical Analysis Systems (SAS). The linear and cubic effects of stage of lactation were as follows:

$$Y = a + b \cdot (DL)$$

$$Y = a + b \cdot (DL) + c \cdot (DL)^2 + d \cdot (DL)^3$$

Where Y = individual observation; a = estimated intercept; b, c, d = slope; DL = day of lactation.

Results

Live-weight, feed intake and digestibility: Live weight changes (C)in kg were explained through the following equation: C in kg = $-11.68 - 0.174 \cdot DL + 0.000914 \cdot DL^2 - 0.00000078 \cdot DL^3$ ($r^2 = 0.931$). The daily body weight gain increased by 1.34 (SD=0.903) g as lactation progressed (Figure 2). Mean live weight of cows during the experimental period was 395 (SD=20.3) kg (Table 2). Cows consumed on average 9.71 (SD=0.319) kg dry matter

(DM) and 8.89 (SD=0.292) kg organic matter (OM). When intake was related to metabolic live weight (LW, $kg^{0.75}$) cows consumed 109 (SD=4.76) g·kg $LW^{-0.75}$. Faeces DM excreted was 4.1 (SD=0.807) kg. The mean apparent digestibility of DM, OM and NDF were 58.0 (SD=7.66), 61.2 (SD=7.42), and 53.4 (SD=9.67) %, respectively.

Milk yield: The decrease of milk yield over stage of lactation (Y) was explained through the following equation: $Y \text{ in kg} = 11.44 - 0.0437 \cdot DL + 0.00013 \cdot DL^2 - 0.00000015 \cdot DL^3$ (r^2=0.96; CV=5.34). Against decrease in milk yield, concentrations of fat and energy increased in late lactation, daily excretions of protein, fat and energy decreased by 0.41 g (SD=0.098), 0.45 g (SD=0.182), 0.035 MJ for protein, fat and energy, respectively. Table 3 presents the mean values for these variables.

Nitrogen balance: Nitrogen intake was 126 (SD=3.20) g day^{-1} (Table 4). This was followed by faecal and urinary nitrogen excretion of 72.7 (SD=14.0) and 19.0 (SD=2.34) g, respectively. Nitrogen retained in the body of the cows was 1.23 (SD=14.4) g over the whole group of cows.

Energy utilization: The gross energy intake was calculated to be 180x5.87 MJ day^{-1}. Similarly the digestible energy intake was 106x14.0.9 MJ d^{-1} (Table 5). The estimated daily metabolizable energy intake was 85.8 (SD=11.3) MJ. Energy used for maintenance (NE_m) was estimated at 43.1 (SD=2.42) MJ day^{-1}. When considering net energy required for body retention, the amount of net energy still available for lactation (NE_L) was calculated to be 33.6 (8.78) MJ d^{-1}.

Water intake and excretion: The quantity of water consumed, used for various activities and excreted is shown in Table 6. The drinking water intake was 48.5 (SD=4.25) kg·cow^{-1}·day^{-1} and did not differ as the lactation progresses. The mean amount of metabolically generated water was estimated at 3.0 (SD=0.346) kg·cow^{-1}·day^{-1}. Water turnover, including feed, drinking water intake and metabolically generated water was 55.5 kg (SD=4.03). The percentages of this total water excreted through faeces, urine and milk were 44.9 (SD=4.15), 19.3 (SD=2.64), 11.1 (SD=3.72) %, respectively. Most of the non-explained part of the water balance (15.9 SD=2.32) was assumed to account for water loss through evapo-transpiration and respiration.

Discussion

The relatively low digestibility of the diet observed in this experiment was similar to that of 58.3 to 60.8% DM digestibility and of 61.3 to 64.0% organic matter digestibility noted by Chilliard *et al.* (1998) and French *et al.* (2001) in tropical cattle fed high fibrous diets.

The excretion of faecal and urinary N as proportion of N intake was in the range of various other studies where N excretion rates with faeces ranged from 31 to 57% and urinary N losses ranged from 16 to 53 % of intake (Hornick *et al*., 1998, Kroeber *et al*., 2000). Urinary N excretion is high in high-protein diets (Kroeber *et al*., 2000), whereas the percentage of faecal N increases with the use of fibrous diets. Despite the inclusion of lablab, urinary N losses remained low, which indicates that the diet was low in easily rumen-degradable protein (Rohr & Lebzien, 1991) and this does not necessarily mean low supply of metabolically available protein. Furthermore, there was on average no N retained in the body, which may suggest that N supply was a limiting factor for performance.

The supply of net energy from the feed was assumed to have been sufficient for the level of milk yield. The levels of digestible and metabolizable energy were sufficient despite the relatively high faecal energy losses. Cows fed concentrate-based diets can lose up to 30% of the gross energy through faeces (Kreuzer *et al*., 1985, Terada & Muraoka, 1994); this rate was 39 % in the present study. Similar results were obtained in other studies with ruminants fed roughage-based diets (Ortigues & Vermorel, 1996). Evidence from weight changes indicates that the early lactating cows had to rely on their body reserve to increase milk yield.

The observation that water consumption changes with the stage of lactation is consistent with reports in the literature. The ratio of water excreted to water intake was similar to the findings of Steiger-Burgos *et al*. (2001). The overall relation of water turnover (Tables 6) to DM intake (Table 2) of 5.70 (SD=0.364) also was similar to the results obtained for Brown Swiss cows (Steiger-Burgos *et al*., 2001). Even the percentage of water excreted via faeces and urine in relation to total water consumed, accounting for 44 (SD=4.15) % and 19 (SD=2.64) %, respectively, was in the same range as found by Kreuzer *et al*. (1985) in cows receiving concentrate-based diets. The drinking water consumption (WI) ranging between 43 and 55 $kg \cdot cow^{-1} \cdot day^{-1}$ exceeded the maintenance requirement calculated by equation (1) of Little and Shaw (1978) including DM intake (DMI, $kg \cdot cow^{-1} \cdot day^{-1}$) and milk yield (MY, $kg \cdot cow^{-1} \cdot day^{-1}$):

$$WI = 12 + 2.15 \times DMI + 0.73MY \quad (1)$$

Water intake was lower than expected in the early stage (62 kg) and approximately as expected in the late stage of lactation (53 kg) when 3 kg extra water for every kg of milk produced is considered as recommended by Barrett & Larkin (1974). The quantity of water consumed was in agreement with the range of 3.5 to 5.5 kg of water per kg of dry diet given for ambient temperatures between –17° and 27°C (NRC, 1980).

Both feed intake and digestibility determine faecal DM excretion. Faecal DM excretion was slightly lower than found by Steiger-Burgos *et al.* (2001) for high yielding dairy cows but higher than in the estimate obtained by Ayantunde *et al.* (2001) for Sahel conditions. This is explained by the fact that the high yielding cows of this study received a diet of higher digestibility than those of the Sahel cows Faecal water contents of 84 and 86% in the early and late lactating cows, respectively, were obtained in this study. Faecal dry matter excretion has an important influence on faecal water loss. Knowledge of DM digestibility could be a factor to improve water intake estimation (Winchester & Morris, 1956). Applying the multiple regression analysis procedure of SAS (1999), the following equation was developed to estimate water intake from DM intake (DMI) and DM digestibility (DMD) was derived from the present experiment:

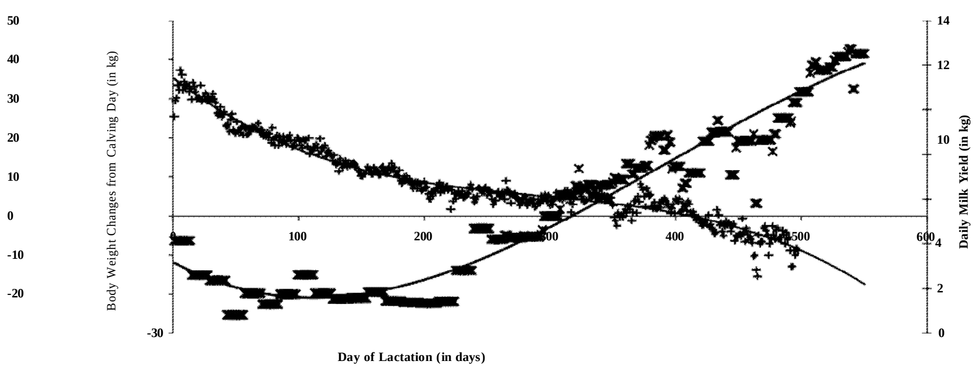
$$WI = 35.9(\pm 38.8) + 3.43(\pm 3.59) \cdot DMI - 35.66(\pm 15.4) \cdot DMD \ \ (r^2 = 0.60;\ CV = 6.75) \quad (2)$$

The following equation (3), including metabolic weight (LW, $kg^{0.75}$), was derived earlier for tropical cattle in dry regions of West Africa fed fibrous diets to estimate water intake (Ayantunde *et al*., 2001). This equation slightly underestimated the actual water intake of the cows in the present experiment. This equation suggests that water intake is negatively correlated with metabolic live weight of the animal; however the low variation in live weight between animal might have produced an artefact here:

$$WI = 6.86(\pm 3.11) \cdot DMI - 0.203(\pm 0.341) \cdot LW^{0.75} \ \ (r^2 = 0.99;\ CV = 8.45) \quad (3)$$

In general, the water intake of cows is influenced not only by live weight, DM ingested and DM digested but also by climatic condition, composition of the diet, characteristics of the water supply and physiological state of the cattle (Little and Shaw, 1978). Higher milk yield achieved with high quality diets may increase water consumption in early lactation stage.

Figure 1: View of Urine and faeces collection from experimental dairy cows *Legend*: Urine collectors were fabricated out of a cone shaped impregnated cloth and attached on Velcro®-tapes, which were glued around the vulva. Stabilized plastic tubes lead the urine into containers.



X Body Weight Change ---------------------------------- $WTCH = -11.68-0.174DL+0.000914DL^2 –00000078DL^3$

\+ Milk Yield ▬▬▬ $MILK= 11.4-0.043DL+0.00013DL^2-0.00000015DL^3$

Figure 2. Body weight change (WTCH) and milk yield of crossbred cows (n=9) during lactation.

According to Roubicek (1969) and unpublished data of ILRI Debre Zeit Station, at 27°C day temperature skin water transpiration accounts for 250 g m^{-2} h^{-1} (24 h average; 400 and 100 g m^{-2} h^{-1} at day time and at night, respectively), and respiratory water loss is at about 23 g m^{-2} h^{-1}. Assuming a body surface area of 2.4 m^2 per cow, this loss rate adds up to 15.7 kg per day. This is very close to the 15.9kg water arrived at by the water balance (Table 6). This value falls within the range of 14–22 kg day^{-1} reported by Kreuzer *et al*., (1985) in cows of higher yield (17–22 kg milk day^{-1}) but kept at lower ambient temperature. In contrast, Kroeber *et al*. (2000) reported lower values of 7–10 kg cow^{-1} day^{-1} water evapo-transpiration in high yielding cows (>30 kg milk cow^{-1} day^{-1}). In the present study a high level of water retention during the 7-day period and high water evaporation from the buckets were unlikely; however, water loss during consumption cannot be totally excluded. The water balance of 15.9kg day^{-1} can therefore be taken as a good estimate of body water loss via evapo-transportation.

The overall water turnover rate of 409 (SD=39.7) $g \cdot LW^{-0.82} \cdot day^{-1}$ from this study falls between values calculated for purebred zebu and temperature breeds of cattle (Roubicek, 1969). Although occasionally extreme values of water intake and turnover rates are observed in tropical cows, variation in these values between the crossbreds of the present study remained low (Table 6).

Table 1: Nutrient composition of the dietary ingredients (($g \cdot kg^{-1}$ DM)

Item	DM	OM	N	NDF	GE	EE
Concentrate mixa	834	918	20.9	257	19.3	25.7
Roughage mixb)	900	917	10.0	676	18.4	12.9
Napier grassc)	127	866	13.1	733	18.4	18.8

[a] Daily ration composed of 2.5 kg wheat bran; 0.5 kg molasses and 0.2 kg bone meal;

[b)] Composed of Maize stover and lablab, 3:1; fed ad *libitum*;

[c)] 3 kg day^{-1}.

Table 2. Live weight, intake, feed digestibility and faeces as well as urine excretion of Holstein x Boran cows (n=9)

Variable	Mean	Std Dev	Minimum	Maximum
Live weight (kg)	395	20.3	350	423
Dry matter intake (DMI, kg day^{-1})	9.71	0.319	9.31	10.2
DMI_m ($g \cdot (kg\ live\ weight)^{-0.75}$)	109	4.77	102	114
Organic matter intake (kg day^{-1})	8.89	0.292	8.52	9.32
Faeces fresh matter (kg day^{-1})	27.7	4.36	22.5	36.0
Faeces DM (kg day^{-1})	4.08	0.806	3.21	5.76
Urine volume (kg day^{-1})	11.0	1.81	8.33	14.6
Apparent digestibilities (%)				
Dry matter	58.0	7.67	42.8	65.9
Organic matter	61.2	7.42	46.1	68.9
Neutral detergent fibre	53.4	9.67	32.2	63.1

Table 3. Milk yield and composition of Holstein x Boran cows (n=9)

Variable	Mean	Std Dev	Minimum	Maximum
Milk Yield (kg day^{-1})	6.52	1.82	3.64	9.06
Energy (MJ kg^{-1})	3.22	0.182	3.03	3.50
(MJ day^{-1})	20.8	5.44	12.7	27.6
Fat (g kg^{-1})	4.85	0.471	4.37	5.58
(g day^{-1})	312	79.4	203	419
Protein (g kg^{-1})	3.22	0.064	3.10	3.30
(g day^{-1})	210	58.4	118	293

Table 4. Nitrogen balance of Holstein x Boran cows (n=9)

Nitrogen turnover (g cow^{-1} d^{-1})	Mean	Std Dev	Minimum	Maximum
Feed N intake	126	3.20	122	130
Faeces N excretion	72.7	14.0	58.9	99.6
Urine N excretion	19.0	2.34	14.6	22.7
Milk N excretion	32.8	9.15	18.5	45.9
Body N retention	1.23	14.4	-17.7	27.5
Apparent N digestibility (%)	42.3	10.5	23.1	52.2

Table 5. Energy intake and excretion (MJ d^{-1}) of Holstein x Boran cows (n=9)

Variable	Mean	Std Dev	Minimum	Maximum
Gross energy intake	180	5.87	173	189
Faeces energy excretion	75.0	15.9	57.4	107
Digestible energy intake	106	14.0	80.0	118
Metabolisable energy intake[a)]	85.8	11.3	64.8	95.9
Milk energy excretion[a)]	20.8	5.44	12.7	27.6
NE_m [a)]	43.1	2.42	38.4	48.2
NE_l [a)]	33.6	8.78	20.6	44.6
NE_g [a)]	9.14	12.1	-10.0	28.7

[a)] Calculated by formulae

Table 6. Water balance of Holstein x Boran cows (n=9)

Water turnover (kg d^{-1})	Mean	Std Dev	Minimum	Maximum
a. Drinking water intake	48.5	4.24	43.6	55.4
b. Water intake contained in feed	3.87	0.035	3.82	3.92
c. Metabolically generated water	3.04	0.346	2.39	3.36
d. Water excretion via faeces	23.6	3.67	19.3	30.2
e. Water excretion via urine	10.1	1.79	7.63	13.8
f. Water excretion via milk	5.73	1.60	3.20	7.97
Water difference (a+b+c)-(e+d+f)*	15.9	2.32	11.3	19.4

*This difference is assumed for evapo-transpiration.

Conclusions

This experiment indicated the performance (weight gain and milk yield), nutrient balances and water intake of crossbred cows. The milk production and weight change curve of crossbred cows could be explained with high accuracy only with day of lactation, but not so with DMI and DMD. Water intake is influenced beside feed quantity also by feed quality, as dry matter digestibility affected the water intake.

Acknowledgements

The experiment was financed by the Swiss Federal Institute of Technology as part of the study on 'New sustainable concept for efficient smallholder dairy nutrition'. The authors would like to convey their appreciation to Aklilu Bogale, Aragaw Bekele, Azeb Tessema, Bekele Andarge, Mulugata Tekle Haimanot and staff of the Debre Zeit ILRI-Animal Nutrition Laboratory for their technical input and assistance during the experiment and chemical analyses of samples.

References

AOAC. 1990. Official Methods of Analyses. Association of Official Agricultural Chemist. Washington D.C.

Ayantunde, A.A., Fernandez-Rivera, S., Hiernaux, P.H.Y., Keulen, H. van, Udo, H.M.J. & Chanono, M. 2001. Effect of timing and duration of grazing of growing cattle in the West African sahel on diet selection, faecal output, eating time, forage intake and live weight changes. Animal Science 72, 117-128

Barrett, M.A. & Larkin, P.J. 1974. Milk and beef production in the tropics. Oxford University Press, Oxford, 240

British Standard. 1963. BS 1741 Total Solids. British Standard.

Chilliard, Y., Ferlay, A., Despres, L. & Bocquier, F. 1998. Plasma non-esterified fatty acid response to an β-adrenergic challenge before or after feeding in energy underfed or overfed, dry or lactating cows. Animal Science 67, 213-223

French, M.H. 1956. The effect of infrequent water intake on the consumption and digestibility of hay by Zebu cattle. Empire Journal of Experimental Agriculture 24, 128-136

French, P., O'Riordan, E.G., O'Kiely, P., Caffrey, P.J. & Moloney, A.P. 2001. Intake and growth of steers offered different allowances of autumn grass and concentrates. Animal Science 72, 129-138

Hornick, J.L., Van Eenaeme, C., Clinquart, A., Diez, M. & Istasse, L. 1998. Different periods of feed restriction before compensatory growth in Belgian Blue bulls: I. Animal performance, nitrogen balance, meat characteristics, and fat composition. Journal of Animal Science 76:1, 249-259

King, J.M. 1983. Livestock water needs in pastoral Africa in relation to climate and forage. International Livestock Centre for Africa. ILCA Research Report 7. Addis Ababa , Ethiopia pp. 95

Kreuzer, M., Mueller, H.L. & Kirchgessner, M. 1985. Energiebilanz und Energieverwertung bei Kühen waehrend und nach ueberhoehter Proteinzufuhr. Zeitschrift fuer Tierphysiologie, Tierernaehrung und Futtermittelkunde 54, 41-54

Kroeber, T.F., Kuelling, D. R., Menzi, H., Sutter F. & Kreuzer, M. 2000. Quantitative effects of feed protein reduction and methionine on nitrogen use by cows and nitrogen emission from slurry. Journal of Dairy Science 83, 2941-2951

Little, W. & Shaw, S.R. 1978. A note on individuality of drinking water by dairy cows. Animal Production 26, 225

MAFF 1985. Energy allowance and feeding system for ruminants. Technical Bulletin 33. London Her Majesty's Stationary Office. 79

National Research Council, 1980. Effect of environmental stress on nutrient requirement. Washington D.C., National Academy of sciences.

Maynard, L.E., Loosli, J.K., Hintz, H.F. & Warner, R.G. 1981. Animal Nutrition, 7th ed., Tata McGraw-Hill Publ., New Delhi. 602 pp.

Ortigues, I. & Vermorel, M. 1996. Adaptation of whole animal energy metabolism to undernutrition in ewes: influence of time and posture. Animal Science 63, 413-422

Rohr, K. & Lebzien P. 1991. Present knowledge of amino acid requirements for maintenance and production. Proceedings of the 6th International Symposium on Protein Metabolism and Nutrition. Herning, Denmark. vol. 1, 127-137

Roubicek, C.B. 1969. Water metabolism. In: Hafez, E.S.E. and Dyer, I.A. (eds.) Animal Growth and Nutrition. Lea & Febiger. Philadelphia, USA. 353-373

SAS (Statistical Analysis System). 1999. SAS giude for personnal computers, version6. SAS Institute. Cay N.C. pp1028

Schmidt-Nielson, K. 1962. Comparative physiology of desert mammals. Missouri Agricultural Experiment Station, Special Report No 21: 1-21

Steiger-Burgos, M., Senn, M., Sutter, F., Kreuzer, M. & Langhans W. 2001. Effect of water restriction on feeding and metabolism in dairy cows. American Journal of Physiology 280, R418-R427

Terada, F & Muraoka, M. 1994. Effect of heat stress on the efficiency of utilization of metabolizable energy for lactation. In: Proceedings of the 13th Symposium on Energy Metabolism of Farm Animals, Mojacar, Spain. EAAP Publication 76, 323-326

Van Soest, P.J. & Robertson, J.B. 1985. Analyses of Forages and Fibrous Foods. A Laboratory Manual for Animal Science. Department of Animal Science. Cornell University. Ithaca. New York. 202

Winchester, C.F. & Morris, M.J. 1956. Water intake rates of cattle. Journal of Animal Science 15: 722-740

Woodford, S.T., Murphy, M.R. & Devis C.L. 1984. The importance of water for lactating dairy cows. In: Illinois Dairy Report. Urbana: University of Illinois pp. 25-28