Livestock water needs in pastoral Africa in relation to climate and forage

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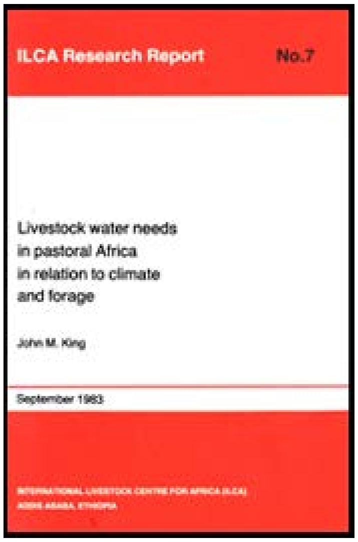
ILCA Research Report No.7

Livestock water needs
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September 1983

INTERNATIONAL LIVESTOCK CENTRE FOR AFRICA (ILCA)
ADDIS ABABA, ETHIOPIA

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ORIGINAL: ENGLISH

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Summary

Water is used by the herbivore as a medium for physical and chemical energy transfer, namely for evaporative cooling and intermediary metabolism. Therefore animal water turnover cannot be considered in isolation from energy metabolism. A detailed discussion of the physiology of water and energy use in the herbivore is given and a diagram of the interrelation between the two has been constructed. A simplified version of this 'soft' model has been used to simulate the energy budget and water turnover of the main livestock species in the African pastoral production system during the dry season. The analytical background to the model has been obtained from the literature, supported by field observations. However, data from Africa are scarce.

The information obtained on water and energy use by livestock in the traditional pastoral system has been applied to water and livestock development in the context of range, woodland and livestock management. There are numerous implications for research, notably for hypothesis and modelling, as well as component research for which priority topics and species are given. The research emphasis is placed on field work which is not as difficult as it used to be, because technical equipment is becoming increasingly compact and rugged and communications between the field and advanced laboratory facilities have improved.

An important contribution that the developer, and hence the scientist can make to the productivity of pastoral systems will be to increase the efficiency with which scarce water and energy resources are used.

Key words

/Water//livestock//pastoral systems/-/body water//water balance//dehydration//energy exchange//thermoregulation//water availability//water use//Zebu cattle//camels//small ruminants//asses//pastoral development/

Preface

Livestock development projects initiated in sub-Saharan Africa over the past two decades have absorbed close to one billion American dollars worth of aid. Much of this aid, particularly during the period 1961 to 1975, has been directed towards the semi-arid and arid zones where the provision of drinking water for man and his livestock has been the largest single item of expenditure. In these zones, which are occupied primarily by pastoral people, shortages of drinking water occur every dry season, of which there are one or two a year depending on the region. Therefore any form of water development might be expected to improve the living standards of pastoral people in normal years and their chances of survival in times of drought.

Unfortunately this is often not so. Water development may contribute to imbalances in the use of land and water resources in dry areas. These imbalances are exacerbated and intensified when they coincide with detrimental climatic fluctuations, both wet and dry, making the effects of drought and flood more severe and leaving a legacy of erosion and desertification. Recent improvements in international communications have given extensive publicity to natural disasters and helped to focus world attention on the problems of water and livestock.

The most recent example of such a catastrophe in Africa was the drought in the Sahel from 1968 to 1973. It caused the collapse of the livestock industry of five countries - Chad, Mali, Mauritania, Niger and Upper Volta - and severely damaged that of two others, Senegal and the Gambia.

It was against this background that ILCA was prompted to put together a series of state-of-knowledge reports on water and livestock problems in Africa. There were a number of scientific disciplines involved, and the subject has been divided into four topics, each of which is dealt with in a separate research report (RR) as follows:

RR 6. *The water resource in tropical Africa and its exploitation,*
RR 7. *Livestock water needs in pastoral Africa in relation to climate and forage,*
RR 8. *Organisation and management of water supplies in tropical Africa,*
RR 9. *Economics and planning of water supplies in pastoral Africa.*

The four reports are best read in relation to one another.

As well as providing technical and economic guidelines for national planning authorities, these reports review the interrelation of animal metabolism, water, climate and forage. They also consider the complexities of human organisation and management upon which the success or failure of the most carefully prepared and executed water development project will largely depend. The authors are primarily addressing senior personnel engaged in scientific research, planning and implementation. The justification for this approach is that if there were simple solutions to the problems of water and livestock in Africa, they would have been found some time ago.

Acknowledgments

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Thanks are also due to those who have commented on the manuscript, particularly the following ILCA staff members: Mr. D.J. Pratt (former Director General), Dr. R.S. Temple, Dr. L.J. Lambourne, Dr. P.A. Konandreas and Prof. R.E. McDowell (Chairman of ILCA's Board of Trustees). The comments of the following outside referees are also gratefully acknowledged: Dr. V.A. Finch, Prof. C.R. Taylor, Prof. P.J. Van Soest, Dr. J.E. Vercoe and Prof. A.J.F. Webster.

Finally I wish to thank Mrs. S.B. Westley, Dr. R.A. Stewart and Mr. S.D. Chater for editorial assistance, and Mrs. G. Maloba for typing the draft.

1. Introduction

The greatest threat to life on land is the danger of dehydration (Schmidt-Nielsen, 1975). Most livestock have to drink at least every other day to be productive, and every few days to survive. The provision of water is therefore of prime importance in all animal production systems.

The overall water cost of animal production is rarely calculated, but a rough estimate can be made using a number of assumptions. For example, the mean body water turnover of a Boran steer (Large East African Zebu) was found to be 140 ml.l^{-1}.d^{-1}, and its water pool between 65 and 70% (King, 1979). If such an animal is marketed at 4 years, weighing 400 kg, then its total water use would be in the region of 28 t. If one also takes into account the water required to grow the forage eaten by the herbivore, which is between 150 and 250 l. kg^{-1} DM of grass, then this figure would increase considerably. McMillan (1965) estimated that the total amount of water required to produce 1 kg of steak was 110 t, and to produce 1 kg of wool was 1000 t. Such information may seem more appropriate to the Guinness Book of Records, but it does serve to emphasise a recurrent theme throughout this and the other research reports in this series on water and livestock. The theme is that one cannot look at animal water use in isolation from the general metabolism of the animal, or water development to the exclusion of the overall production system for which it is required. The ramifications of research on water and livestock are numerous, and it is difficult to know where to draw the line.

The problems of providing water for livestock vary with different species and breeds of livestock, and the ecological zones in which they occur. It is therefore important to establish the relative importance of different animals and their distribution across the continent.

The area of interest to ILCA is sub-Saharan Africa, whose southern limit is the border of the Republic of South Africa. The distribution of livestock by country within sub-Saharan Africa is given in Table 1. The exact numbers vary between authors; for example, Watson et al (1977) give higher figures for the Sudan than those in the table. Nevertheless, by relying mainly on one authority, FAO (1977), it is hoped that the bias will be in the same direction, namely an underestimate. There are also a number of omissions in the table, but the species on which no information is given are probably unimportant in the countries concerned. The final two columns of Table 1 express the biomass of livestock by country on a metabolic weight basis, so that the relative importance of national herds made up of different mixes of species can be compared as a percentage of the total livestock biomass in sub-Saharan Africa. It can be seen that 4 of the 38 countries account for more than half the livestock biomass, namely Ethiopia 21 %, Sudan 13%, Nigeria 9%, and Tanzania 8%. The addition of a further 3, Madagascar, Kenya and Somalia with 5% each, accounts for two thirds of the livestock biomass. On a regional basis, eastern Africa and the Horn contain 55%, francophone and West Africa 30%, central and southern Africa 10%, and Madagascar 5% of the total livestock biomass.

The use of metabolic weight for comparing the nutritional demands of livestock has its drawbacks. For example, desert animals have lower metabolic rates than animals from temperate regions (Schmidt-Nielsen, 1972) even if they are smaller in size, as is the Bedouin goat compared with the Negev mountain goat (Shkolnik et al, 1972). Also, dwarf West African livestock may have lower maintenance requirements than predicted from the exponent of 0.75, because they may reduce their endogenous heat production in response to a hot, humid environment. Nevertheless, metabolic weight seems more appropriate than a 'numbers' approach which overemphasises the importance of smallstock, or the conversion of numbers to livestock units (LUs). The problem with LUs is that there is a twofold difference in size between breeds of the same species in different regions of the continent; thus different countries use LUs of different weights. Dahl and Hjort (1976) list eight different units, with ratios of smallstock to cattle which vary from 2:1 to 12:1.

Table 1. Livestock numbers and biomass per country in sub-Saharan Africa, 1976.

Country	Livestock numbers ('000 head)								Biomass	
	Donkeys	Horses	Mules	Camels	Cattle	Goats	Pigs	Sheep	Million kg$^{0.75}$	% of total

Angola	5	1	0	0	3000	910	360	205	155	1.7
Benin	1	6	0	0	800	840	365	850	59	0.6
Botswana	40	9	2	?	2200	1050	19	425	118	1.3
Burundi	0	0	0	0	800	653	32	311	46	0.5
Cameroon	64	59	?	0	2655	1633	412	2105	170	1.8
Central Afr. Rep.	1	0	0	0	610	566	62	76	35	0.4
Chad	300	145	?	310	3658	2424	6	2424	258	2.8
Congo	0	0	0	0	50	101	44	52	4	0.0
Djibouti	3	0	0	25	18	580	?	98	9	0.1
Equatorial Guinea	?	?	?	0	4	7	8	31	1	0.0
Ethiopia	3860	1510	1420	960	25963	17064	17	23065	1958	21.1
Gabon	0	0	0	0	5	64	5	59	1	0.0
Gambia	4	0	0	0	310	94	8	95	16	0.2
Ghana	25	4	0	0	1100	2000	400	1800	94	1.0
Guinea	3	1	0	0	1550	385	35	420	80	0.9
Guinea Bissau	3	0	0	0	258	180	176	70	17	0.2
Ivory Coast	1	1	0	0	600	1000	210	1000	50	0.5
Kenya	150	2	0	564	7500	4100	67	3611	461	5.0
Liberia	0	0	0	0	35	175	93	176	6	0.1
Madagascar	1	2	0	0	9842	1300	680	700	483	5.2
Malawi	?	?	0	0	700	739	189	88	43	0.5
Mali	400	150	?	178	4080	3929	25	4219	303	3.3
Mozambique	20	?	?	0	1420	570	183	132	76	0.8
Namibia	63	42	5	?	2850	2000	33	5000	201	2.2
Niger	350	200	?	260	2760	5100	27	2300	243	2.6
Nigeria	700	250	?	17	11300	23000	900	7900	871	9.3
Rwanda	?	0	0	0	717	570	75	252	42	0.5
Senegal	196	226	?	25	2380	873	160	1689	162	1.8
Sierra Leone	0	0	0	0	305	179	36	68	17	0.2
Somalia	22	1	21	2000	2600	8000	8	7000	413	4.5
Sudan	672	20	1	2827	15395	10105	7	15262	1186	12.7
Tanzania	162	?	0	0	14362	4602	24	2900	738	8.0
Togo	2	3	0	0	235	630	270	750	28	0.3
Uganda	16	0	0	?	4900	2150	190	1100	260	2.8
Upper Volta	180	100	?	5	1900	2300	150	1300	137	1.5
Zaire	0	1	0	0	1144	2256	627	711	91	1.0
Zambia	1	0	0	0	2300	283	36	50	110	1.2
Zimbabwe	93	10	1	0	6100	2050	200	770	315	3.4

Source: Numbers derived from FAO (1977), and zeros from ILCA (unpublished observations).

There is a strong correlation between metabolic rate and body water turnover; a lower metabolism uses less water for the transfer of nutrients and for evaporative cooling because it generates less heat. Thus the metabolic rate and water turnover are higher in young and highly productive animals, and lower in older and less productive animals (Macfarlane et al, 1966a). The rate at which mammals use water is slightly faster than the rate at which they use energy because water is used in cooling as well as metabolism. Water turnover is best expressed in relation to the size of the body water pool rather than the bodyweight, since the body contains varying amounts of fat and bone. In desert ruminants, turnover has been found to vary with the size of the body water pool to the power of 0.82 (Macfarlane and Howard, 1972). There is more scope for divergence from the mean exponent for water turnover than for metabolism, because water conservation and non-evaporative mechanisms for heat dissipation are much more highly developed in some species than in others.

Nevertheless, an approximate idea of the relative demands of the different species of livestock in sub-Saharan Africa for forage and water may be obtained from their metabolic biomass and the exponent relating body water turnover to pool size (Table 2). The foregoing calculations indicate that of the available forage and water resources cattle take nearly 70%, sheep and goats 10% each, camels and equines 5% each, and pigs 1%. Cattle are thus seven times as important as any other species on a continental basis, and the zebu is therefore the main focus of this report.

Table 2. Relative demand for water and forage of different species of livestock in sub-Saharan Africa.

			Metabolic biomass ($kg^{0.75}$)		Functional biopool[a] ($1^{0.82}$)	
Species	**Number ($\times 10^6$)**	**Mean weight (kg)**	**($\times 10^6$)**	**(% of total)**	**($\times 10^6$)**	**(% of total)**
Donkeys	7.2	125	269	2.9	281	2.9
Horses	2.7	250	172	1.8	189	1.9
Mules	1.5	188	74	0.8	79	0.8
Camels	7.2	312	533	5.7	594	6.1
Cattle	136.4	165	6 280	66.7	6 701	68.5
Goats	104.5	20	988	10.5	909	9.3
Pigs	6.2	40	99	1.0	96	1.0
Sheep	89.1	25	996	10.6	932	9.5
Total	354.8		9 411	100.0	9 781	100.0

[a] Body water pool (1) taken as 70% of liveweight (kg).

Source: Weights from ILCA (1979a); Wilson (1978b), and J.M. King (unpublished).

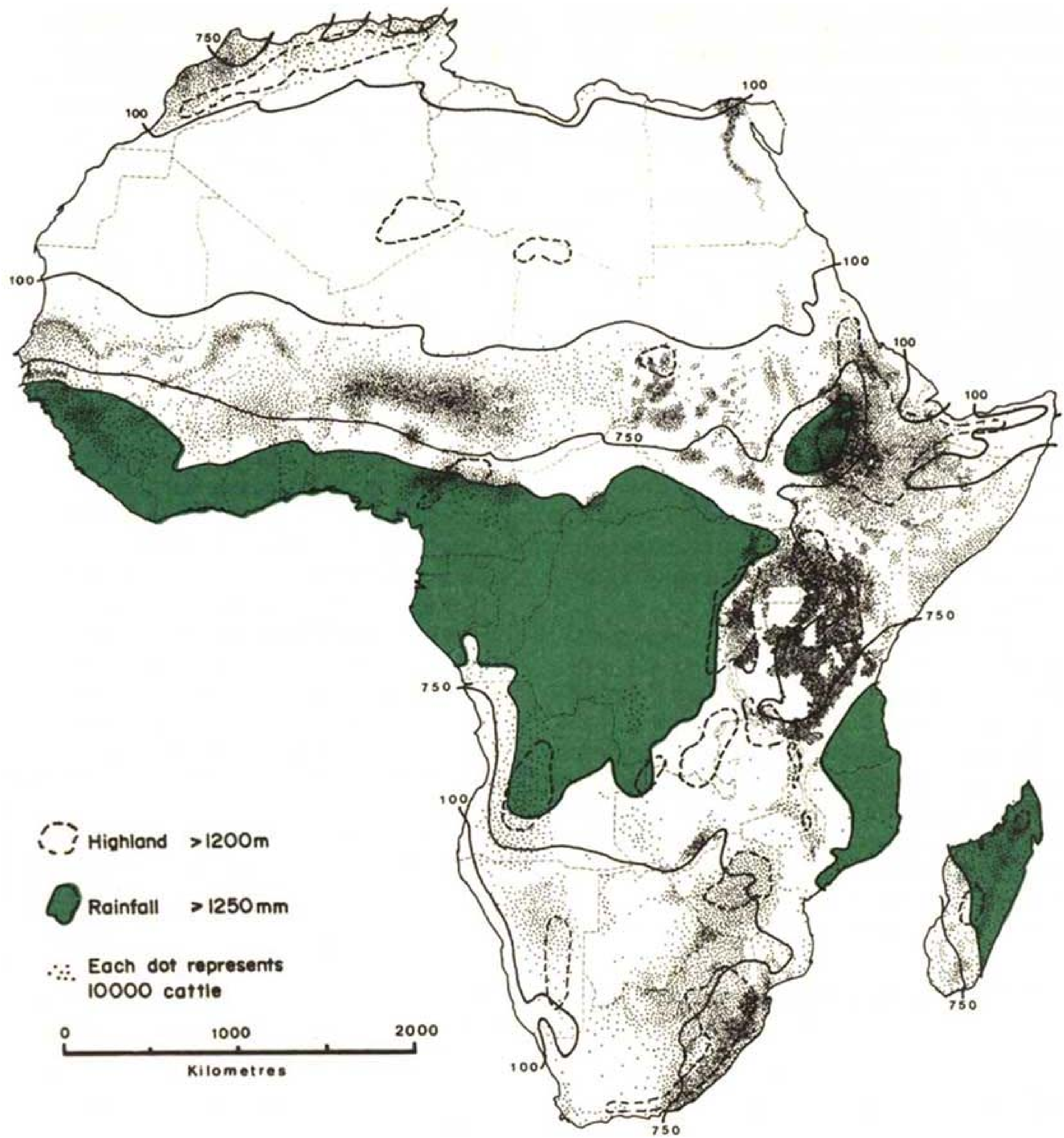
The relation of livestock to the water resources of Africa may be inferred from Figure 1, in which the highland contour (1200 m a.s.l.) and some rainfall isohyets have been superimposed on the distribution of cattle. The distribution of other breeds of livestock in relation to cattle is as follows: camels, donkeys, desert goats and sheep occupy the arid flank, intermediate breeds of smallstock and equines occur with cattle, and pigs and small or dwarf varieties of sheep and goats occupy the humid flank. The isohyets in Figure 1 are those for: 100 mm, which is the limit for cattle distribution except in the presence of irrigation; 750 mm, demarcating the edge of the dry Sahelian zone; and 1250 mm for the humid end of the Sahelo-Sudanian zone. The rainfall in most of Africa does not exceed 1250 mm and, in those regions, values for the Penman estimate of annual potential evaporation vary from about 1200 mm in the highlands to 3100 mm at sea level (Wood-head, 1968). Computation of the index of water available for plant growth in East African rangeland (Woodhead, 1970) indicates a shortage of water for 2 to 9 months of the year depending on the altitude, the amount of precipitation and whether the rains are unimodal or bimodal. Similar relations for rangeland production and rainfall have been produced by Le Houérou and Hoste (1977) for the whole Sahelo-Sudanian zone. The more humid areas of West, central and East Africa are of limited value for livestock production because of the tsetse fly (Ford, 1971). Trypanotolerant cattle do occur in the tsetse belt (ILCA, 1979a) but they represent only about 5% of the cattle population of sub-Saharan Africa.

The number of countries in sub-Saharan Africa in which there is an annual shortage of water and grazing for livestock, and the possibility of a severe drought, is 27 out of a total of 38. Admittedly, 10 of these countries have highland areas in which the majority of the national herd are kept - for example, 80% of the livestock of Ethiopia and Kenya (ILCA, 1977; Chemonics and Hawkins, 1977). Other countries, such as Mali, Sudan and Chad, have extensive river and lake floodplains. Nevertheless, after allowance has been made for the water resources in each country, which are considered in more detail by Classen et al (in press), it is probably true to say that 50% of the livestock of sub-Saharan Africa occur in areas where there is a shortage of water and forage at some time during the year.

There is thus a sizeable livestock population at risk during the dry season, of the order of 175 million head. These animals are not raised under commercial ranching conditions of the kind found in the arid areas of the more industrialized countries, such as Australia or the USA. They are kept to provide the daily subsistence of people living frequently on agriculturally marginal lands, peripheral to centres of power, assistance and investment, and with few options open to them in the face of adverse environmental conditions.

The size of the human population largely dependent on these livestock can be estimated using the following assumptions, based on information provided by the Kenya Maasai and substantiated by Dahl and Hjort (1976): one twelfth of the cattle herd is lactating at any one time; the average daily yield of milk for human consumption is 1.5 l per lactating cow in the wet season; this amount supplies the milk component of the diet of an average member of the household, which is about two thirds of a person's dietary calorific intake. Even if only half the number of cattle given in Table 2 occur in areas where water and forage are seasonally limited, the cattle population concerned is of the order of 68 million head. Because wealthy cattle owners need additional labour and also attract more dependents, it is reasonable to suppose that the human population is somewhat larger than the milk supply will allow on the basis of Dahl and Hjort's assumptions. Thus one may assume that 5 to 6 million people are dependent on these animals for their survival, or a much larger number for part of their livelihood. The estimate of the total human population in the dry lands of sub-Saharan Africa who base their livelihood on animal production is 17 million people. Of course the whole continent is not usually affected by drought at the same time, and 'only' 100 000 to 200 000 people died when they lost about 80% of their livestock in the Sahel drought (UN, 1977). Nevertheless, the slender resources of the pastoral production system are already being exploited to the limit in many regions. For example, a Rendille tribesman in northern Kenya, weighing over 70 kg at the start of the season, may expect to have lost 10 kg by the end of it; if he drops to less than 58 kg he will be in very poor health (H.J. Schwarz, unpublished). There is only a small margin of safety left in the system, and any further degradation of the rangelands will result in drought conditions over much larger areas of Africa during normal years.

Figure 1. Cattle distribution in Africa in relation to highland and rainfall.



What are the trends in livestock numbers and management in the semi-arid rangelands of sub-Saharan Africa? The growth in numbers between the early 1960s and the mid-1970s was about 20% (Table 3). Not all this growth occurred in the semi-arid areas, in fact in parts of East Africa (D. Western, unpublished) and presumably the Sahel, herds which were severely depleted by the droughts in the 1960s and 1970s may only now have recovered to their original numbers. However the cattle numbers in many arid and semiarid parts of Africa in the mid-1970s were still estimated by Bourn (1978) to be above the optimum large herbivore biomass suggested by Coe et al (1976).

The outlook for livestock management, given generally scarce range resources, is hardly more encouraging. It is now belatedly realized that some traditional pastoral systems had achieved a well balanced ecological adaptation to their environment, maintained by a complex social structure which is closely related to the regulation of access to a limited water resource (Helland, 1980). The provision of development aid, particularly water and veterinary services, can have a very disruptive effect on such systems.

It is ironic that this realization should occur at a time when traditional livestock systems are disintegrating in the face of new technologies. It is impossible to put the clock back, but lessons must be learnt from the experiences of the past few decades. For a start, we should try to understand the production systems with which we are interfering. From the animal science point of view, this means looking more closely at the indigenous livestock. The pastoralist is primarily concerned with risk reduction strategies, given the limited resources available to him and the likelihood that they will become scarcer in the future (unless there is a dramatic breakthrough in such areas as tropical legumes and population control). For the moment the tribal herdsman achieves productivity through the survival of his stock and its rapid powers of recuperation, and by an increase in animal numbers rather than by high individual animal performance. Consequently, the introduction of temperate or locally 'improved' breeds with their higher demands for water and good quality forage may be inappropriate at present.

Table 3. Recent population numbers and trends of different species of livestock in sub-Saharan Africa.

	Million head				Population changes	
Species	**1961-65**	**1974**	**1975**	**1976**	**Million head**	**%**
Donkeys	7.31	7.04	7.11	7.19	- 0.12	- 2
Horses	2.31	2.61	2.68	2.74	+ 0.43	+ 19
Mules	1.35	1.44	1.44	1.45	+ 0.10	+ 7
Camels	6.79	6.38	6.91	7.17	+ 0.38	+ 6
Cattle	106.25	129.78	132.59	136.40	+ 30.15	+ 28
Goats	90.94	99.50	102.46	104.46	+ 13.52	+ 15
Pigs	3.73	5.83	6.02	6.22	+ 2.49	+ 67
Sheep	73.49	82.64	85.97	89.11	+ 15.62	+ 21
Total	292.17	335.22	345.18	354.69	+ 62.57	+ 21

Source: FAO (1977).

Table 4. The relative importance of different animal products in sub-Saharan Africa.

		Agricultural role[a]						
Species	**% of total biomass (kg$^{0.75}$)**	**Milk**	**Meat**	**By products**	**Draught**	**Pack**	**Riding**	**Blood**
Cattle	67	++++	+++	++	+++	+	+	+
Goats	11	+	+++	++				
Sheep	9	+	+++	++				
Camels	6	++++	++	++	++	+++	++	+
Donkeys	3				++	+++	++	
Horses	2				++	++	+++	
Pigs	1		++	++				
Mules	1				++	+++	+++	

[a] + = positive role.

Source: Table 2 and J.M. King (unpublished).

The agricultural role of the different species of livestock in sub-Saharan Africa, together with the relative importance of the different animal products, is shown in Table 4. As already indicated, the dominant animal is the zebu cow, which is a multi-purpose animal which must supply the household with milk. The average amount of milk taken per cow is about 90 kg per annum, whereas calf production is in the region of 150 kg (ILCA, 1979a). Camels take over the role of cattle in the drier areas, producing a similar weight of calf per annum but with more milk (1460 kg) being taken for human consumption (section 5.2.2). The percentage of the cattle herd kept for power varies from 0% in many pastoral communities to between 30 and 50% of the herd in the dryland farms of the Sahel and Botswana, and the highland farms of Ethiopia (Reed et al, 1974; ILCA, 1978; ILCA, 1979c). A figure of 15% for camels in Southern Darfur is given by Wilson (1978a). Smallstock are kept primarily for meat, although byproducts such as hides, skins for water bags, and wool may make an important contribution to the household economy. Pigs and small and dwarf breeds of ruminant livestock occur in the more humid zones where water is not a major constraint to production. They will therefore receive little attention in this report. The other species, with the exception of the horse and mule which make up only a small proportion of the total livestock population, will be considered in some detail.

The emphasis of this report is on livestock water and energy turnover in the dry season under the present range management conditions in Africa, and those predicted for the immediate future (chapter 5). The implications and applications of this information to management, development and research will be discussed in chapters 6 and 7. However, before embarking on the more practical aspects of the problems of animal water needs in relation to climate and forage, a considerable part of the report has been devoted to general physiological principles (chapters 2, 3 and 4). These chapters on body water, water balance and factors affecting water turnover describe some of the components of a water and energy model. The examples of physiological mechanisms are not confined to conventional livestock if the mechanisms are better understood or developed in other species, especially African game animals.

The reason for this description of fundamental physiology is that, once the animal scientist has grasped the underlying principles, he should be able to model his own field situation if this differs from the examples given. However, it is equally appropriate for the more casual reader to turn from this introduction to chapter 5 onwards, and treat the intervening sections as reference material.

2. Body water

In order to understand livestock water needs and how water dependence varies in different circumstances, it is necessary to look at body water functions in livestock, starting with the way water is stored and distributed in the animal.

2.1 Functions

Under semi-arid conditions and a daily watering regime, indigenous livestock in Africa use, or turn over, between 5 and 30% of their body water pool (defined in section 2.2) daily, depending on animal species and season (King, 1979). This water is used for two main functions; intermediary metabolism and cooling.

Intermediary metabolism includes all the biochemical reactions and interconversions that take place in the animal. Water acts as a solvent of absorbed particles, including gases, conveying them to and from their sites of metabolism. The resultant solutions osmotically control the distribution of fluids within the body compartments, with the aid of various feedback regulating mechanisms. This aspect of the subject is beyond the scope of this report, but for those who wish to pursue it further the main components of the intermediary metabolic system are described by Siebert (1973).

In most herbivores in sub-Saharan Africa, the major function of water is to dissipate internal or absorbed heat by evaporative cooling through sweating or panting.

The flows of water and energy through the animal body have been simplified and combined in Figure 2. Most of these flows can be quantified, and an energy and water budget measured. For example, in zebu cattle in the Kenya highlands during the day, the main heat exchanges have been shown to be absorption of shortwave solar radiation and emission of longwave radiation by the coat (Table 5). About 1% of the energy exchanged is heat which is absorbed and stored during the day and dissipated at night. In the tropical lowlands, the environmental heat load is higher and evaporative heat loss more important.

2.2 Body water pool

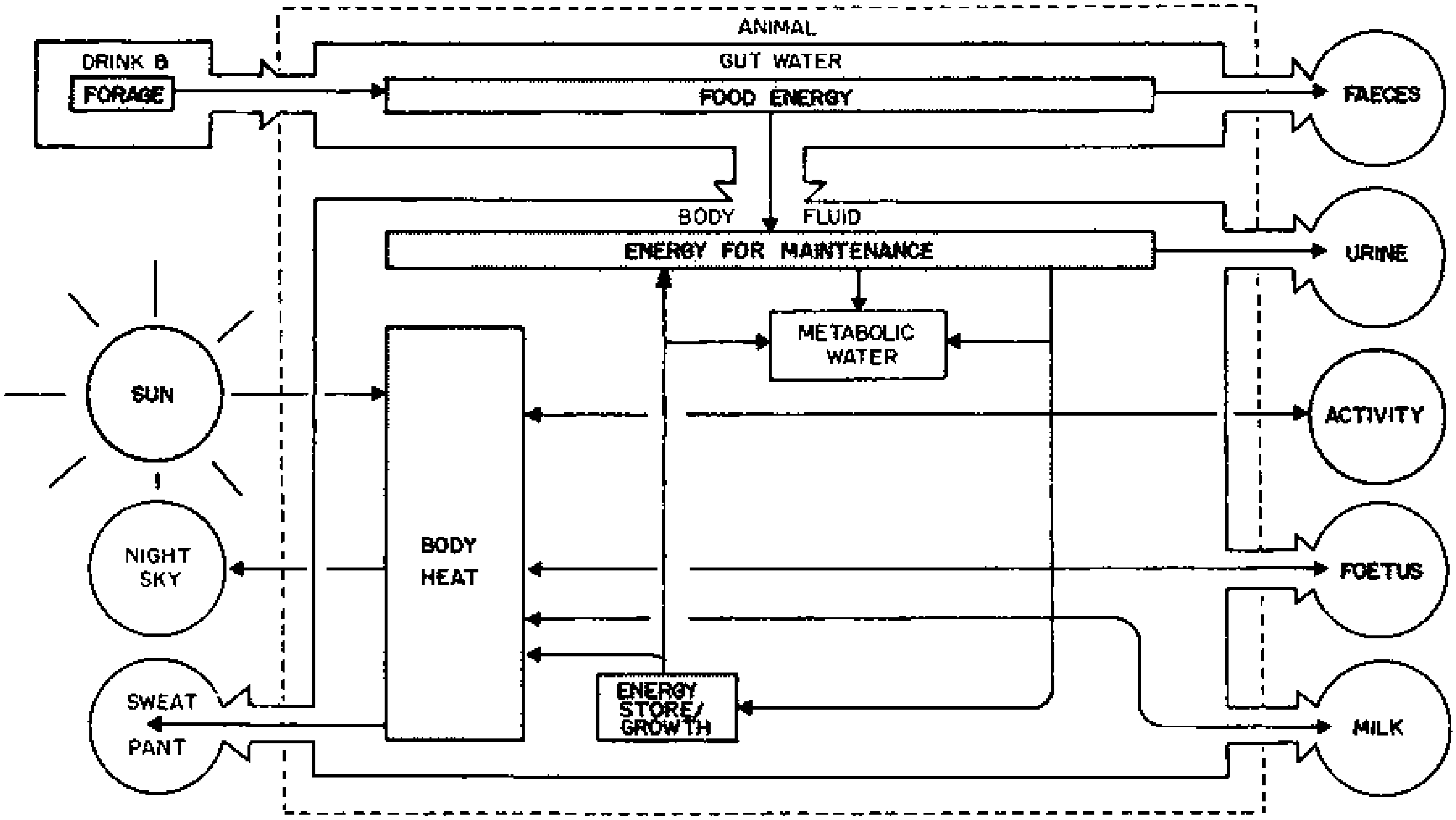
About 99% of all molecules in the body are water, which forms about 70% of the bodyweight of a tropical ruminant (Macfarlane and Howard, 1972). Its distribution through the body water compartments is fairly constant if the alimentary tract and fat content of the animal are excluded: about 45% of bodyweight is intracellular water and 25% is extracellular, divided between plasma (5%) and interstitial fluids (20%).

Table 5. Energy budget of a zebu steer from 09.00 to 15.00h in a near-natural environment at 1430 m altitude in Kenya.

Heat exchange	% of net gain	% of net loss
Absorption of shortwave solar radiation	71	
Metabolic heat production	29	
Longwave re-radiation from coat		57
Sweating		21
Conduction and convection from skin		16
Respiratory evaporation		5
Total	100	99

Source: Finch (1976).

Figure 2. Water and energy flow through an ungulate in Africa.



The total body water pool is all the water in the animal including the alimentary tract, which has a large volume, particularly in ruminants. The moisture content of the reticulo-rumen seldom falls below 85%, even on a dry diet (Macfarlane, 1971). Based on this moisture content, the average contribution of reticulo-rumen water to total body water has been calculated for a variety of African ruminants (Table 6), classified according to feeding habits (Hofmann, 1973). The volume of rumen contents may vary by nearly 100% between the wet and dry season or even on alternate days in livestock on a 2-day watering regime, when sheep drink 18% of their total body water pool, goats 20%, zebu cattle 14% and camels 10% (King, 1979). Larger fluctuations are associated with enforced dehydration.

The proportion of body water in the other carcass components of a ruminant are given in Table 7, using as an example a 2-year-old Boran steer fed a dry maintenance ration. It can be seen that the components with the lowest water content are bone and fat, although the values are higher than the 20% and 6-20% respectively reported by Brody (1945), presumably because of a higher proportion of connective tissue. Bone is relatively inert, but fat represents the main energy pool of the animal, with a value of 39.3 $kJ.g^{-1}$ compared with protein at 18.0 $kJ.g^{-1}$ and carbohydrate at 17.6 $kJ.g^{-1}$ (Lusk, 1931). Thus the energy value of the carcass of most domestic animals has been derived from analysis based primarily on the fat content (Callow, 1947). Because of its low water content an increase in the proportion of body fat is often associated with a decrease in percentage body water pool. At birth, the fat content of the body is negligible and the body water pool is about 77% of bodyweight. As the animal matures, fat is deposited until it accounts for up to 35% of bodyweight in ruminants in temperate regions, while total body water can drop to 50%. It is difficult to measure the fat content of a live animal directly, but it has often been estimated indirectly from the tritium-predicted body water pool (e.g. Shumway et al, 1956; Searle, 1970). When this technique was applied to the zebu in Africa (King and Finch, 1982), the following regression was obtained:

$y = 60.46 - 0.801\ x\ (r^2 = 0.798, P < 0.001)$

where y equals dissectable body fat, and x equals tritium-predicted body water pool, all expressed as a percentage of bodyweight of zebu steers with a dissectable body fat of <10%. Although the inverse relationship was expected, it was not easy to explain in lean, starving animals in which the proportions of other components with very different water contents, such as bone and hide, were also changing. The use of such prediction equations outside the conditions in which they were derived is therefore unwise. As Webster (1978) has remarked, 'The quite common predictive use of correlations between marker dilutions and the contents of compartments they do not mark, is a thoroughly bad habit'. One can reduce the error by using the approach of

Little and MacLean (1981), who noted that in castle and sheep the sum of total body water plus total body fat minus the DM content of the alimentary tract was virtually 80% of the fasted bodyweight.

2.2.1 Water storage

The long held belief that there are sacs in the forestomachs of the camel specifically for storing water has been refuted by Schmidt-Nielsen (1965). Nevertheless, after drinking water moves two or three times more slowly from the reticulo-rumen to the blood in camels than it does in cattle (Siebert and Macfarlane, 1971). The release of ingested water through the kidney does not start until after 1 day in camels, compared with 12 h in Merino sheep, and 4 h in *Bos taurus* cattle (Macfarlane and Howard, 1972). The main purpose of this retention is to prevent hypotonic solutions passing into the bloodstream until salts have been added. Nevertheless the result is some degree of water storage, particularly in the more arid-adapted animals.

Table 6. Proportion of total body water in the reticulo-rumen of some African animals classified according to feeding habits.

Grazers		Mixed feeders		Selective concentrate feeders	
Species	**%**	**Species**	**%**	**Species**	**%**
African buffalo	20	Haired sheep	24	Grey duiker	12
Wildebeest	18	Haired goat	24	Suni	10
Zebu	17	Eland	15	Steenbok	9
Oryx	15	Thomson's gazelle	15	Bushbuck	9
Hartebeest	14	Camel	13	Dik-dik	9

Source: Schmidt-Nielsen (1965); Hofmann (1973); King et al (1975); Kay et al (1980).

Table 7. Water content of carcass components of a 2-year-old Boran steer.

Carcass component		Water content	
	Weight (kg)	**%**	**l**
Slaughter loss	7.0	80[a]	5.6
Blood	7.2	81	5.8
Hide	18.0	67	12.0
Horns	-	-	6.9
Head	13.0	54	
Feet	6.0	49	2.9
Heart, diaphragm, respiratory, urinary and genital tracts	5.6	72	3.8
Urine and bile	0.1	90[a]	0.1
Liver	2.4	72	1.7
Contents of forestomachs	18.8	86	16.1
Contents of small intestine	4.3	90	3.9
Contents of large intestine	4.9	82	4.1
Gut wall	10.9	80	8.8
Dissectable fat: internal	3.4	40	1.4
Dissectable fat: subcutaneous, intermuscular, hump	11.2	47	5.3
Butcher's bone: legs	14.6	20	2.9
Butcher's bone: loin	2.8	42	1.2
Butcher's bone: neck and thorax	7.7	34	2.6
Carcass lean	74.3	75	56.0
Kidney	0.3	75	0.3
Dissection loss	3.6	80[a]	2.9
Total or average	216.1	67	144.3

[a] Estimate

Source: J.M. King and V.A. Finch (unpublished).

Water also appears to be stored in the extracellular and intracellular fluid spaces in some ungulates under certain environmental conditions, judging by their tolerance of 15 - 20% dehydration without depression of appetite and lactation. For example, Shkolnik et al (1972) reported expanded plasma volumes in Bedouin goats associated with high tritiated water (TOH) spaces, although their figures of 85% TOH spaces may need downward correction. It has also been shown in cattle and buffaloes in the tropics that, as the water turnover rate increases in response to heat stress, the body water pool enlarges (Siebert and Macfarlane, 1969; Kamal and Sief, 1969).

These illustrations suggest that there is a need to re-examine the concept that a camel drinks 'for the past' and not 'for the future'. It certainly drinks to make up a deficit, but its intake may also include a provision for the future.

2.2.2 Oedema

The oedematous condition is characterised by an excessive accumulation of fluid in tissue spaces. Fluid normally passes into these spaces from the arterial end of the capillaries, where the hydrostatic pressure of the blood is greater than its osmotic pressure. It will stay there if the position is not reversed at the venous end of the capillaries or if there is a blockage of lymphatic drainage (Schmidt-Nielsen, 1975).

A non-pathological oedematous condition is said to be achieved by camel traders, who allow a very thirsty camel to drink its fill after it has been given a large dose of salt. The resultant subcutaneous oedema can make a thin camel look temporarily well covered (Williamson arid Payne, 1978).

There are numerous cases of pathological oedema in African livestock, frequently associated with a reduced blood osmotic pressure due to hypoproteinaemia. For example, failure of amino-acid anabolism is associated with malnutrition and liver disease; continuous haemorrhage from the gastrointestinal tract, resulting in a loss of blood volume and erythrocytes as well as plasma protein, is caused by infestations of blood sucking nematodes, or by coccidia or salmonella; trypanosomes destroy erythrocytes. As a result, fluid drains to the dependent parts of the body, notably the submandibular space, brisket and abdomen. Oedema of the limbs, scrotum or vulva are additional features of trypanosomiasis in the horse (Blood and Henderson, 1960; BVA, 1976).

During starvation there comes a point when the energy reserves of the animal have become severely depleted and the rise in total body water changes from a physiological to a pathological condition, probably associated with a rise in extracellular fluid volume (Macfarlane et al, 1966c; Springell, 1968). The stage at which this occurs in the zebu must be shortly after the dissectable fat reserves have been exhausted, when its total body water pool is 70% of its liveweight (King and Finch, 1982). The clinical picture of oedema can be complicated by dehydration and, in acute cases, by peripheral circulatory failure and anaemic anoxia (Blood and Henderson, 1960).

Blockage of the lymphatic or venous drainage occurs following liver fibrosis and obstruction of the hepatic portal. For example, liver flukes cause ascites - an accumulation of fluid in the abdominal cavity. Cardiac insufficiency, due to endocarditis or pericarditis will also cause oedema. The resultant congestion of the lungs is a common terminal event (Blood and Henderson, 1960). In East Coast fever in cattle such congestion may also be due to a terminal anaphylactic reaction (A.D. Irvin, unpublished), which is another cause of oedema.

3. Water balance

In all animals, the body water pool must remain reasonably constant in the long term, although livestock adapted to arid areas may be able to tolerate fairly large short-term fluctuations. As already suggested, animals drink primarily to replace lost fluid, rather than in anticipation of future needs. Thus water loss largely dictates water gain, and will therefore be dealt with first. The size and speed of body fluid loss is affected partly by the factors outlined in chapter 4 and partly by the tolerance of the particular species or age group to dehydration.

3.1 Dehydration

The symptoms of dehydration as described in man probably apply also to animals, although at greater levels of body water depletion. In man, signs of thirst are very strong when as little as 2% of bodyweight has been lost, but do not get progressively worse as dehydration proceeds; after 4% weight loss the mouth is very dry and at 8% the tongue is swollen and speech difficult. Severe thirst and some mental derangement are apparent at 10%; at 12%, recovery is only possible with some assistance and it may be necessary to give fluids by injection or *per rectum*. The actual lethal limit for man is probably between 15 and 25% of bodyweight (Mount, 1979).

By contrast, a 10% decrease in fat-free bodyweight (i.e. a 9% weight loss in a tropical ungulate) represents only moderate dehydration. It is countered by withdrawing fluid from the alimentary tract, from tissue spaces and then from the cells to maintain circulating blood volume, provided that the osmotic pressure of the blood is sufficiently high. Essential parts of the body, including the central nervous system, heart and skeleton, contribute little of this water: the major loss occurs from connective tissues, muscle and skin. Consequently the first and most important clinical sign of dehydration is dryness and wrinkling of the skin which subsides slowly after being picked up into a fold. It gives the body and face a shrunken appearance. The eyeballs recede into the sockets, but this is due to pert-orbital fat loss. According to Blood and Henderson (1960), there is an increase in tissue metabolism of fat, then carbohydrate and finally protein to produce metabolic water, but Schmidt-Nielsen (1975) pointed out that much of the water produced in this way could be used up dissipating the heat associated with its production. Loss of bodyweight occurs rapidly, along with muscular weakness, lack of appetite and increased thirst. The increased tissue metabolism under relatively anaerobic conditions results in the formation of acid metabolites, acidosis, and therefore a rise in the respiratory rate. The temperature rises slightly, the heart rate increases and the pulse has a small amplitude and low pressure (Blood and Henderson, 1960).

In a hot environment, the signs of more severe dehydration (15 to 30% decrease in fat-free bodyweight) are acute. The immediate source of water loss is from the bloodstream. If the water is not replenished, the blood becomes more viscous, placing an additional load on the heart. The heart responds by an increase in stroke rate but a decrease in stroke volume, causing a decrease in blood circulation. As a result the body temperature rises, because one of the most important functions of the bloodstream is heat transfer from the body core to the skin. If this condition is not reversed by spraying or immersion in cold water plus rehydration, death will occur as a result of an explosive rise in body temperature, rather than as a direct effect of water depletion. Clinical signs of hyperthermia occur in many animals at a rectal temperature of about 39.5°C. Heart and respiratory rates increase, with a weak, large-amplitude pulse, and nervous system activity is depressed, so that the animal becomes dull, stumbles while walking and tends to lie down. When the temperature reaches 42.0°C, respiration is laboured arid general distress is evident. Beyond this point the pulse becomes very rapid and weak, and respiration shallow and irregular. The prime cause of death is probably from depression of the respiratory centre in the brain. Collapse, convulsions and terminal coma occur-in most species when a temperature of about 42.0°C is reached (Adolph and Dill, 1938; Blood and Henderson, 1960; Schmidt-Nielsen, 1975).

The most common cause of dehydration in a hot environment is loss of water due to evaporative cooling. Water turnover rates have not been measured in dehydrated animals in sub-Saharan Africa, but a study was carried out with camels, cattle and sheep in the Australian desert, where the maximum ambient temperature was 42°C and solar radiation was measured at 1160 for W.m^{-2}. The cattle (*Bos taurus*) lost 7-8% of their body water per day and survived for 3-4 days, Merino sheep lost 4-6% per day and lived for 6-8 days and camels lost 1-2% and survived for 15-20 days (Macfarlane and Howard, 1972).

In a cooler environment, death from dehydration occurs more slowly, with a deterioration of body functions occurring at a greater degree of dehydration. Much of this deterioration can probably be related to the breakdown of the normal functions of the blood. The most important of these functions include: transport of nutrients, metabolites, excretory products, gases, hormones, and non-respiratory blood cells, transfer of heat, and transmission of force for ultrafiltration in capillaries and kidneys (Schmidt-Nielsen, 1975).

The commonest cause of dehydration in cool environments is diarrhoea, which is often combined with systemic states such as toxaemia or septicaemia. Any form of gastro-intestinal impaction, obstruction or distension also produces dehydration by stimulating saliva and gut secretions (Blood and Henderson, 1960). In sub-Saharan Africa, scours and heat stress frequently occur together and are probably the main cause of death in young stock.

The ability to withstand dehydration has been ascribed to the maintenance of a normal plasma volume. This volume is maintained primarily by the osmotic pressure of the plasma proteins. These proteins leak out of the vascular bed much more quickly in animals such as cattle (*Bos taurus*), which are not arid-adapted, than in camels, which are good at maintaining their plasma volume (Siebert, 1973). In man, the most important event in heat acclimatization is the expansion of the plasma volume (Senay et al, 1976). Lactating Bedouin goats are reported to have an expanded plasma volume of 8.5% bodyweight, which means that there can be a 40% reduction before the plasma volume equates with the 5% value found in most other ruminants (Shkolnik et al, 1979). Similar sized reductions in plasma volume have been recorded in Indian desert sheep, but it is not clear whether the initial plasma volume was an abnormally large proportion of bodyweight (Purohit et al, 1972). Although the plasma volume decreased, the plasma sodium concentration remained constant, associated with a doubling of urinary sodium levels (Gosh et al, 1976).

3.2 Channels of water loss

Under African ranching conditions, livestock use 5 to 30% of their total body water pool per day (King, 1979). This loss is reduced to as little as 1.5% in dehydrated, arid-adapted animals such as the camel (Schmidt-Nielsen, 1965).

There are four main avenues of water loss: evaporation, urine, faeces and lactation.

3.2.1 Evaporation

Evaporative cooling may account for 20 - 30% of the total dissipation of the effective radiative heat load in a tropical ruminant and 80% of the water loss (Taylor, 1972; Finch, 1972b). In addition there is an obligatory water loss from the respiratory tract which is probably >10%, and a small insensible water loss through the skin (King and Finch, 1982). In general biological terms, the smaller the animal the larger the surface area to volume ratio and thus the greater the efficiency of evaporative cooling. On the other hand, the larger the animal the greater the volume per unit surface area and hence the larger the water reserve which can be used for evaporative cooling (Edney, 1966).

The relative contribution of sweating or panting to evaporative heat dissipation in a number of different domestic animals is shown in Table 8. Among ungulates in Africa, buffaloes, camels, cattle, donkeys and some of the larger antelopes sweat, whereas wildebeest, oryx, sheep, goats and many smaller gazelles pant. Insensible perspiration and non-panting respiratory heat loss account for a relatively small amount of the total loss in hot, dry conditions. Although panting seems to be completely adequate as the sole means of heat loss among sheep, sweating can also be important in closely shorn or haired sheep over the first few hours of heat stress (Hofmeyr et al, 1969; Taylor et al, 1969; Jenkinson, 1972).

Table 8. The relative contributions (%) of sweating and panting to evaporative heat loss in various domestic animals in a hot, dry environment.

	Relative contribution (%) to evaporative heat loss					
	Donkey	**Camel**	**Cow**	**Sheep/goat**	**Dog**	**Pig**
Sweat	100	95	65	40	10	0
Pant	0	5	35	60	90	100

Source: Jenkinson (1972).

There are a number of reasons why smaller animals, with their relatively higher heat production and absorption, should pant rather than sweat. Panting appears to be the more efficient of the two methods of evaporative cooling. Both methods use latent heat from the body core, but sweating can also use solar radiation on the body surface. Panting also provides its own airflow over moist surfaces, thus facilitating evaporation. Salt and electrolytes are not lost, as in sweating, unless the saliva drips out of the mouth. Finally, panting cools the nasal and oral passages whence cool blood flows into the venous sinus, bathing the carotid plexus. Thus the blood supply to the brain can be kept cool, even when the body temperature is rising (Taylor and Lyman, 1972). The disadvantages of panting include a risk of respiratory alkalosis, particularly in the goat (Jenkinson, 1972), and the increase in work and therefore heat production by the respiratory muscles. However, much of this work is reduced by the elastic property of the respiratory system, which has its own natural frequency of oscillation. The high respiratory rate associated with panting has the effect of keeping the system oscillating at its own resonant frequency with the minimum of muscular effort. Thus, the thermoregulatory efficiency of panting is high in such species as sheep, which show no increase in total body heat production above normal levels (Hales and Brown, 1974).

As 1 g of water changes from liquid to vapour, whether by panting or sweating, it binds about 2425 J of heat. In terms of heat exchange this is a very efficient use of water when it is realized that to heat 1 g of water from freezing to boiling point requires only 490 J. Nevertheless, evaporation can represent a very significant loss of body water. A fully hydrated camel weighing 260 kg lost 91 of water a day through sweat when standing in the desert sun. This quantity represented a loss of 4% of total bodyweight, and a loss much in excess of 25% would probably be fatal. Assuming that heat load and therefore evaporation are proportional to body surface, then water loss under hot, desert conditions increases exponentially with decreasing size. There is very little difference in water loss per hour in the camel at 1.0%, and man at 1.5%, but the rate in animals weighing 2.5 kg is nearly 5%. Many animals also have lower lethal limits than the camel (Schmidt-Nielsen, 1965). The need to preserve vital functions, as an animal becomes dehydrated, results in a reduction in the rate of evaporative cooling. The sequel to this reduction is either a rise in body temperature or a depression of heat production.

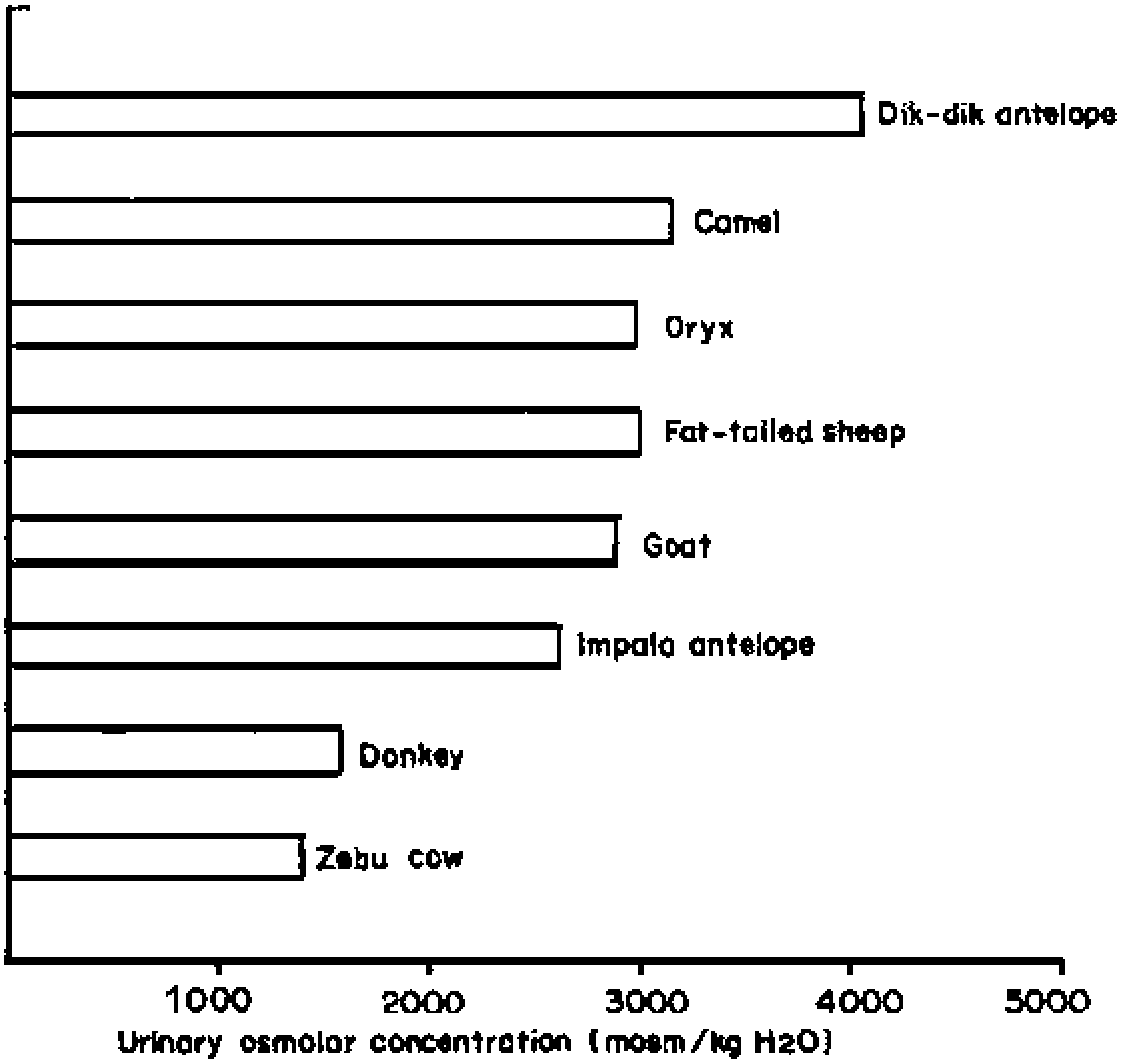
Pathological conditions of the respiratory tract and skin may interfere with normal evaporation. For example, dermatitis from mange mites, virus pox or bacteria may result in excessive fluid exudate and require parenteral administration of fluids (Blood and Henderson, 1960).

3.2.2 Urine

Livestock species vary in terms of their ability to concentrate urine and/or decrease renal urine flow and retain metabolites in the body fluids. Camels, sheep and goats are better adapted to arid conditions in this sense than zebu cattle or donkeys, as shown in Figure 3 (Maloiy and Taylor, 1971; Maloiy, 1972). Although less water tends to be lost from the body through urine than through the faeces, the scope for varying urine concentration and flow is greater. Thus, the desert sheep is only 30% more efficient than the zebu at extracting moisture from its faeces but at least 100% more efficient at concentrating its urine.

Among African ungulates, the highest levels of urine concentration have been recorded for the gerenuk and dik-dik at over 4000 mosm.kg^{-1} (Hoppe, 1976) - a low figure compared with desert rodents, which can concentrate their urine to over 9000 mosm.kg^{-1} (MacMillen, 1972). The reason for the difference may be that large animals cannot avoid high environmental heat loads, and therefore have high water losses from evaporation. The amount of water saved by concentrating their urine is relatively little compared with that lost by evaporation. In contrast, the entire water balance of small rodents living in burrows can be designed round an efficient renal mechanism for water conservation (Schmidt-Nielsen, 1972).

Figure 3. The maximal urinary osmolar concentrations of several East African mammals under severe dehydration.



Source: Maloiy (1972)

Diseases of the urinary system will upset the normal water balance of the animal but are masked by symptoms of pain and toxaemia. The commonest pathological conditions are cystitis and pyelonephritis in cows following a difficult parturition, and urolithiasis in castrated males (Blood and Henderson, 1960).

3.2.3 Faeces

Faecal water is a potentially larger source of water loss than urine. This loss is not confined to exogenous water, because half the total body water pool can pass through the salivary glands and rumen per day. Therefore the ability to extract and reabsorb faecal water in the colon is important. A breakdown of the water reabsorption mechanisms in the large intestine results in diarrhoea and can cause dehydration. *Bos taurus* cattle can reduce faecal moisture content to 60%, sheep to 50% and camels to 45% (Macfarlane, 1964). The observation that the faeces of zebu cattle contain less water than do those of European cattle in the same dietary and environmental conditions (Quartermain et al, 1957) may explain in part the lower water requirement of the zebu (Phillips, 1960). Even in donkeys, faecal water content seldom drops below 60%, so that in this species and cattle, one third to one half of the total daily water loss is in the faeces (Schmidt-Nielsen, 1965).

Table 9. Average composition of milk from indigenous arid-adapted Ethiopian livestock and temperate-type cattle.

Constituent	Milk composition (%)				
	Barka cattle	**Adal goats**	**Adal sheep**	**Adal camels**	**Temperate-type cattle**
Moisture	86.1	88.2	86.4	85.6	87.6
Ash	0.6	0.6	0.6	0.9	0.7
Protein	3.8	3.3	4.4	4.5	3.2
Ether extract	5.0	2.9	4.1	5.5	5.4
Carbohydrate	4.5	2.8	3.7	3.4	4.8

Source: Knoess (1977); Williamson and Payne (1978).

3.2.4 Lactation

Milk production represents a severe drain on the water resources of an animal. The water turnover of lactating camels and sheep in a hot, Australian environment has been measured at 44% above that of non-lactating animals (Macfarlane and Howard, 1972), while dairy cattle in the tropics require an extra 3 l of drinking water for every litre of milk produced (Barrel and Larkin, 1974). However, the moisture content of the milk of arid-adapted ruminants is not very different from that of other livestock (Table 9), probably because the young suckling animal needs water as much as nourishment from milk.

3.3 Channels of water gain

The provision of drinking water for livestock is the main concern of this series of research reports on water and livestock. Accordingly, mean daily water requirements are given in Table 10. The problem is that drinking is only one of a number of avenues of water intake, and it may not even be the largest one. The relative importance of the different forms of water intake will vary with weather, diet and management, within a species or breed as well as between them.

3.3.1 Drink

Mean values for drinking water intake by African ruminant livestock are given in Table 10. However, when planning a water supply, the capacity is usually designed to meet the maximum requirements of the animal, both in terms of its daily requirements and the amount it can drink at one visit. The requirements in practice (Classen, 1977), have been found to be well below the theoretical maximum values obtained by deducting the contribution of respiratory and metabolic water inputs from the maximum body water turnover rates obtained in the field (King, 1979). The explanation is probably that maximum values are associated with the ingestion of a good quality forage with a high rather than low moisture content.

Table 10. Estimated daily drinking water requirements for non-lactating livestock under African ranching conditions.

		Daily drinking water requirement (1)		
Species	**Weight (kg)**	**Mean**	**Theoretical maximum**	**Practical guideline for development**
Goat	30	2.0	5.4	5.0
Sheep	35	1.9	5.2	5.0
Zebu bovine	350	16.4	56.1	25.0
Camel	500	18.4	34.0	30.0 (est.)

Source: Barrett and Larkin (1974); Classen (1977); King (1979).

The maximum amount an animal can drink at one visit to a watering point varies with its degree of dehydration and the time it is allowed to spend near the water. In many parts of East Africa, Classen (1977) found that indigenous zebu cattle drank about 23 l when watered daily, up to 35 l after a very long walk on 2-day watering regime, and a maximum of 45 l on a 3-day regime, but at the risk of water intoxication and death. French (1956b) found that mature zebu oxen on a 2-day watering regime could drink 70 l in 1 h. Following severe water deprivation, cattle, sheep, camels and donkeys can all drink a large amount rapidly (Schmidt-Nielsen, 1965). Macfarlane and Howard (1972) found that camels which were dehydrated by 20 to 25% replaced 60% of the weight lost as water (80 - 1001) in the first drink, while sheep and cattle replaced 75%. The animals replaced all the weight lost from dehydration in 1 or 2 days. Field (1977) observed that camels belonging to pastoralists at North Horr, Kenya drank three times over a period of 2.3 h and assumed that this behaviour was necessary for complete rehydration. However, where there is considerable pressure of stock on a watering point, animals may not be given a chance for a second drink. In such a situation, it is not clear whether the animal learns to drink a very large amount in a short time, or whether body water use is cut back to the smaller amount that can be replaced in one drink. Otherwise, many livestock would become more and more dehydrated as the dry season progressed. After a large drink, livestock often stagger about, then lie down and are left undisturbed for an hour or two before being moved away (R. Sandford, unpublished). Their behaviour may relate to water intoxication, or to physical discomfort resulting from mechanical interference with normal bodily functions caused by a distended rumen.

Water intoxication occurs following ingestion of excessive quantities of water, especially if a great deal of salt has been lost due to severe exercise or high environmental temperatures. The water is absorbed into the bloodstream, reducing the plasma osmotic pressure. This reduction may be sufficient to cause the erythrocytes to swell and burst, resulting in a severe haemolytic anaemia. Cellular hydration occurs, particularly in the brain, causing a condition analogous to cerebral oedema. This results in nervous signs, including muscle weakness, tremor, restlessness, ataxia, convulsions and terminal coma. It may be avoided in a susceptible animal by giving limited access to water at the first drink (Blood and Henderson, 1960).

Severe water intoxication is uncommon in ruminant livestock indigenous to the dry regions of Africa. They have developed mechanisms to cope with it, similar to those described for the camel and the Bedouin goat. In these last two species, large volumes of drinking water are retained in the rumen until the osmolality has been raised with urea and electrolytes from the extracellular fluid, especially via the saliva, and also from desert plants with a high salt content. Absorption of water is slower from the rumen than it is further down the alimentary tract. Thus the osmotic stability of red blood cells in camels, zebu cattle, and certain haired smallstock is probably never challenged (Choshniak and Shkolnik, 1978). The same appears to be true of donkeys, even though their entire alimentary tract may be flooded when they drink (Maloiy and Boarer, 1971).

McDowell (NRC, 1980) describes another form of water intoxication in studies of sheep in a hot room. Under these conditions, one in five sheep started to consume very large volumes of water with a corresponding reduction in feed intake. These sheep died as a result of starvation, due to the substitution of water for gut fill. A similar proportion of range sheep brought into feed-lots in Iran died for the same reason.

Animals that are too weak to drink may be rehydrated with isotonic fluids containing appropriate electrolytes (0.60% sodium chloride, 0.27% lactate, 0.04% potassium chloride and 0.02% calcium chloride). Oral administration is satisfactory provided gut absorption is normal. Otherwise the intraperitoneal route is preferred because a large intravenous injection may cause cardiac embarrassment. An adult bovine may be given 4 l of isotonic solution intravenously in 30 minutes without untoward effect (Blood and Henderson, 1960). Although this amount may represent nearly 20% of blood volume, it makes less than a 2% contribution to the total body water pool.

The quality of drinking water is often as important as the quantity. Water quality is affected by total soluble salt concentration, the presence of some salts specifically toxic to animals even in low concentrations, and possible contamination with disease-producing micro-organisms or their spores.

High evaporation rates from lakes and dams in Africa can raise the mineral content of drinking water; borehole water is also frequently brackish (saline). The response of livestock to highly saline drinking water is to increase their water intake, but at a certain concentration the appetite becomes depressed and fluid intake is reduced. The reason is that the higher concentration of salt requires a greater proportion of the water ingested to be used for salt excretion, until not enough water is left for other functions. The salt concentration at which this depression occurs is a measure of arid adaptation in a species, as shown in Table 11. In practice, if animals become accustomed to a salty water supply they can tolerate much higher salt concentrations than if forced to drink the more concentrated solutions without a preliminary conditioning period (French, 1956a).

Table 11. Tolerance of salty drinking water by different livestock species.

Species	% total salts in drinking water
Camel	5.5
Goat	1.5
Sheep	1.3-2.0
Cow	1.0-1.5
Donkey	1.0
Horse	0.9
Pig	0.9

Source: French (1956a), Wilson (1967, Macfarlane (1971); Maloiy (1972).

Table 12. Safe levels of toxic elements and ions in livestock drinking water.

Element	Level (mg. l^{-1})	Remarks
Arsenic (as As)	1.0	Inorganic oxide, especially from dips
Boron (as B)		Present at < 4 mg.l^{-1}, whereas 450 mg.l^{-1} inhibits growth
Cadmium (as Cd)	0.01	Accumulates in liver and kidneys
Calcium (as Ca)	1000	<700 mg.l^{-1} desirable for beef, esp. if Mg present
Chromium (as Cr)	1-5.0	Industrial effluent, but not readily absorbed

Copper (as Cu)	0.5-2.0	Essential trace element, but could reach toxic level from wide agricultural use
Fluoride (as F)	2.0	See text
Iron (as Fe)	10.0	Scouring caused by grazing pasture irrigated with high-Fe water
Lead (as Pb)	0.5	Cumulative poison
Magnesium (as Mg)	250-500	Predisposes to rickets if Ca content low, sulphate causes scouring
Mercury (as Hg)	0.002	Health hazard to human beings consuming meat
Molybdenum (as Mo)	0.01	Only dangerous if accumulated in (irrigated) pasture
Nitrate (as NO_3)	90-200	Sources are deep wells filled by seepage from highly fertile soil, or dams containing much decaying organic matter, e.g. manure
Selenium (as Se)	0.02	To compensate for plant ability to concentrate Se
Sulphate (as SO_4^{2-})	1000	High magnesium sulphate causes severe problems
Zinc (as Zn)	20	Natural and industrial contamination, but relatively non-toxic

Source: Hart (1974).

Salts which cause specific toxic effects are listed in Table 12, together with recommended working levels in drinking water (derived in Australia) which should provide an adequate margin of safety. The amount of information on water analysis is very variable across Africa, but there are some documented cases of toxic ion effects. For example, fluorosis in man and livestock is a problem in volcanic areas and where drinking water is obtained from deep boreholes (Williamson, 1953; Walker and Milne, 1955; Murray, 1967; Said, 1981).

Contamination of stock drinking water with urine, faeces, other animal discharges, or even animal carcasses sometimes occurs in pastoral areas. Examples of bacterial diseases spread by each of these contaminants are leptospirosis, salmonellosis, brucellosis and anthrax respectively. Drinking water is less likely to spread viral diseases, but may be implicated in the spread of foot-and-mouth and rinderpest, among others. A number of stock parasites may spend part of their life cycle in or near water, such as protozoa, flukes, flat-worms and round-worms (BVA, 1976). Because they are frequently introduced via faecal contamination, the faecal coliform level may be used as an indicator of the presence of pathogens. The maximum monthly mean should be less than 1000 organisms per 100 ml or five times that in any one sample (Hart, 1974).

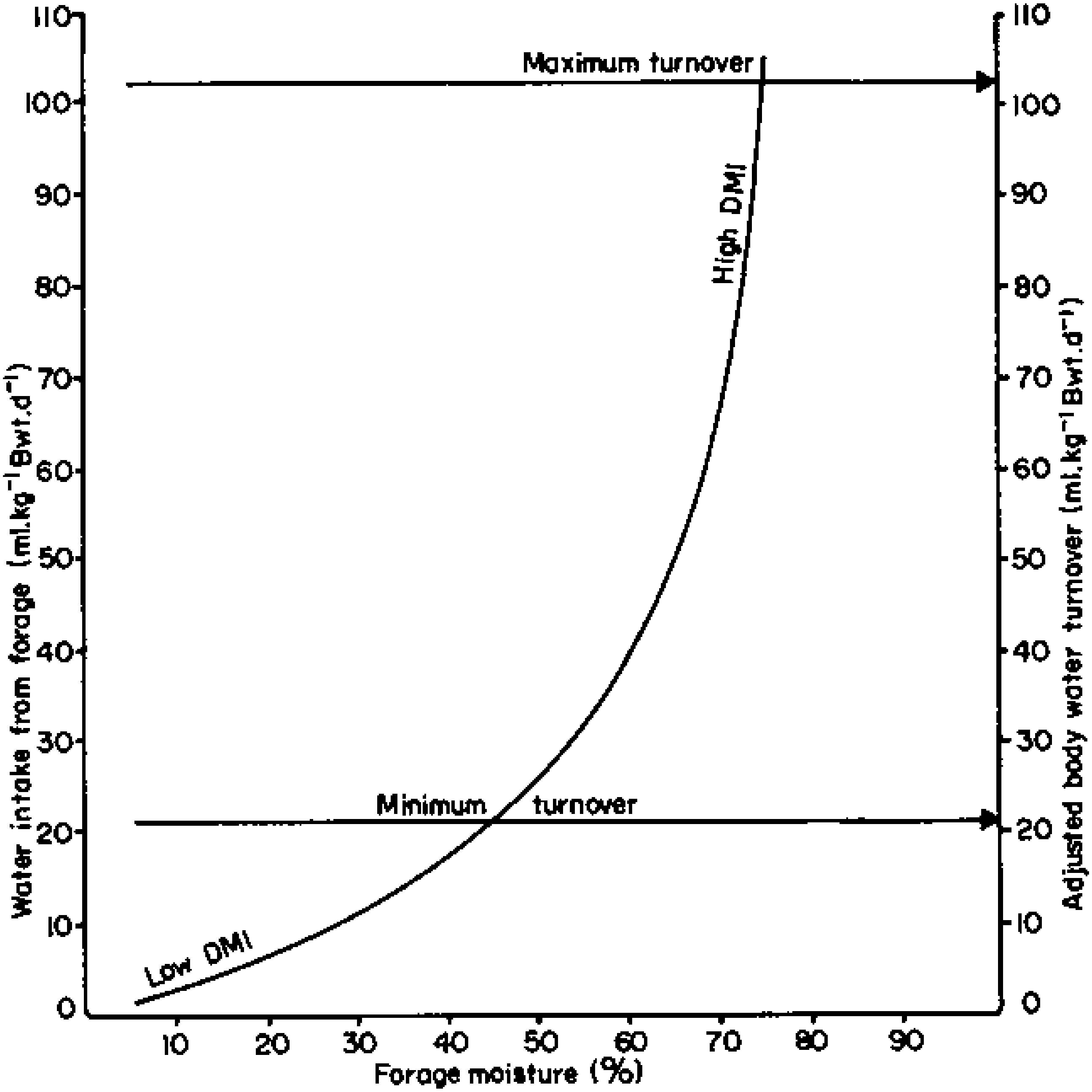
Not much information is available on other contaminants, but these could nevertheless be borne in mind. Blue-green algae toxins have commonly killed livestock in Australia (Hart, 1974), and pesticides such as DDT, which is still used in Africa, could build up in the water of dams or lakes draining agricultural areas, particularly if they do not have large outlets and if they lose much of their water through evaporation.

3.3.2 Water in food

After deduction of water drunk from total body water turnover, the balance of water intake is made up of water in and on food, inspired and absorbed through the skin, as well as from the oxidation of organic compounds during metabolism. The most important of these non-drinking water sources is water in the vegetation.

During and immediately after the rains the moisture content of grass may be more than 80% and of browse more than 70%. At such high moisture contents many herbivores can go for days without drinking. However, during the rainy season ephemeral water ponds are widespread and so the ability to do without drinking water is not of value. An exception is the grazing of porous, volcanic hills, which hold no standing water and can therefore be exploited by livestock only during the rains, whereas hills of other soil types are usually held in reserve for dry-season grazing. The ability to go without drinking water for days or even weeks, once the ephemeral water has disappeared and the vegetation is starting to dry out, is a priceless asset of some game animals, camels and to a lesser extent desert goats and sheep. The forage moisture threshold at which an animal does not need to drink is illustrated from a study of domestic oryx under African ranching conditions (Figure 4). These conditions are defined as: day-grazing on natural pasture where forage quantity is not limited, drinking water available daily, and penning animals at night. In Figure 4, the theoretical curve of water intake from forage has been constructed, starting with a low DMI (2% bodyweight) at low forage moisture content, and ending with a high DMI (3.5%) for very green grass. This curve has been superimposed on the actual maximum and minimum values obtained for total body water turnover, adjusted by subtraction of estimates of respiratory and metabolic water inputs. High levels of water intake from forage are usually associated with high levels of body water turnover. Nevertheless there are times when, and ways in which, the body water turnover can be kept below the water intake from forage, so that the oryx does not need to drink (chapter 4).

Figure 4. Relation of forage moisture to water intake from forage, and to a range of values for adjusted body water turnover in the domestic oryx.



The curve of water intake from forage is similar for indigenous livestock, but their body water turnover rates are higher (Table 13). They will therefore be more dependent on drinking water than the oryx, unless they consistently eat forage with a higher water content. A rough estimate of the moisture content of the diet of each species was obtained by hand grab sampling the plant parts the animals were seen to be eating during each water turnover study (Table 14). The per cent moisture content of the diet of mixed feeders such as smallstock, and particularly dry-season browsers such as eland and camel, is higher than that of grazers such as zebu cattle and oryx. This finding is obvious from measurements, during the dry season, of the water content of herbs and browse which is usually >30%, whereas grass may be <10%. Nevertheless, the contribution of water in browse to body water turnover over the year does not materially alter the ranking of different species' dependence on drinking water, which is similar to their ranking for water turnover (Table 15). The main reason is that the amount of water from forage obtained at dietary moistures <40% is relatively small (Figure 4).

Table 13. Values for adjusted[a] body water turnover in African game and livestock on a day-grazing regime.

Species	Adjusted water turnover (ml.kg^{-1}.d^{-1})		
	Minimum	Maximum	No. of trials
Small East African goat	62	166	12
Eland	53	149	15
Boran zebu	51	150	10
Dorper-type sheep	50	140	12
Camel	38	76	5
Oryx	21	102	15

[a] Adjusted by subtraction of metabolic and respiratory water input.

Source: Adapted from King (1979).

Table 14. Estimated water content (%) of diet of different species under African ranching conditions.

	Water content (%)	
Species	Mean	S.E.
Oryx	13	3.8
Zebu	15	5.4
Sheep	26	5.5
Goat	29	3.8
Camel	34	1.7
Eland	36	2.6

Source: King (1979).

In arid areas there is usually a variety of juicy plants which would appear to offer livestock an alternative source of water as well as food. Some of these plants are sufficiently palatable to be selected even when there is drinking water available, for instance the juicy herb *Commelina* and the swollen stem of *Pyrenacantha malvifolia* (Field, 1975). Other plants such as aloes are only taken towards the end of the dry season. Some bushes with juicy leaves also have a high salt content, which may increase rather than decrease the herbivore's water requirements. For example, it has been found in Australia and the Middle East that sheep more than doubled their water turnover rates when moved from a natural pasture to one high in salt bush (Atriplex spp.) (Wilson, 1966; Degen, 1977a; 1977b). In Africa, game and livestock browse salt bush (*Suadea monoica*) during the dry season. Whether or not this diet increases their water turnover presumably depends on whether they sweat or pant, and, if they sweat, how much salt is secreted by the sweat glands.

Table 15. Comparison of water turnover and water drunk (ml. kg.$^{-1}$.d^{-1}) by browsing and grazing livestock

Species	Adjusted turnover[a]		Water drunk		Feeding habit
	Mean	S.E.	Mean	S.E.	
Goat	94	4.3	65	4.2	Mixed feeder
Eland	83	4.2	68	3.6	Browser
Sheep	78	4.8	54	4.7	Mixed feeder

Zebu	74	5.2	47	4.5	Grazer
Camel	41	2.4	37	2.6	Browser
Oryx	35	3.5	29	4.7	Grazer

[a] Adjusted by subtraction of metabolic and respiratory water input.
Source: King (1979).

3.3.3 Guttation, dew and hygroscopic plants

The contribution of dew and guttation to water intake has been measured on improved pasture in Australia, where sheep obtained between 30 and 130 ml. $kg^{-1}.d^{-1}$ from these sources (Brown and Lynch, 1972). It would be extremely difficult to measure water intake from dew and guttation under semi-arid conditions on natural pastures. Dew forms nearly every night in some of the semiarid regions of Kenya, but only during the cooler months in real deserts. Wild impala have been observed licking water from short vegetation in the early morning (Lamprey, 1963), and in much the same way sheep deprived of water were observed licking dew off pasture and fences (Brown and Lynch, 1972).

Some plants become hygroscopic when dessicated during the dry season, and may acquire a 20 to 40% moisture content during the night, even without visible dew. Such plants can provide an important source of water for nocturnal grazing animals (Buxton, 1923; Schmidt-Nielsen, 1965). For example, Taylor (1968) estimated that oryx and Grant's gazelle could obtain their water requirements from the desert herb *Disperma* if they fed in the evening, night and early morning. If the wild oryx does not need to drink when the forage moisture is <40%, then it has either increased its DMI to 3.5% of bodyweight at 40% forage moisture or lowered its minimum body water turnover rate, which is more likely. Figure 4 relates to the domestic oryx on a day-grazing regime. Unfortunately, most domestic animals in Africa have to be penned at night to prevent human and animal predation.

3.3.4 Respiratory and cutaneous water intake

Although there is a net water loss from the respiratory system and through the skin, these two components together make a significant contribution to the input side of the water balance equation. The amount of water (kg) in the inspired air which is exchanged with the water pool accounts for about 10% of total water intake, and may be calculated as follows (Weast et al, 1965):

water in inspired air (kg) =

r.h. × sat. water vap. × resp. min. vol.

where r.h. is relative humidity (%), sat. water vap. is weight of 1 m^3 of saturated water vapour (kg) and resp. min. vol. is respiratory minute volume (m^3).

The amount of air inspired (m^3) was calculated from data on zebu cattle weighing about 220 kg (Finch, 1973) as:

$$6.64+3{,}00\ f$$

where f is the breathing rate per minute. Normal values over 24 h for zebu cattle on a maintenance diet are in the region of 110 m^3 of inspired air containing 1.4 kg water (King and Finch, 1982).

Cutaneous water exhange was not measured, but it is assumed to be about 10% of the water exchange via the respiratory system (D. Robert-shaw, unpublished). More water is absorbed through the skin if the animal is actually rained on, but cutaneous water intake probably remains insignificant compared with other forms of intake.

The effect of these two components was observed during feeding trials in covered pens on Galana ranch, Kenya. It was noted that livestock reduced their water intake on rainy days, which was explained by their lower requirement for evaporative cooling due to the drop in ambient temperature when it rained (Stanley-Price, in press). However in such a situation there is also a marked increase in the relative humidity and hence the water content of the inspired air.

3.3.5 Metabolic water

The oxidation of organic compounds during metabolism leads to the formation of water from the hydrogen present. Attempts to measure this process in fasting cattle based on the dilution of tritiated water were unsatisfactory (J.E. Vercoe, unpublished). Therefore it is still calculated indirectly. An example of the calculation of metabolic water produced from nutrient intake is given in Table 16. Alternatively, the amount of water (g) has been estimated at 0.0294 × total heat production (kJ) (Morrison, 1953).

Besides being an avenue of water gain, there is a generally held belief that the oxidation of fat deposits makes a net contribution to the total body water pool, not just from the hump of the camel and the fat-tail of the sheep, but from deposits in any animal, for example the pig (Skipitaris, 1981). However this assumption has to be qualified by the circumstances (Schmidt-Nielsen, 1965). For instance, metabolic water is a product of oxidation but, in the process of inspiring the oxygen, water is expired. It has been calculated that in a hot, dry environment (ambient temperature 36°C and r.h. 10%) an animal loses 23.5 g of respiratory water in the process of producing 12.3 g of metabolic water (D. Swift, unpublished). As well as water, metabolic heat is generated (418 kJ).

Part of this heat (13.6%) is offset by the heat of vapourisation of the expired water. If the remainder (361 kJ) had to be dissipated by sweating, it would cost 149 ml of water (section 3.2.1). The relationship between metabolic water yield and the water that could be required to dissipate the heat of combustion varies with the organic matter being oxidised. Thus 1 g of fat yields 1 ml of water, but could require 14 ml for vapourisation; 1 g of protein or carbohydrate yields about 0.5 ml of water and could require 6.5 ml of sweat.

Schmidt-Nielsen (1965) has argued that the water of oxidation is only of value where the vapour pressure gradient between the expired air and the environment is shallow, for example in a humid burrow, and when the endogenous heat production is low enough to allow heat storage or dissipation by non-evaporative means, for instance as metabolic rate decreases. Low metabolic rates may be expected to be associated with low water turnovers. Thus the relative contribution of metabolic water to total input is much higher (15-35%) when the rate of turnover (k) of the body water pool is low (k <0.05) than when it is high (k>0.15, metabolic water 5%). For example, penned zebu, eland, haired sheep and goats had a mean rate constant of 0.10 and metabolic water was calculated as 8% of total input, whereas oryx had a rate constant of 0.05 and their metabolic water production contributed 16% (King et al, 1978).

Table 16. Indirect calculation of metabolic water production in ruminants eating a hay/lucerne mixture (g $H_2O.g^{-1}$ DMI)

Data required	Crude protein	Crude fibre	Ether extract	Nitrogen free extract	Ash	Total
Amount per g DMI (g)	0.125	0.363	0.022	0.395	0.100	1.000
Digestibility	0.637	0.592	0.654	0.551	-	-

Amount digested (g)	0.080	0.215	0.014	0.218	-	-
Water per g oxidised (g)	0.420	0.560	1.070	0.560	-	-
Metabolic water (g)	0.034	0.120	0.015	0.122	-	0.291

Source: King et al, (1978), based on van Es (1967).

3.3.6 Milk

It is recognized in pastoral production systems that the amount of milk left for the calf may not be enough to achieve maximum growth, unless the peak demands of man and the calf happen not to coincide. For example, if the average daily milk yield of a Boran cow is 3.7 kg and only half is available for the calf, then there will be a shortfall of about 1 kg below the figure of 2.9 kg required for rapid growth (Dahl and Hjort, 1976). Thus malnutrition from milk deprivation has come to be accepted as one of the main causes of slow growth and high-mortality of calves in pastoral areas.

However, the water content of milk may be as important to the unweaned animal as its nutritive value. For example, Stephenson et al (1981) measured the daily fluid intake from trough water and milk by free-ranging Merino lambs as 155 ml. kg^{-1} during the Australian summer. They concluded that milk intake was inadequate to meet the lambs' fluid demands and that insufficient watering points could be a significant factor affecting lamb survival. The daily fluid requirement of the Maasai lamb or Small East African kid, penned in the shade near the *boma*, or fortified night enclosure, would be lower than that of the free-ranging Merino. However, it is likely to be higher than the mean value for adjusted body water turnover of the adult sheep and goat given in Table 15. Based on data of milk yields in the Small East African Goat (C.P. Peacock, unpublished) and Small East African Zebu (P. Semenye, 1982), values for body water turnover must be: <110 ml. kg^{-1}.d^{-1} in kids weighing 7 kg at 2 months, and <74 ml. kg^{-1}.d^{-1} in calves weighing 30 kg at 2 months. The conclusion is that the water requirement of the calf may not be met because its turnover rate associated with optimum growth would be higher than the rate given, which nevertheless demands the peak milk intake of 2.5 kg. d^{-1}.

In Maasailand, suckling livestock are unlikely to be taken to water before they are 1 to 2 months old, and it is not clear whether signs of dehydration are recognized. Where the climate is hotter and drier, as in the extreme north of the Sahel in Mali, unweaned stock, which are kept in camp for 4 to 6 months depending on the species, are given water from a water skin. The amount varies from 1 to 21.d^{-1} in kids to 5 to 101 every fourth day in camel calves (Swift, 1979).

3.3.7 Faeces and urine

When milk is the only source of water input (apart from respiratory and metabolic water), then milk intake can be estimated from the turnover of tritiated water in the body of the young ruminant (Macfarlane et al, 1960). However, when this technique of tritiated water dilution was applied to the milk intake of suckling rodents and dogs, the results made little sense until it was found that 50 to 80% of the water lost by the young was recycled by the dam by licking up the urine and faeces. Thus more than 30% of the water secreted in the milk was recycled in the dam (Baverstock and Green, 1975). It is not known if this form of water recycling is important in any large African ungulates.

4. Factors affecting water turnover

Different species of livestock have different rates of water turnover, and in general animals adapted to dry environments have lower rates of turnover than those in more temperate zones. Body water turnover is also determined by the size of the animal. The role of water in energy production, thermoregulation and other processes means that there are a number of other factors which affect the turnover rate of body water. These are discussed in detail in this chapter.

One of the main functions of water in the body is as a vehicle for intermediary metabolism. There is a relationship between energy metabolism and body size, derived by Brody (1945) and Kleiber (1947), which is:

$F = 0.293\ w^{0.75}$ (4.01)

where F is fasting metabolism (MJ NE. d^{-1}) and W is bodyweight (kg).

Therefore one might expect a relationship between body water turnover (y) and body pool size (x). This was demonstrated in six species of ruminant in Kenya by the following regression
(Figure 5):

$\log y = 0.836 \log x - 0.619$ ($r^2=0.82$) (4.02)

The exponent of x is very similar to that of 0.82 obtained by Macfarlane and Howard (1972) from a wider variety of desert animals.

The reason for the increase in the value of the exponent of body size in equation (4.02) versus equation (4.01) is that water serves another function besides intermediary metabolism, namely evaporative cooling. The effect of having two different power functions is to increase the water to energy turnover ratio with increasing size (Table 17). However, larger animals may exploit water conservation mechanisms related to their bulk, and thus be an exception to the rule (sections 4.2.4 and 4.2.5).

The interrelation between water required for metabolism, evaporative cooling, and total water loss may be expressed in a simple diagram (Figure 6) which links more complex diagrams (Figures 7 and 8). There is a wide range of values for total water loss (Table 18). Moreover, the rate at which water is used for metabolism or cooling is highly variable. The relative importance of the different avenues of water loss has already been discussed (section 3.2). The next step is to try and quantify the effect of the different factors on rates of passage. A model of the heat exchange of the animal with its environment, which calculates evaporative water loss, is in preparation (D.M. Swift, unpublished). When it has been published it will provide a better structure for the contents of section 4.2 on thermoregulation. The next step would be to add energy production (section 4.1) to the model. Neither topic has been addressed sufficiently rigorously in this report to allow modelling except at a very crude level. Nevertheless it does lay the foundation for future work.

Table 17. Daily water turnover versus fasting energy expenditure according to size.

Body weight (kg)	Water turnover (1)	Energy metabolism (MJ)	Water to energy ratio
40	3.90	4.66	0.84
300	21.00	21.12	0.99
500	32.20	30.98	1.04
1000	77.45	52.10	1.49

Source: Brody (1945); Figure 5.

Figure 5. Derivation of an approximate metabolic unit for body water turnover from the slope (0.836) of the regression of turnover on pool size between species.

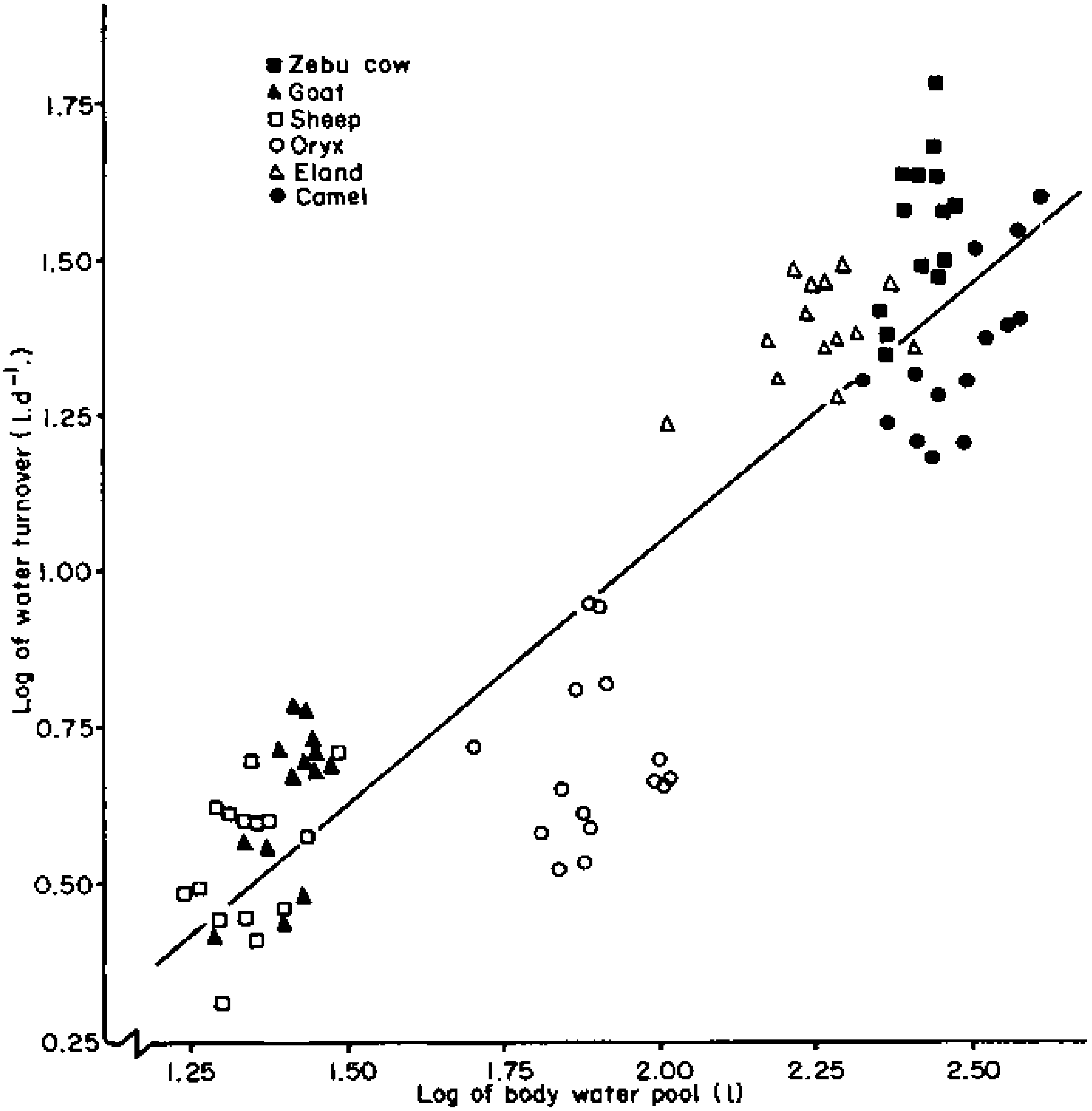
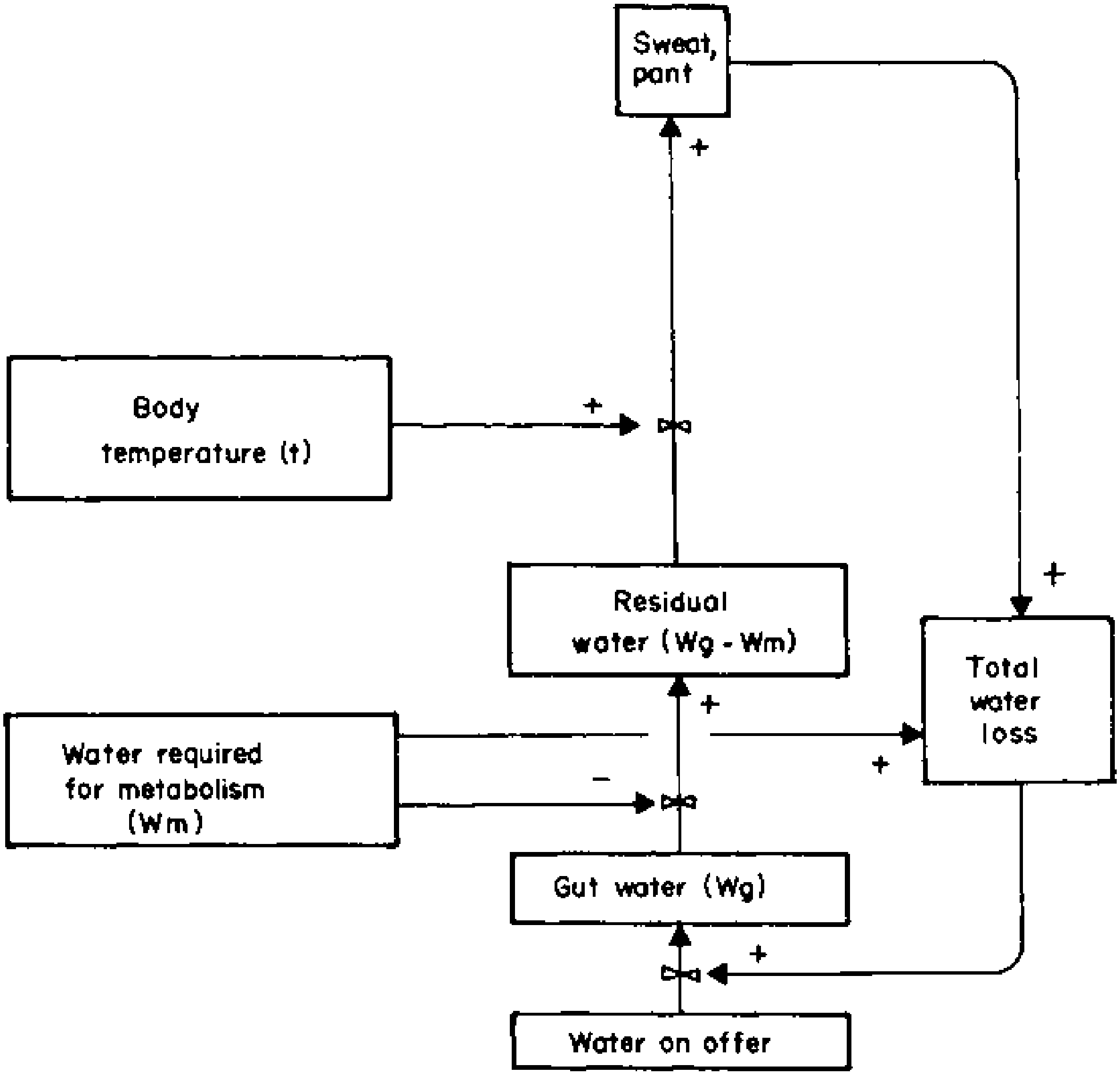


Table 18. Values for body water turnover in game and livestock on a day-grazing regime.

	Water turnover (ml.l^{-1}.d^{-1})		
Species	**Minimum**	**Maximum**	**Ratio (max: min.)**
Small East African goat	117	302	2.6
Dorper-type sheep	103	278	2.7
Zebu cattle	97	274	2.8
Eland	90	242	2.7
Camel	53	106	2.0a
Oryx	41	170	4.1

[a] Probably an underestimate due to the small number of trials.
Source: Adapted from King (1979).

Figure 6. Interrelation between energy metabolism. body temperature and total water loss.



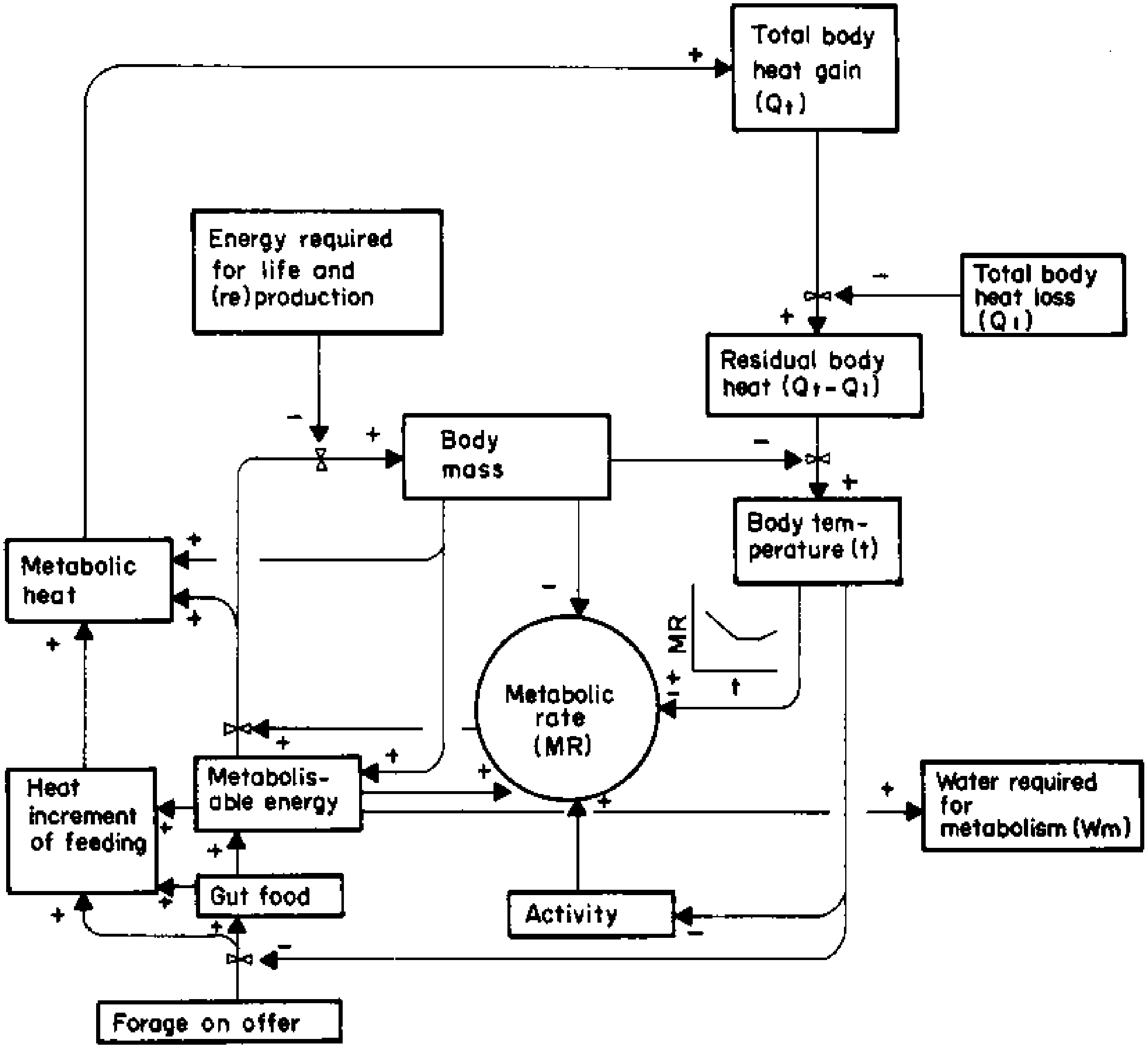
4.1 Energy production

Nutrition exerts a profound effect on body water turnover. There is a significant, positive, linear relationship between faecal output and water turnover in cattle and sheep (Siebert, 1971; Macfarlane et al, 1974). However, the nutritional effects are not constant but depend on the form in which food is acquired, the way in which it is used, and the heat increment of feeding and energy utilisation. The interactions of those effects are shown in Figure 7. Note that the diagram has two components in common with Figure 6, namely body temperature and water required for metabolism, which are the main avenues by which nutrition influences total body water use and loss. The effect of body temperature on metabolic rate can be either positive or negative as illustrated graphically. It is discussed in more detail in section 4.1.3.

4.1.1 Forage intake and metabolism

The effects of forage intake on body water turnover depend on four major characteristics of the food eaten. The first is the water content of the forage which, in certain situations, has a significant positive correlation with water turnover (King et al, 1975). Very green vegetation can supply all the water needs of the animal and more. Theoretically, plant moisture content may even restrict appetite when it is retained in ingested forage by the sponge effect of coarse structural components (Van Soest, 1982). However, the water is usually released from the forage and is rapidly absorbed from the rumen or passed out in moist faeces. Absorbed water can be excreted from the kidneys of sheep at a rate of 30 l.d so that the DMI of sheep grazing green grass was not limited by its moisture content of 83% (Macfarlane et al, 1966b). Similarly it has been shown that cattle can use grazing with a moisture content of 75-83% very efficiently (R.E. McDowell, unpublished), implying a high body water turnover rate.

Figure 7. Flow chart of intermediary metabolism.



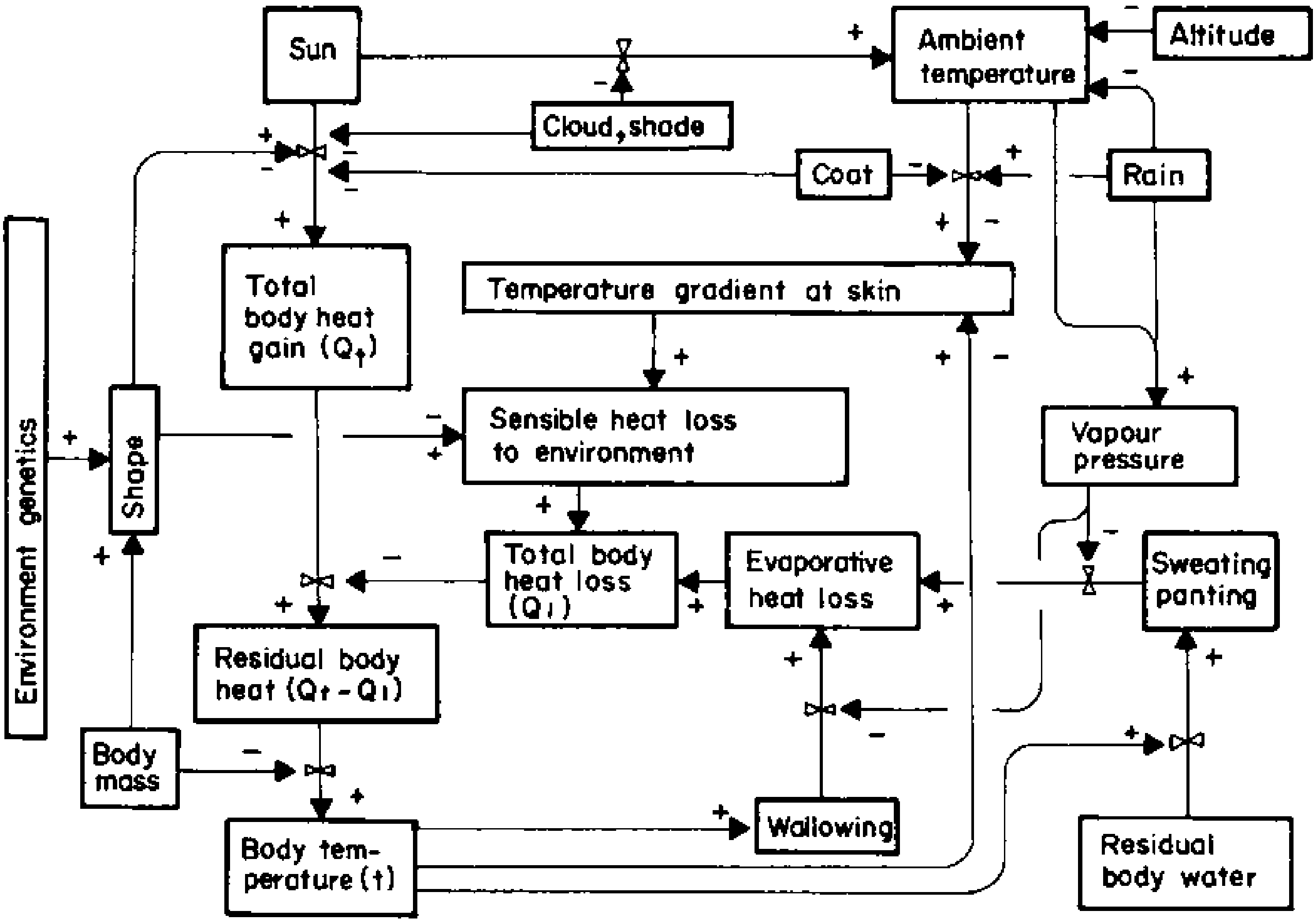
There is a second reason for the significant, positive correlation between vegetation moisture and body water turnover. Green forage usually has a high digestibility and nutritional value, thereby allowing increased DMI and a raised metabolism with its concomitant demands for water (Forbes, 1968; Springell, 1968).

At the other end of the scale, very dry forage will produce a low demand for water for intermediary metabolism, but paradoxically might increase the water needed to dissipate the extra heat increment of feeding, and to facilitate digestion and excretion. For example, if the DMI of grass (of 10% moisture and 40% apparent digestibility) was 2% of bodyweight, then daily water intake from it would be 3 ml. kg bodyweight $^{-1}$ and faecal water output 27 ml. kg bodyweight^{-1}.

The salt content of the forage also affects water turnover, as discussed in section 3.3.2.

The term metabolism may be applied to the modification of all categories of food digested. However, the total energy intake of the herbivore is usually the most important factor determining total output of animal products, as long as the relatively small protein, mineral and vitamin requirements are met (Williamson and Payne, 1978). This statement may not be entirely true for high yielding dairy cows (Fuquay, 1981), but such animals are not associated with pastoral production systems. The main source of energy from forage is carbohydrate. The fat content of the diet of herbivores is usually very low (1-4%), except in the newborn suckling animal when it provides 30% of DMI and 50% of caloric intake (Van Soest, 1982). Milk intake has already been discussed in section 3.3.6.

Figure 8. Factors affecting environmental heat load and thermoregulation.



Increases in DMI result in increases in metabolic rate and productivity. The extra water requirements for different forms of production have been estimated for farm animals in the British Isles at the highest temperatures experienced there (Table 19). They are included for reference when water turnover is estimated in the pastoral situation (section 5.1.8) for which no such data exist.

4.1.2 Starvation

A severe reduction in DMI produces a similar reduction in body water turnover. Nevertheless, metabolic processes must continue if the animal is to survive, and so body tissues are catabolised to make up the shortfall in food intake. This tissue mobilisation produces metabolic water as a byproduct (section 3.3.5) and a continuing use of water for metabolism. However, the need is reduced by 20 to 30% in the zebu because of the depression of metabolic rate in response to a diet of half that of maintenance. The resultant reduction in body water turnover by 30 to 40% is therefore an expression of both a reduced DMI and a lowered resting metabolic rate (Finch and King, 1979; 1982).

4.1.3 Endogenous heat production

Endogenous heat is both a by- and an end-product of metabolism, as shown in Figure 7. Its effect on body water turnover becomes important when, combined with exogenous heat, it exceeds the upper critical heat load on the animal, which then has to resort to evaporative cooling. The significance of the upper critical heat load is that at higher heat loads metabolism actually increases, due to the oxygen cost of evaporative heat loss and the increase in metabolism associated with a rise in body temperature (Robertshaw and Finch, 1976). It is depicted in the small graph relating body temperature (t) to metabolic rate (MR) in Figure 7. It is known as the Q_{10} effect and can be explained by the fact that a rise in temperature accelerates most chemical reactions (Schmidt-Nielsen, 1975).

Although endogenous heat production may contribute less than one third of the total heat load on the animal (Table 5), it may be the portion which can be most easily reduced by the animal, by decreasing its activity and food intake. Walking and feeding account for 90% of the diurnal activity of livestock under African commercial ranching conditions (Lewis, 1975; 1977; 1978).

Table 19. Water requirements[a] of farm animals in the British Isles at the highest temperatures experienced.

Animal	Environmental temperature (°C)	Water intake (1.kg^{-1} DM eaten)
1. Beef cattle	15-21	4.1
	21-27	4.7
	>27	5.5
2. Lactating cows		As for 1. with additional allowance of 0.871 water/kg milk produced
3. Pregnant cows (last 4 months)		1. values × 1.5
4. Sheep	15-20	2.5
(growing and fattening)	>20	3.0
5. Pregnant ewes:		
3rd month		4. values × 1.5
4th month		4. values × 1.8
5th month		4. values × 2.2
6. Lactating ewes:		
1st 8 weeks		4. values × 1.5
2nd 8 weeks		4. values × 1.25

[a] Water from food and drink.
Source: McDonald et al (1976).

Pastoral cattle often have to walk long distances between grazing and water. But the extra water cost of walking *per se* is negligible if the solar heat load is moderate. For example, when the total solar radiation was 2140 ± 138J. cm^{-2}.d^{-1}, the cost of walking 16 km instead of 8 km.d^{-1} was an extra 4.4 ml.kg^{-1}.d^{-1} for zebu cattle on a half maintenance ration. When total solar radiation rose to 2385 ± 59 J.cm^{-2}.d^{-1} the water cost of travelling the extra 8 km was significantly higher ($P < 0.005$), by an extra 11 ml.kg^{-1}.d^{-1}. The reason was that the walking period of the cattle travelling 16 km.d^{-1} extended into mid-afternoon, when the environment was at its hottest (Finch and King, 1982). The impact and avoidance of high solar heat loads will be considered in more detail in the next section. The present discussion is concerned with the heat produced from walking, which can be considered from two angles: total energy expenditure and heat production over a given distance is least when the zebu cow is encouraged to walk at about 3 km.h^{-1}; however, the rate of heat production will be reduced as speed declines to 1.5 km.h^{-1}, when the energy cost flattens out at 20% above that of standing still, except in the starving zebu, when it appears to go on declining (section 5.1.3). Such control of endogenous heat production may be abandoned by dehydrated cattle when they approach water. Classen (1977) reported that very thirsty and debilitated animals will run to water and may die from exertion and overdrinking. Perhaps the extra exertion precipitates an explosive rise in body temperature (see section 3.1).

The mechanism responsible for a reduction of food intake in heat-stressed animals is not clear (Van Soest, 1982), but its effects are. The reduction will affect the heat increment of feeding, which is about 40 kJ.MJ^{-1} metabolisable energy (ME) when eating and ruminating fresh herbage on temperate grasslands (Webster, 1980). The sequel to reduced intake will be a reduction in the heat increments of production and maintenance (Robertshaw and Finch, 1976). This drop in heat production may be partly offset by mobilisation of body tissues (section 4.1.2).

Thus the immediate effect of inactivity and inappetence is to reduce endogenous heat production by about 30% and the total heat load in the free-ranging animal by 10 to 20%. The longer term effect of the reduction in ME due to lack of appetite is a reduction in metabolic rate which is related to or caused by a reduction in endocrine activity. Chronic exposure to heat depresses thyroid activity, as well as plasma cortisol and growth hormone concentrations and turnover rates. All three hormones act in cooperation and are calorigenic (Thompson, 1976; Robertshaw and Finch, 1976). Chronic exposure to heat stress also depresses libido and spermatogenesis, or suppresses oestrus and ovulation, and causes luteolysis and embryonic mortality, particularly in temperate breeds of livestock (McDowell, 1972). All these reductions in metabolic activity, and its byproduct endogenous heat production, will reduce body water turnover.

4.2 Thermoregulation

As already indicated, livestock in sub-Saharan Africa use larger amounts of water for evaporative cooling than for intermediary metabolism, to dissipate the high solar energy load. The way in which the residual water available for sweating and panting (Figure 6) contributes to total body heat loss is shown in Figure 8. This diagram shows evaporative heat loss acting negatively, via total heat loss, on the same vertical column of components of body heat gain through to body temperature as in Figure 7, but with the superimposition of the sun on top. Of course, not all heat loss occurs via evaporative cooling, nor is it always hot in the tropics. The way in which thermoregulation affects body water turnover involves a complex interaction of climatic variables with behavioural responses and anatomical or physiological adaptations of the animal.

4.2.1 Environmental heat and humidity

During the daylight hours almost all the heat gained from the environment comes directly or indirectly from solar (shortwave) radiation. Heat is gained from convection, conduction and long-wave radiation only if the temperature of the air and of objects in the habitat is higher than the skin temperature of the animal. The degree to which the habitat heats up varies with its composition. For example, desert sand reflects 30-40% of the incoming radiation, desert shrubs 30-38%, and green grass about 25% (Barry and Chorley, 1971). Although green vegetation reduces the reflectivity (albedo) of the ground, it does not heat up. Instead it acts as a heat sink for longwave radiation, for example from a warm animal, because it is at a lower temperature than its surroundings as a result of transpiration. Thus, even during the day, there is usually a net outflow of longwave radiation from the animal, and this increases at night. In order for this dry heat loss to balance the solar heat gain, the ambient temperature must be low, as it is at high latitudes or high altitudes. There is a 6.5°C drop, or adiabatic lapse rate, for every 1000m increase in altitude. Therefore, if sweating accounts for 21% of the net heat loss of a zebu cow at 1675 m a.s.l. near the equator in Kenya (Table 5), it will account for a much larger proportion at sea level provided the atmosphere remains dry. Because sweating can account for up to 80% of the water used by a ruminant in the tropics, it is not surprising to find correlations between ambient temperature or solar radiation and total body water turnover. For example, on a ranch in Kenya situated 180 m a.s.l. a significant correlation was obtained between daily mean ambient temperature up to 29°C and body water turnover (x) in the zebu (Figure 9), namely:

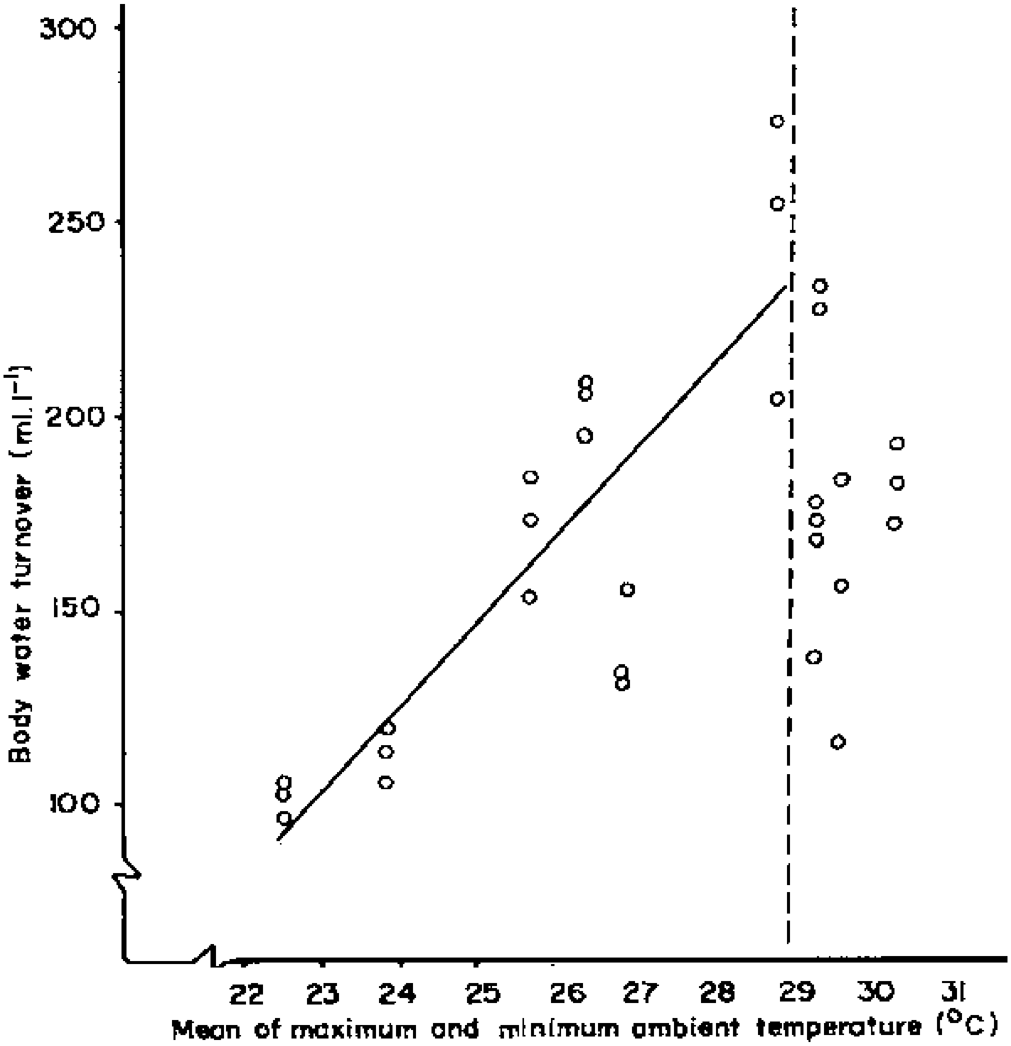
$y = 21.518x - 390$ ($r^2 = 0.71$)

Equally significant relationships ($P < 0.001$) were obtained between direct and diffuse solar radiation and total body water turnover, for example in eland and oryx (Figure 10). It should be noted that the intercept of the regression line in Figure 10 is lower in the oryx than the eland, but that thereafter the response of body water turnover to increasing heat load is similar in both species - a point which will be discussed in section 4.2.3.

Figures 9 and 10 both illustrate that at high heat loads, above 29°C 'mean' ambient temperature for the zebu, or at high levels of solar radiation - 505 $W.m^{-2}$ for the eland, and 475 $W.m^{-2}$ for the oryx - the body water turnover rate declines. The regressions have been interrupted at this point to emphasise the phenomenon. Inclusion of plots to the right of the dashed vertical lines or the use of curvilinear regressions does not improve the fit. The explanation for the sudden decline in response would appear to be that the animals dissipate the increasing environmental heat load by increased evaporative cooling only up to a level determined by the body water turnover rate. In eland and cattle this rate approached 18 and 24% respectively, and if exceeded could result in severe dehydration even when drinking daily. The cut-off point of 12% in the oryx is more difficult to explain. It may be associated with less extravagant water cooling mechanisms, and be related to a natural inclination to avoid daily watering even when it is offered. For all species, the reduction in body water turnover rates at higher heat loads than those mentioned above implies that (a) other forms of heat load are being decreased and/or (b) other thermoregulatory mechanisms are being brought into play, or (c) homeothermy is being abandoned (sections 4.2.3, 4.2.6 and 4.2.7).

The value of sweating as a cooling mechanism varies in the different climatic zones of Africa, because the rate at which water evaporates from the body varies inversely with the water vapour pressure in the air. However, at moderate humidities this reduction is much smaller than might be expected. It can be explained by assuming that the rate of sweat secretion is unchanged and an increase in humidity causes a temporary reduction in evaporation and a build-up of moisture on the skin. As a result the vapour pressure at the skin surface increases, automatically re-establishing the vapour pressure gradient between skin surface and air until evaporation is in equilibrium with the rate of sweat secretion. At extremely high levels of humidity there are more marked reductions in evaporation (Thompson, 1976). Such high levels of vapour pressure can occur, both in the humid tropics and in housed livestock, where they may be the main cause of variation in heat stress and body water turnover rather than the relatively small seasonal fluctuations in ambient temperature (Kamal and Seif, 1969; Siebert and Macfarlane, 1969; Kamal and Johnson, 1971).

Figure 9. Relation between daily total body water turnover and mean ambient temperature in zebu cattle under African ranching conditions.



Source: J.M. King (unpublished)

The combined effect of temperature and humidity has been developed into an index (THI) by the United States Weather Bureau to describe discomfort in man. The index appears to be applicable to animals (McDowell, 1972):

THI = 0.72 (ºC + ºC) + 40.6

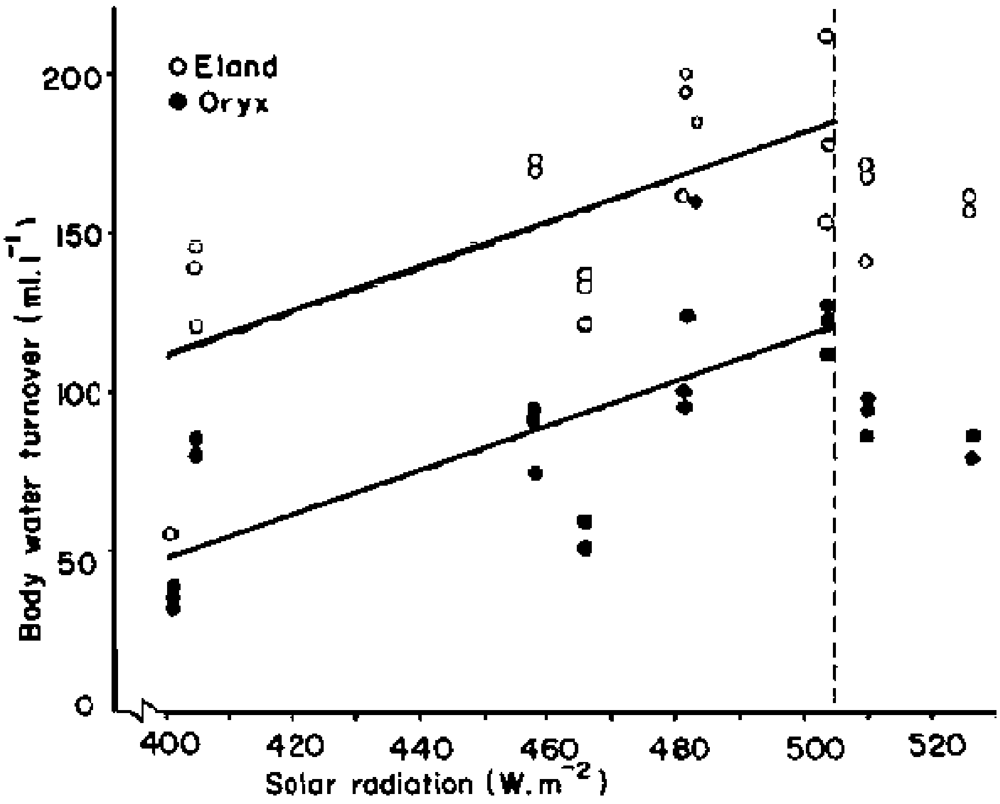
db wb

where

db = dry bulb temperature in °C, and
wb = wet bulb temperature in °C.

When this index was applied to Holstein cattle at the University of Missouri by Johnson et al (1963) it was found that cows appeared comfortable when the index was below 70, but there was reduced milk yield and food intake above 75; all age groups showed measurable degrees of discomfort at an index value of 78 and above. These findings from North America are relevant to a number of dairy projects in the coastal areas of West Africa, where potentially high-yielding Holstein cattle are producing barely enough milk to support their calves, despite expensive housing. The cattle are often thin and their lack of productivity is blamed on such factors as poor nutrition and intermittent water supply. However, when the THI values for adjacent areas, calculated from climatograms published by Pagot (1974), are plotted on a monthly basis and related to the response observed by Johnson et al (1963), it becomes apparent that temperate dairy breeds kept in these areas suffer from heat and humidity stress for much of the year (Figure 11).

Figure 10. The relation between daily body water turnover and solar radiation in domestic eland and oryx under African ranching conditions.



Source: King et al (1975).

4.2.2 Cold and rain

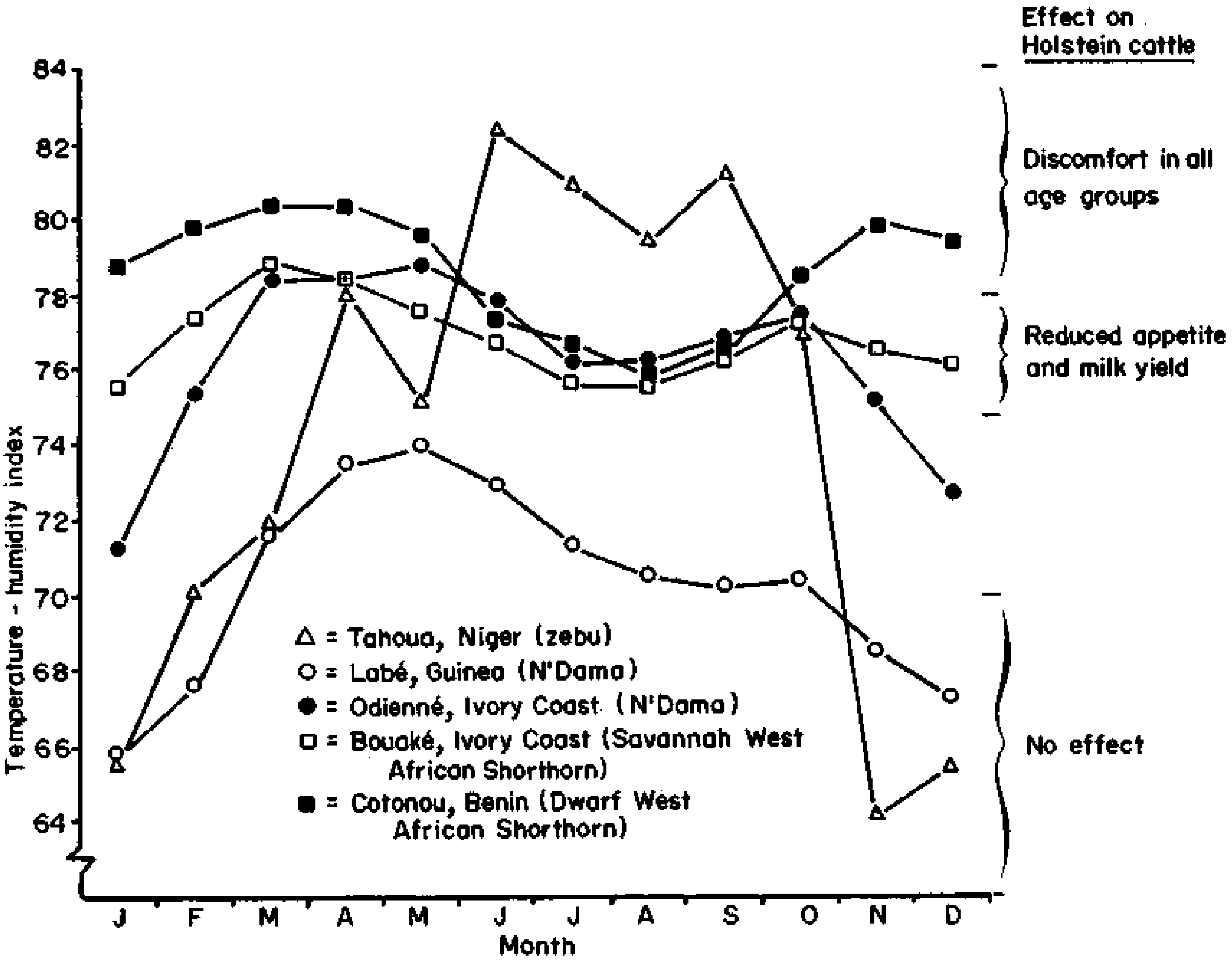
Although most of the discussion in this report is concerned with heat stress, in the northern and southern African deserts (in winter) and in the highlands (every night) the ambient temperature falls sufficiently far below the animal's critical body temperature to stimulate thermogenic heat production. Rainfall accelerates heat loss from the animal by increasing the conductivity of the coat. The result is an extra demand on the nutritional intake and reserves of the animal, which may be sufficiently important to influence the type of animal selected by the pastoralist as well as its management (sections 4.2.4 and 7.2.1).

Thermogenic heat production causes a slight increase in body water use. However, this is accompanied by a reduction in insensible water loss from the skin as a result of peripheral vasoconstriction, as well as increased condensation of saturated expired air in the respiratory passages which have been cooled by the cold inhaled air (Schmidt-Nielsen, 1975). Thus the net effect of cold ambient temperatures is to reduce water loss.

4.2.3 Behavioural response to heat stress

The activity of herbivores on tropical rangeland is a mixture of vital activities, such as feeding and walking to water, plus 'behavioural amelioration' (Macmillan, 1972) of a frequently hostile environment. The resultant compromise gives the typical activity pattern of herbivores on a day-grazing, night-enclosure regime (Figure 12). Herbivores with access to night grazing may be expected to spend a greater proportion of the day idle or in the shade, whereas those that are confined at night can only avoid high heat loads at the expense of feeding time (Lewis, 1977; 1978).

Figure 11. Mean monthly values for THI at places of origin of West African cattle, and the effects of a similar climate on Holstein cattle in Missouri.



Shade seeking is one of the more conspicuous forms of behavioural amelioration. As the dry season progresses, wild impala have been observed to move lower down the catena on which they graze, moving to where the vegetation is greener and the shade is deeper (Jarman, 1973). In the absence of shade, sheep will stand with their heads under each other's bellies; this manoeuvre may serve the dual purpose of avoiding overheating the hypothalamus and the attentions of the nostril fly (*Oestrus ovis*).

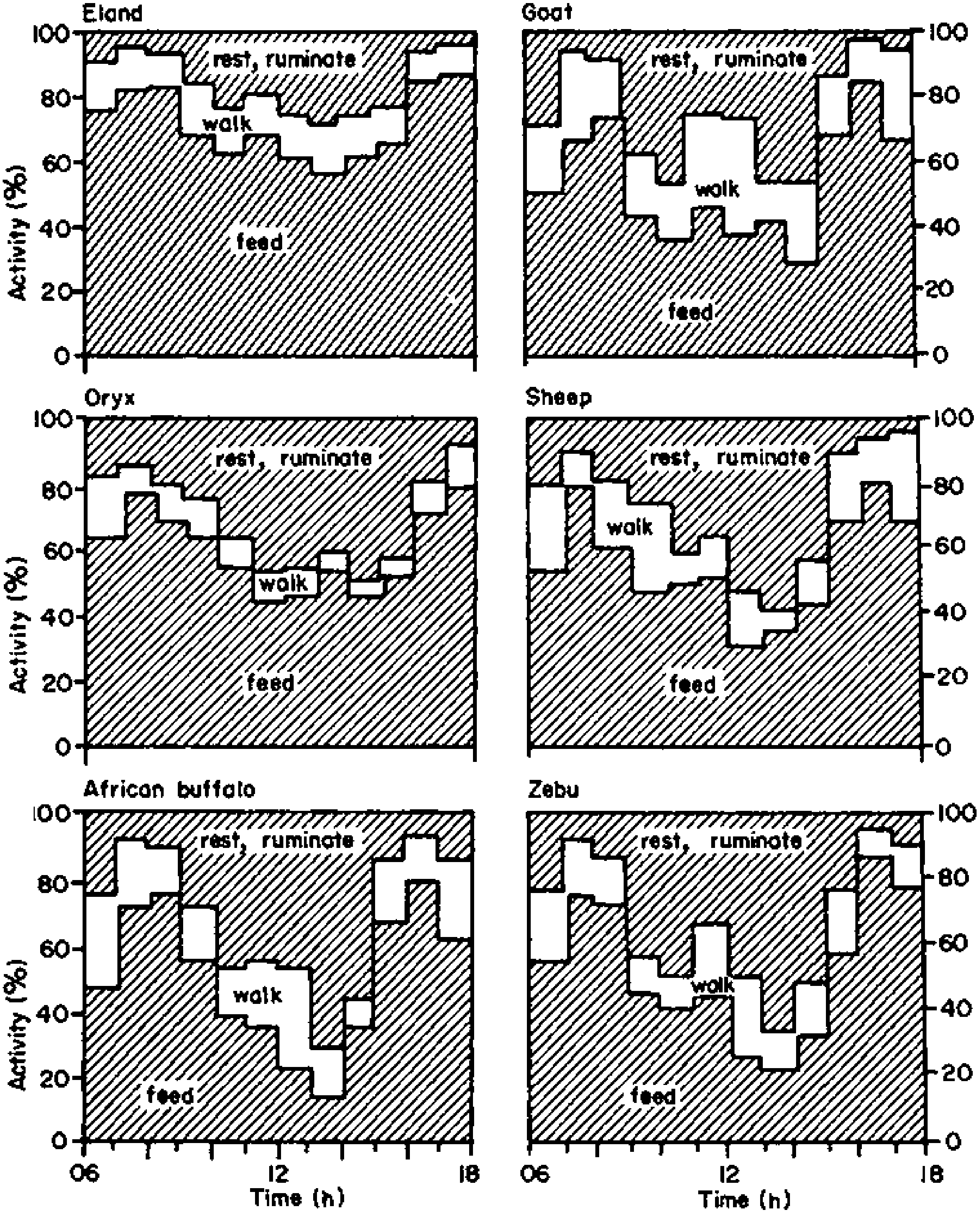
Wallowing is also a useful behavioural adaptation, allowing an animal to use evaporative cooling without any loss of body water. A high rate of evaporation can be sustained for more than 2 h if the animal wallows in mud rather than water (Ingram, 1965).

4.2.4 Coat characteristics

The structure and colour of an animal's coat will affect the flow of energy and water across the skin (Hutchinson and Brown, I 969).

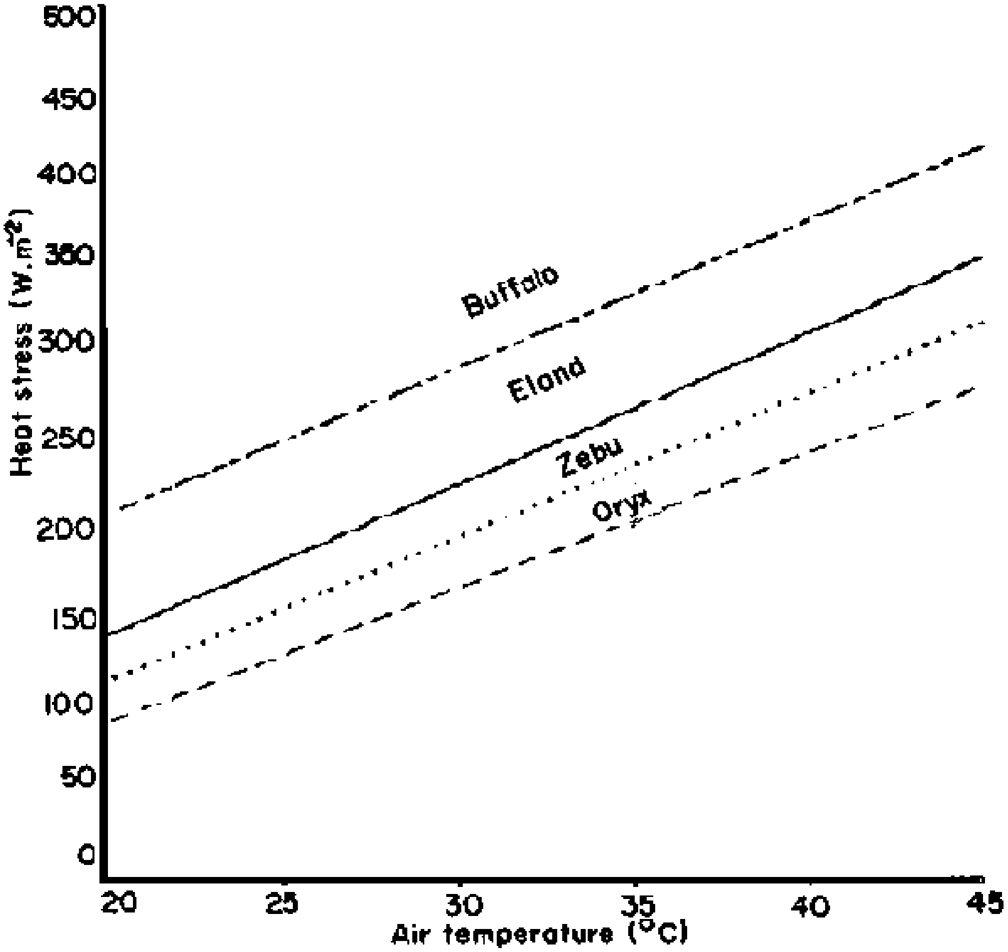
The heat stress on the animal from the radiant environment has been defined as the inward sensible heat flow at the base of the coat (Finch, 1972a). This heat stress on the skin has been calculated by Lewis (1977) in four African ruminants at varying-air temperatures for a constant radiation load (Figure 13). Because the intercepts of the regressions were different, he concluded that the hair barrier to solar heat was different. The greatest heat stress occurred in the African buffalo, with its sparse black coat. Next was the eland, which has a coat colour with a low absorption coefficient (0.75) similar to the brown zebu (0.78) but a coat structure which is sparse and short (hairs 0.22 mm long) compared with the cow (0.30 mm long) (Finch, 1972b; 1973). The least heat stress occurred in the oryx, which has a coat colour with an absorption coefficient of about 0.65 (Stewart, 1953) and a coat structure which is dense and long (hairs 0.4 mm long) (V.A. Finch, unpublished). The fact that the slopes of all four regression lines were parallel implied that convective heat loss was essentially the same in all species and is directly related to air temperature.

Figure 12. Mean hourly distribution of main activities of African ruminants on a day-grazing regime.



The heat arriving at the skin surface makes thermoregulatory demands on an animal, and the physiological response of evaporative cooling by sweating or panting increases the water turnover. For example, it has been found that shearing Merino sheep during the Australian summer doubled their water turnover compared with that of unshorn sheep (Macfarlane et al, 1966b). Similarly, the lower body water turnover of oryx compared with eland at a given solar radiation load (Figure 10) could be ascribed not only to superior water conservation mechanisms but also to the different characteristics of the coat.

Figure 13. Predicted relationship between heat stress on the skin and air temperature in African ruminants with different coat characteristics.



Source: Lewis (1977)

Within a species which has a variety of different coat colours, the effect of colour can be considerable. For example, Finch and Western (1977) showed that the inward sensible heat flow at the base of the coat was greater in black cattle than in brown, where in turn it was considerably greater than in white cattle (Table 20). Water drunk, on a daily watering regime, followed a similar pattern to radiation absorbed. When drinking was restricted to every 2.5 days, all colours drank the same amount, which was to the limit of their gut capacity. During the days between drinking the dark cattle became dehydrated more rapidly, their body temperatures rose more, and their appetites were depressed more than in the light coloured cattle.

The same authors point out that dark coat colours become an advantage with increasing altitude and decreasing air temperatures, which may drop to 5°C at night in certain pastoral areas of Kenya. In such situations the local zebu cattle have to expend energy on thermogenesis because they are poorly insulated and not physiologically adapted to a cold climate. When the sun rises, black cattle rapidly absorb solar radiation, whereas white cattle continue to waste chemical energy on thermogenesis to keep warm. At the end of the dry season, if animals are starving, coat colour may make the difference between life and death.

Table 20. Mean values (±SE) of sensible heat flow (W.m^{-2}) towards the animal for l black, 1 white and 2 brown steers for 3 days measured between 09.00 and 15.00h at 1430 m a.s.l. in Kenya.

Cattle colour	Radiation absorbed	Sensible heat loss	Inward sensible heat flow
Black	691 ± 14	573 ± 7	118 ± 24
Brown	630 ± 6	531 ± 7	99 ± 17
White	549 ± 14	499 ± 8	50 ± 15

Source: Finch and Western (1977).

Finch and Western (1977) found a number of field situations where cold and heat appeared to exert a strong selective pressure on cattle coat colour in Kenya, and concluded that the relationship was clearly recognized by the pastoral tribes. For example, in a country-wide survey of cattle colours they found a linear decrease in the proportion of light coloured cattle in the herd with altitude, and an increase with predicted heat stress and potential evaporation, these last two environmental parameters being closely correlated. The relation between per cent light cattle per herd (y) and potential evaporation (*x*) was:

$y = 0.07x-73.9$ ($r^2 = 0.82$) (Figure 14).

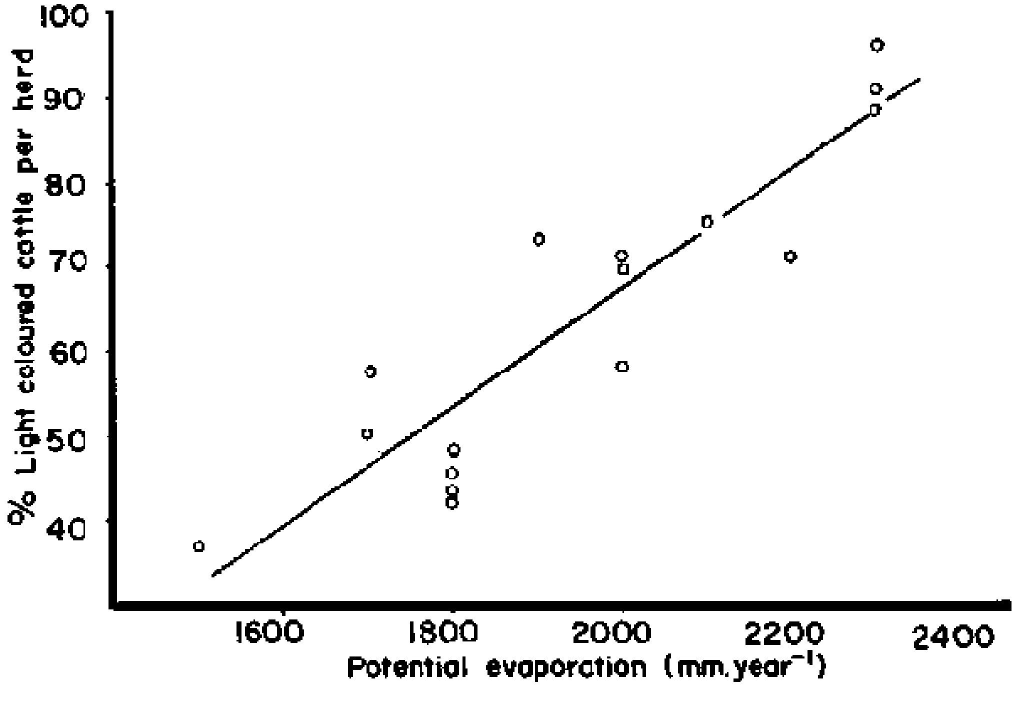
During the droughts of 1973 and 1975, significantly more white than black cattle died in the Amboseli area of Kenya, where dark cattle predominate and night temperatures fall below 10°C. However at Hola, in the hot dry country of eastern Kenya where white cattle predominate, the Orma herders reported that proportionately more black than white cattle die during droughts.

Coat characteristics which are favourable for evaporative heat loss may be different from those which provide insulation from the environmental heat load. Under dry conditions, sweat evaporates at the skin surface and the hair insulation encourages heat to be drawn from the skin and not the air (Schmidt-Nielsen, 1965; Edney, 1966). Thus evaporation of sweat under a thin layer of insulating hair is probably the best physical compromise in allowing the skin to lose heat while providing protection from high solar radiation (Macfarlane, 1964). In the hot humid tropics, where high ambient temperature and relative humidity may contribute more to heat stress than solar radiation, a thick coat may not be an advantage. The sweat evaporates more slowly than it accumulates and the hair becomes wet. One can speculate that as a result environmental heat is conducted through the wet coat to the skin surface, while evaporative heat loss occurs at the tip of the hairs.

Woolly coats can be an advantage in animals that pant to lose heat. There is no doubt about the advantage of wool as an insulator against the cold, and McDowell (1972) has suggested that wool is an advantageous covering in a hot dry climate, but not in a humid one. The reason given is that wool growth is usually associated with more sebaceous secretion than hair, and the resultant oily coat absorbs less radiation and also tends to retard evaporation from the skin. However, woolly coats are not a feature of smallstock in sub-Saharan Africa, where Wilson's 'rule' tends to apply - namely that coats are hairy rather than woolly in hot regions (Edney, 1966). However, exceptions can be found, such as the woolly Macina sheep indigenous to the hot, humid Niger delta in Mali. Haired sheep and goats sweat considerably as well as pant to lose heat, although they can reduce cutaneous evaporation when dehydrated (Maloiy and Taylor, 1971; McDowell, 1972).

There are a number of other coat characteristics that have not been considered, such as reflectance rather than colour (e.g. black is often shiny), and protection of skin against photosensitisation. However, the subject of coat characteristics has probably been discussed as much as is warranted here because, in some instances, the coat may be little more than a phenotypic expression of other physiological adaptations to a particular environment. For example, the fawn coat colour of African donkeys looks as if it might contribute to heat tolerance, but the coat structure is thin and no marked temperature gradient has been measured between the outer hair surface and the skin (Bullard et al, 1970).

Figure 14. The relation between proportion of light-coloured cattle in herds and potential evaporation in Kenya.



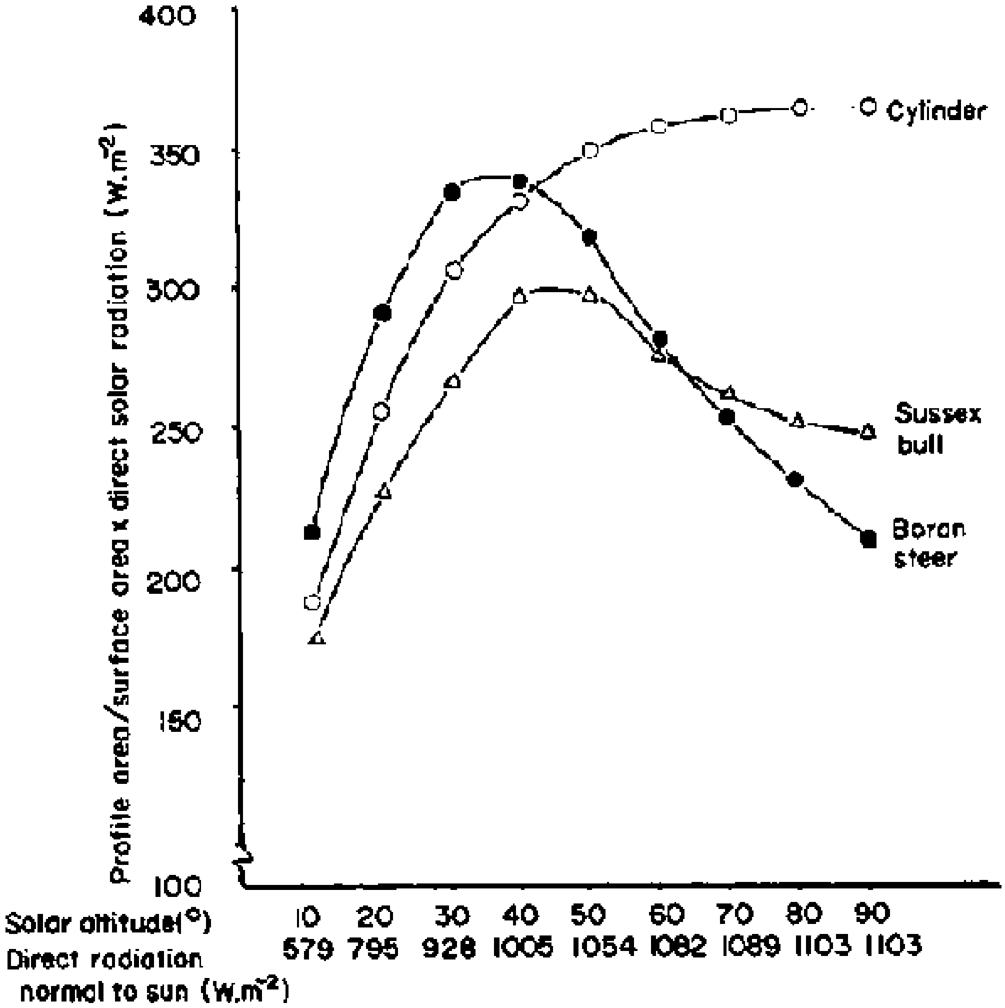
Source: Finch and Western (1977)

4.2.5 Mass, shape and appendages

Although the outward appearance of an indigenous animal cannot be used in isolation from its internal physiological adaptations to explain its suitability for particular environment (McDowell, 1972), external body characteristics do play a role in the interaction of the animal with its environment. Their effect on body water turnover is exerted primarily through their influence on the heat exchange of the animal. For example, a large body mass may be an advantage in absorbing residual body heat, but if the sun is the main source of heat load, the less direct sunlight that is absorbed by the body the better. Therefore the profile area at right angles to the solar beam should be as small as possible, particularly at solar altitudes between 40 and 90° when radiant intensity is reaching its peak. At these higher solar altitudes it has been shown that the profile areas of cattle decrease in proportion to their total surface area at a rate greater than radiant intensities are increasing. This results in a decrease in heat absorbed at higher solar altitudes (Finch, 1976). For a cylinder, the ratio of the profile area to total surface area remains constant, and the radiation absorbed continues to increase at higher solar altitudes (Figure 15). Thus at midday the direct solar radiation absorbed by a Boran steer is only 58% of that absorbed by a cylinder. The radiation absorbed by a Sussex bull has been shown to be 17% more than that absorbed by a Boran steer. This difference may be partly explained by the fact that the entire male has a thicker neck and shoulders than the steer, but it may also be due to the Sussex having a broader and longer back than the razor-backed zebu.

A number of hypotheses have been formulated concerning the effects of climate on the mass and shape of animals. Bergson's rule states that similar or related animals are smaller in warm regions than in cold ones, and Allen's rule that the peripheral parts of animals in hot regions are extended. Mount (1979) has shown that pigs reared at 5°C had shorter limbs, smaller ears and were more hairy than their litter mates reared at 35°C. Edney (1966) suggested that the advantage of long legs, neck and ears is to present a greater surface area for convective cooling.

Figure 15. Variation in the amount of direct shortwave radiation absorbed at different solar altitudes by a cylinder, a Sussex bull and a Boran steer.



Source: Finch (1976), which includes data from Riemerschmid (1943).

In sub-Saharan Africa, another generalisation seems to apply - namely that wild and domestic ungulates are smaller in the hot, humid regions than their conspecifics in the hot dry savannas (Dorst and Dandelot, 1970; ILCA, 1979a; 1979b). Pagot (1974) noted an association between the volume of a cow's body and the surface and position of the climatogram for the place in West Africa where it had evolved. The salient features of the climatograms have been summarised in Table 21, which shows an inverse relationship between bodyweight or height against atmospheric humidity at similarly high mean ambient temperatures. The places referred to in the table are the same as those for which the THI has been plotted in Figure 11. The conclusion is that, notwithstanding the accepted influences of genetics and disease, the evolution of dwarf breeds may also be related to a chronic hormonal response to an environment in which it is difficult to dissipate heat (see also section 4.1.3).

The indigenous *Bos taurus* breeds of West Africa have been displaced from all but the tsetse fly belt of Africa by zebu cattle and their established Sanga crossbreeds with the pure *Bos taurus*. The reasons behind the success of zebu will be examined further in section 7.3.2. The conspicuous features of mass, shape and appendages of the animal have been assumed to have something to do with its more successful adaptation to drier environments. However, the experiments carried out to test this hypothesis have proved difficult to evaluate, particularly when they do not relate to the kind of environment in which the zebu normally thrives. An example of such an environment on Galana ranch in Kenya is given in Table 22, and will be referred to in the ensuing discussion.

Table 21. Height and weight of various races of West African cattle and the climate where they evolved.

		Adult cow				Mean temp.		Mean relative humidity	
Species	**Breed**	**Withers height (cm)**	**Weight (kg)**	**Place**	**Altitude (m a.s.l.)**	**°C**	**SE±**	**%**	**SE±**
Bos indicus	Zebu	>125	350	Tahoua,Niger	386	28	1.3	38	7.4
Bos taurus	N'Dama	110	280	Labé, Guinea	1025	23	0.5	66	5.2
Bos taurus	N'Dama	105	260	Odienné, Ivory Coast	432	27	0.4	70	4.4
Bos taurus	Savannah WAS[a]	95	200	Bouaké, Ivory Coast	376	27	0.3	75	2.3
Bos taurus	Dwarf WAS	85	170	Cotonou, Dahomey	167	28	0.4	83	0.8

[a] WAS = West African Shorthorn.
Source: Pagot (1974); ILCA (1979a; 1979b).

The larger size of the zebu (especially Boran cows weighing 400 kg) is appropriate to the hot, dry Galana environment. They are reputedly better walkers than *Bos taurus* breeds, but it is unclear if this attribute has been tested or if zebu have proportionately longer legs. The main heat load is from solar radiation and so the narrow, short profile to the sun is relevant, particularly when examining skin area in relation to size. According to Brody (1945) and Macfarlane (1964), *Bos indicus* cattle have a greater surface-area to mass ratio (12 - 20%) than *Bos taurus*. However, Branton et al (1966) found that the differences were more apparent than real in some zebu cross-breds, especially after adjusting for weight at constant age, because what some *Bos taurus* cattle lack in appendages they make up for in extra body length. The appendages of the zebu, notably the dewlap and navel fold, are poorly vascularised and not adjacent to the main sources of heat production in the body, which reduces their value as radiators and convertors (McDowell, 1972). On the other hand, the location of the skin folds on the dependent parts of the neck and trunk increases surface area without increasing exposure to the sun at midday.

Table 22. Example of an environment in which zebu cattle thrive: Galana ranch, Kenya, 180 m a.s.l.

Environmental factor	Mean	Maximum	Minimum
Annual rainfall (mm)	500	1000	150
Annual potential evaporation (mm)	2200	2500	2000
Daily solar radiation ($W.m^{-2}$)	500	600	400
Ambient temperature (°C):			
daily maximum	33.5	37.9	28.2
daily minimum	21.0	23.7	14.2

daily range	12.5	16.6	8.8
Daily wind speed (km.h^{-1})	8.7	12.8	4.7
Values at 15.00h for:			
ambient water vapour pressure	2.5	4.2	1.9
THI	81.3	86.5	76.7

Source: Woodhead (1968); Bille and Heemstra (1979); J.M. King (unpublished).

The sweat rate on the dewlap was 70% lower than elsewhere (McDowell, 1972). The density of sweat glands was also 36% lower on the dewlap than on the side of Sindhi and Sahiwal cattle, but still 10% more than on the sides of Jersey, Friesian and Red Poll cattle (Nay and Hayman, 1956). Sweating is undoubtedly an efficient way of cooling for the zebu, because the ambient vapour pressure is usually low (Table 22). Yet, in an environment in which water is severely limited for much of the year, it seems unlikely that cattle could maintain high sweating rates for very long without suffering severe dehydration (section 3.2.1). Radiant heat loss is probably the main component of loss because the mean temperature gradient is from the animal to the environment. It is augmented by convection, particularly in the late afternoon when wind speed is at its highest (Tables 22 and 23).

Table 23. Rectal temperatures (°C) of hydrated livestock in Africa.

Species	Rectal temperature (ºC)
Camel	36.0-39.3
Horse	37.5 -38.3
Cow	37.6-39.0
Pig	38.3-39.3
Sheep	38.3-40.5

Source: Schmidt-Nielsen (1965), MacKenzie and Simpson (1971); Degen (1977c).

The ears of zebu cattle are larger than those of European breeds but, although they are very vascular, their surface area in relation to total body surface area is small (2%), making them of questionable significance in terms of overall heat loss capability (McDowell, 1972). However, the capacity of the vascular bed and the blood flow can be increased by vasodilation and arterio-venous anastomoses, which have been found in the ear of the calf (Goodall, 1955). Peripheral vasodilation is important in allowing heat flow to the skin surface for evaporative, radiative and convective heat loss (Thompson, 1976). For these last two avenues of heat loss to be effective there must be a marked temperature gradient between the ear and the environment, which is not usually present during the heat of the day. Animals such as the elephant, which use their ears for cooling, do not dilate the blood vessels and increase blood flow in the ear until about 18.00h. Then the temperature in the ear becomes higher than that of the general body surface as well as the environment (Hiley, 1975).

There is one other conspicuous appendage, namely the hump, which increases in size as a zebu improves in condition. It has been postulated that localised storage of fat may reduce the interference of fat layers over the body with the dissipation of heat (Schmidt-Nielsen, 1965). On the other hand insulating layers of fat could work both ways, and need not interfere with the transference of heat from the body core to the surface via the cardiovascular system. Looking at the hump in terms only of heat exchange and energy storage may be wrong, because it contains a considerable amount of lean and fibrous tissue which could relate to the zebu's role as a draught animal in its places of origin in Asia (McDowell, 1972), a role which it still occupies in parts of Africa, particularly Ethiopia.

An attempt was made to assess the collective value of these appendages for heat loss by comparing the response to heat stress of intact zebu (Red Sindhi) bulls with those from which the dewlap, hump and about 10 cm of each ear had been removed (Branton et al, 1966). The authors concluded that there was no justification for the popular association of a superior heat loss capacity with the external characteristics typical of zebu breeds. However it is difficult to relate their experiment to the real world in which the African zebu is to be found. The thermal stress applied in the laboratory was a temperature of 35 - 40°C and a relative humidity of 60% for 6 h. In such conditions the temperature gradient from the animal to the environment could be reversed, and conductance of heat into it would then be reduced by vaso-constriction (Schmidt-Nielsen, 1965; 1972). The appendages would therefore have been a disadvantage unless they were the prime site for sweating, which they were not. The THI in the laboratory was much higher, at 92.8, than that on Galana ranch, which was 81.3. The latter value is high enough to cause discomfort in temperate-type cattle (Figure 11) but the THI is not the most appropriate description of the main heat load, which is from the sun, for which the size, shape and appendages of the zebu may be adapted. One of the two criteria taken to indicate susceptibility to heat stress,- namely raised rectal temperature and respiratory rate, is also suspect because it fails to take into account the value of a labile body temperature (section 4.2.7) in a natural environment with a reasonable diurnal temperature range (Table 22) and a shortage of water.

The zebu cow may not be the best example of adaptation of mass, shape and appendages to the natural thermal environment by African livestock. The preceeding discussion could have focused on other long-legged, razor-backed desert livestock with fat humps, rumps or tails. For example, the large, pendulous ears of the black-haired and black-skinned Nubian goat look particularly functional: the dorsal surface of the ear is covered with short grey hairs, presumably to reduce absorption of solar radiation.

4.2.6 Body temperature fluctuation

All mammals must maintain a fairly stable deep body, or core, temperature in spite of fluctuations in the environmental temperature and the animal's activity. However, different species and breeds tolerate slightly varying ranges of core temperature, and this characteristic may be related to environmental heat tolerance. Marked departures from the core temperature are associated with extremes of ambient temperature, disease, injury or the administration of drugs (Mount, 1979).

In a moderate African climate, most hydrated ruminants show a diurnal fluctuation in core temperature of 1.5 to 3.9°C (Bligh and Harthoorn, 1965). This diurnal fluctuation is due to some heat storage during the day and heat loss at night. Any further rise in core temperature is accompanied by an increase in evaporative heat loss and some depression of endogenous heat production. A drop in core temperature causes energy expenditure as thermogenesis.

East African sheep and goats are examples of animals with a narrow range in core temperature, i.e. they are obligatory homeotherms. These species appear unable to increase their range of diurnal body temperature by more than 1-2°C in response to heat stress (Maloiy and Taylor, 1971). Instead, they maintain a relatively constant body temperature by panting as soon as they are subject to heat stress. Water intake in African sheep has thus been related directly to respiration rate (Quartermain, 1964), and it has been assumed that the heat tolerance of both species depends on the availability of water to support heat loss by evaporation (Bligh, 1972). Degen (1977c) has pointed out that sheep have relatively high rectal temperatures of 38.7 to 40.5°C, which implies that they absorb less environmental heat and use less evaporative water than might have been expected.

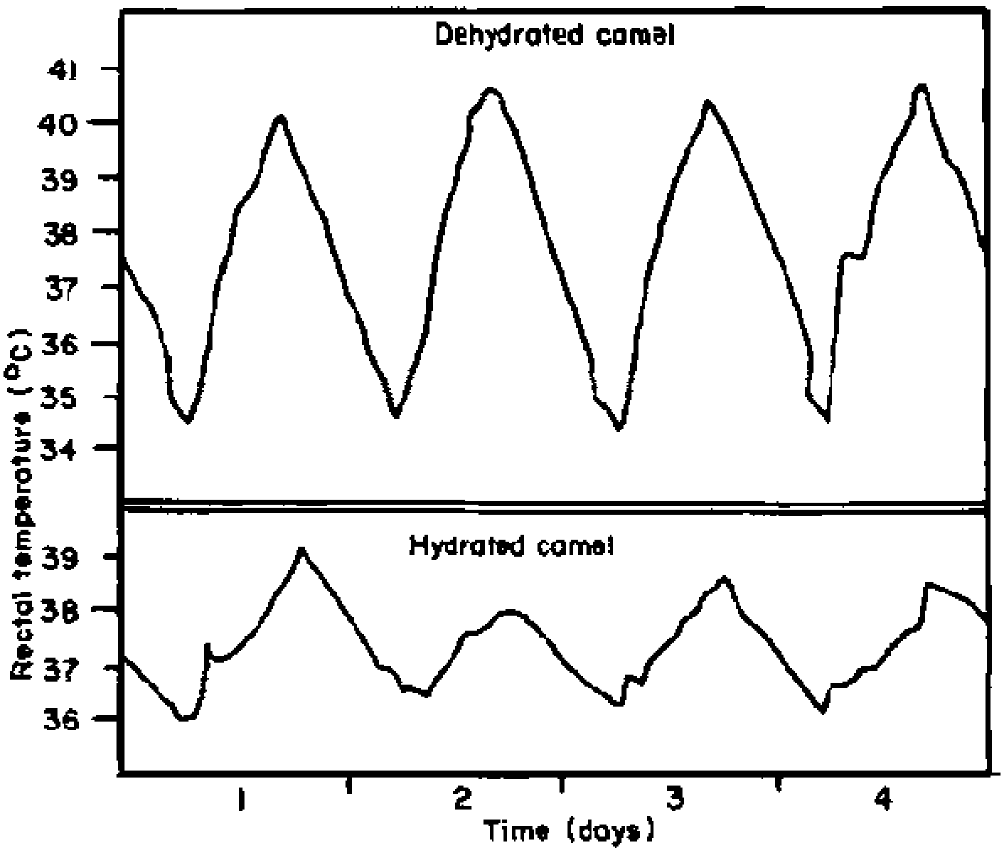
African donkeys also have a narrow range of core temperature, from 37 to 39°C in fully hydrated animals. Under heat stress, they keep their core temperature within this range by evaporative cooling, with a sweat rate 2.5 times that of camels (Schmidt-Nielsen, 1965).

By contrast, the variability in core temperatures is particularly wide among N'Dama cattle. During March in the Gambia, when the days are hot and sunny and the nights are cool and windy, the mean rectal temperature of 10 N'Dama cattle tethered in the open with *ad lib* food and water was 35.9 ± 0.77°C in the early morning and 39.7 ± 0.84°C in the late afternoon, giving a range of 3.8 ± 0.84°C with or without trypanosome parasitaemia. Extreme values were 34.4 to 41.1°C, with a range of 6.7°C in one animal, apparently related to greater exposure to solar heat load (Greig and McIntyre, 1979). The N'Dama requires far less water than the zebu (Pagot, 1974), probably as a result of this high thermolability.

When an animal is dehydrated there is often a further extension of the thermoneutral zone by an upward shift in the threshold temperature for evaporative heat loss and a downward shift in the threshold temperature for heat production (Bligh, 1972). The best known example of this increased diurnal core temperature fluctuation in response to dehydration is in the camel (Figure 16). The animal saved about 1.3% of its body water pool by allowing its body temperature to rise from 34°C to 41°C during the day and disposing of the stored heat at night. An important reduction in heat gain from the environment was also achieved at high body temperatures due to the reduced temperature gradient. The combined effect of these two factors was observed to reduce heat dissipated by a 260 kg camel during the 10 hottest hours of the day in the Sahara to 380 kJ, compared with 1265 kJ in the hydrated state. Water lost by evaporation was reduced from 9.1 to 2.81, that is from 4.7% to 1.4% of the body water pool (Schmidt-Nielsen, 1965).

More recently, loss of homeothermy at night has been demonstrated as a response to starvation. Boran steers on daily watering but half-maintenance rations allowed their body temperatures to drop to 36.8°C compared with 37.8°C in steers on a maintenance ration. The saving in thermogenesis was estimated as 740 kJ, without which the starving cattle would have had to raise their metabolic rate 1.3 times. There was also a lowered sweat rate, so that the body temperature rose rapidly during the morning but was then regulated at the upper range for well fed cattle. The advantage of regulating heat storage in this way lay not in conserving water (although water loss was reduced), but in maintenance of body temperature at an optimum level for metabolic efficiency (Finch and King, 1982).

Figure 16. Daily temperature fluctuation in a hydrated and dehydrated camel.



Source: Schmidt-Nielsen (1965)

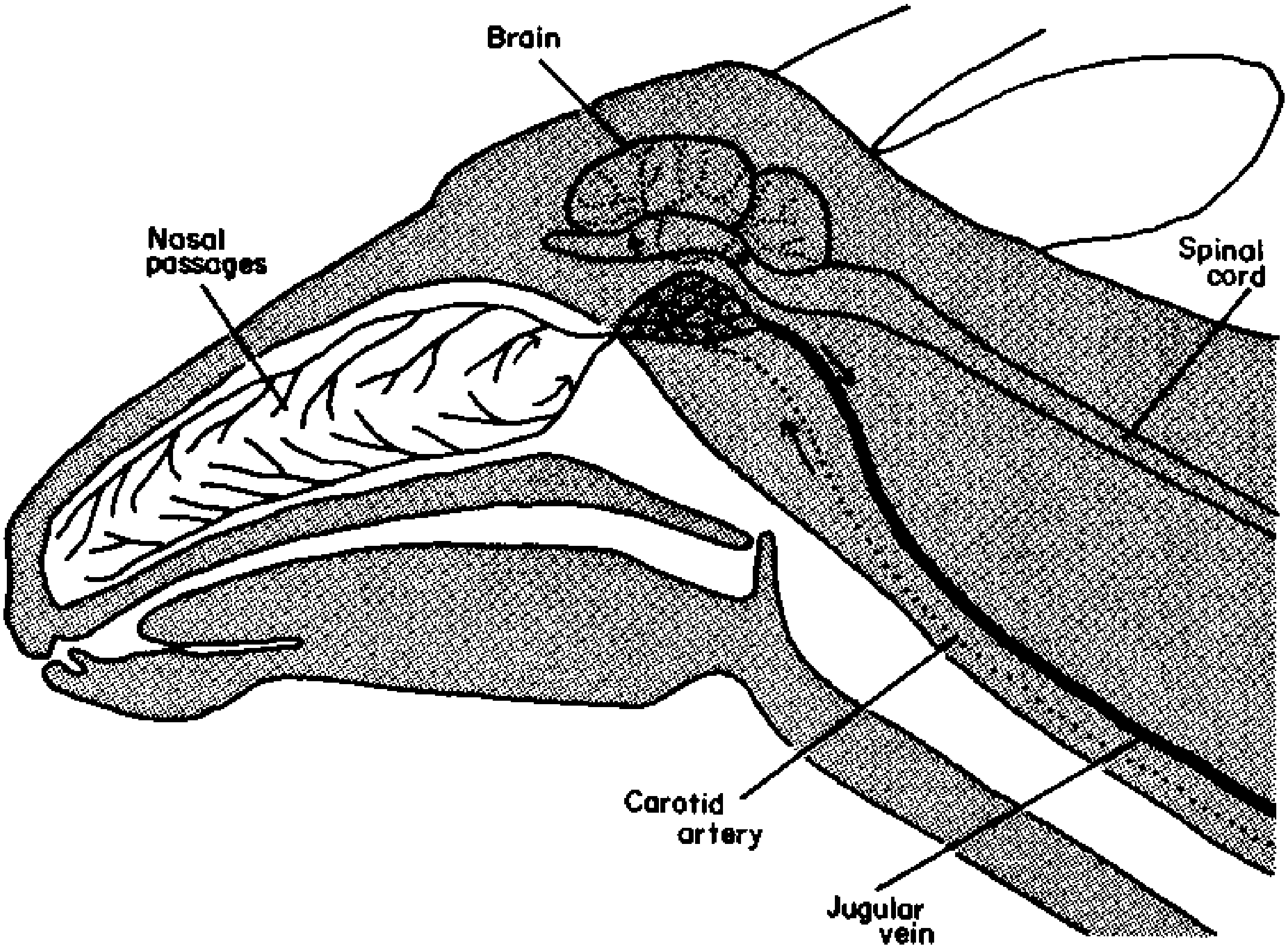
Thermolability is exploited in different ways by African game animals, according to their size. The core temperature in an eland can be as low as 32.8°C in the early morning. It takes a lot of solar energy to raise the body temperature to nearly 40°C, when evaporative cooling is initiated. In small animals such as the gazelle, weighing 10 to 60 kg, the body heats up too quickly in the sun for the low early morning temperature to conserve much water. Instead, the upper critical temperature is allowed to rise quickly from 40°C to about 42°C without initiating panting or sweating, thereby reducing the temperature gradient to the environment. The oryx, a desert dwelling ruminant of intermediate size weighing about 150 kg, employs both mechanisms (Taylor, 1970a; 1970b).

4.2.7 Counter-current cooling

The term counter-current cooling refers to the flow of blood in opposite directions in contiguous blood vessels. The heat in the arterial blood, which is coming from the body, is transferred to venous blood from the surface, so that the arterial blood is cooled before it reaches the brain.

The lethal limit to the rise in core temperature is about 6°C above the normal maximum, and depression of central nervous activity, particularly in the respiratory centre, occurs before that (Schmidt-Nielsen, 1975). Yet rectal temperatures as high as 46.5°C have been observed in running antelopes, and may be a normal response. Overheating of the brain in such circumstances is prevented by selective cooling of its blood supply. In ungulates this supply comes primarily from the external carotid artery, which passes through a pool of venous blood at the base of the brain where it divides into a rete (network) of fine vessels. The venous blood comes mainly from the rich submucosal capillary network of the nasal turbinate bones. These capillaries have been cooled by evaporation from the walls of the nasal passages as the animal breathes (Figure 17). It follows that selective cooling of the brain is probably better developed in ungulates that pant rather than sweat to lose heat. Nevertheless, the carotid rete has been demonstrated in domestic bovids and the oryx, and may be called into play when the animal is dehydrated (Daniel et al, 1953; Taylor, 1969). Apart from saving water by limiting evaporative cooling to the brain and not the whole body, the amount of water vapour lost may be reduced by recondensation in a well developed nose. Hoppe (1977) observed that droplets of water appear at the nostrils of the dik-dik, and that these are immediately licked off and swallowed. He also remarked that the trunk-like nose is longest in Gunther's dik-dik, which lives in the hottest areas inhabited by these species.

Figure 17. Heart of an ungulate showing counter-current cooling mechanism to reduce the brain temperature[a].



[a] *Counter-current cooling of arterial blood on its way from the heart to the brain occurs in the cavernous sinus, where the carotid artery ramifies into hundreds of smaller vessels (........). There venous blood (--------) from the oryx's nasal passages, cooled by respiratory evaporation, lowers the arterial blood temperature. Arrows indicate direction of blood flow. A brain cooler than the body temperature may be vital to desert survival.*

Source: Taylor (1969)

Selective cooling of the brain to less than 41°C, which was 2.9°C below body temperature, has been demonstrated in sheep, goats and gazelle (Baker and Hayward, 1968; Taylor and Lyman, 1972; Degen, 1977c). In the goat, an additional source of heat exchange can be provided by the horn, which is the only superficial area that has a major drainage through the cavernous sinus (Taylor, 1966). There does not appear to be any information on the possible thermo-regulatory function of the horns of other tropical ruminants.

Counter-current cooling also occurs in the scrotum, because spermatogenesis is suppressed at normal rectal temperatures. The combination of dropping the testes away from the body and coiling the artery round the scrotal veins results in a temperature of the testes about 6°C below the core temperature of a ram in an ambient temperature of 21°C (Waites and Moule, 1961).

4.3 Water availability

The effect of excess water intake is to raise body water turnover. This excess is rarely caused by drinking but is commonly caused by very green forage (sections 3.3.1 and 3.3.2). Lack of water is associated with dry forage and an inadequate watering regime. It obviously causes a reduction in body water turnover, but the way it does so is of interest.

4.3.1 Watering regime

For the watering regime to be adequate for ungulates eating dry forage, the following criteria must be met: the degree of dehydration must not exceed the temporary water holding capacity of the alimentary tract; the animal must have enough time to drink its fill; and the frequency of watering must be such as to prevent body water loss from reaching the stage of clinical dehydration.

In general, ruminants can replace 15-20% of their bodyweight at the first drink and 20-25% within 1-2.5 hours (section 3.3.1). The capacity and speed of fluid replacement appears to be higher in the more arid-adapted animals. For example, Saharan camels, weighing presumably about 450 kg, tolerate a loss of 100 l body water and replace it within 7-30 minutes (Gauthier-Pilters, 1974). Haired sheep and goats can drink up to 24% of their hydrated bodyweight in a few minutes. Dehydration does not reach a critical level in Indian desert sheep until they have lost 30% of their bodyweight, which is the stage at which Bedouin goats stop eating (Taneja, 1965; Shkolnik et al, 1972; More and Sahni, 1978; Williamson and Payne, 1978; C.R. Field, unpublished).

The donkey has a depressed appetite at 20% dehydration, but can restore all the water lost in 2-5 minutes. The ingested water floods the whole alimentary tract right up to the anal sphincter (Schmidt-Nielsen, 1965; Maloiy, 1970).

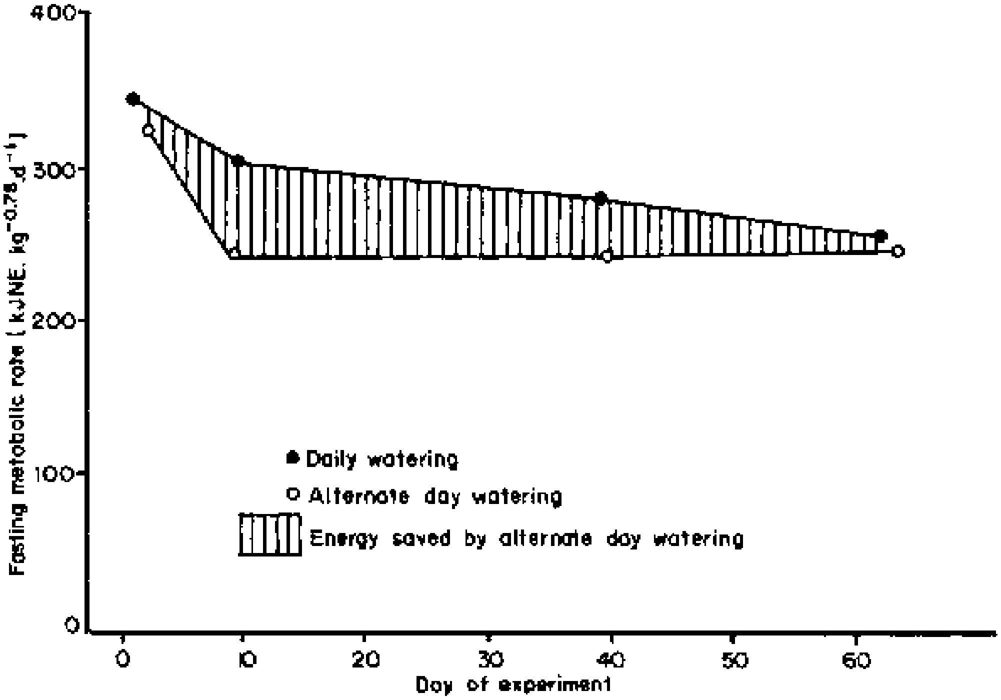
4.3.2 Water restriction

The effects of water restriction are felt mainly in the areas of energy production (section 4.1) and thermoregulation (section 4.2).

Where food is freely available a reduction in water intake reduces food intake. For example, when access to water was reduced to 1 h at 48 h and 72 h intervals, zebu oxen reduced their consumption of chaffed hay to 94% and 92% of their intake when water was available all the time. Their water consumption also decreased to 88% and 69% respectively of the original intake. All decreases were highly significant. There was no significant decrease in the starch equivalent consumed on 48 h watering, despite the 6% reduction in DMI. The reason was that more of the crude fibre fraction of the hay was digested than when water was freely available. There was, however, a significant lowering in energy intake when watering frequency was reduced to once every 72 h (French, 1956b).

When fed a ration which provided only half their maintenance needs, zebu cattle on alternate day watering suffered no restriction of appetite compared with those on daily watering. But the reduction in their fasting metabolic rate to two thirds the value at maintenance (section 5.1.2) occurred more rapidly (Figure 18). The resultant energy saving, due to the quicker drop in demand, was estimated at 66 MJ NE (95 MJ ME) less than in cattle on daily watering (Finch and King, 1979). This work needs repeating because of the limited number of points on the graph.

Figure 18. The effects of daily and alternate day watering on the metabolic rate of zebus walking 16 km. d^{-1} on a half maintenance ration.



Source: Finch and King (1979)

When the quality of grazing is low, cattle voluntarily restrict their intake and turnover of water, thereby controlling their nitrogen balance and achieving protein maintenance on diets which would normally be below maintenance requirements (Payne, 1963). The reason is that, on a low nitrogen diet, a high water intake and high urine volume flush urea out of the plasma so that it is not available for re-use in protein nor to stimulate microbial digestion of crude fibre. Thus differences in performance between animals fed a low nitrogen diet, or those grazing pastures low in nitrogen, may be partly related to differences in nitrogen metabolism caused by differences in water intake (Vercoe, 1971).

Lack of residual water for cooling and its effect on the ruminant, notably on thermolability and endogenous heat production have already been discussed in sections 4.2.6 and 4.1.3 respectively.

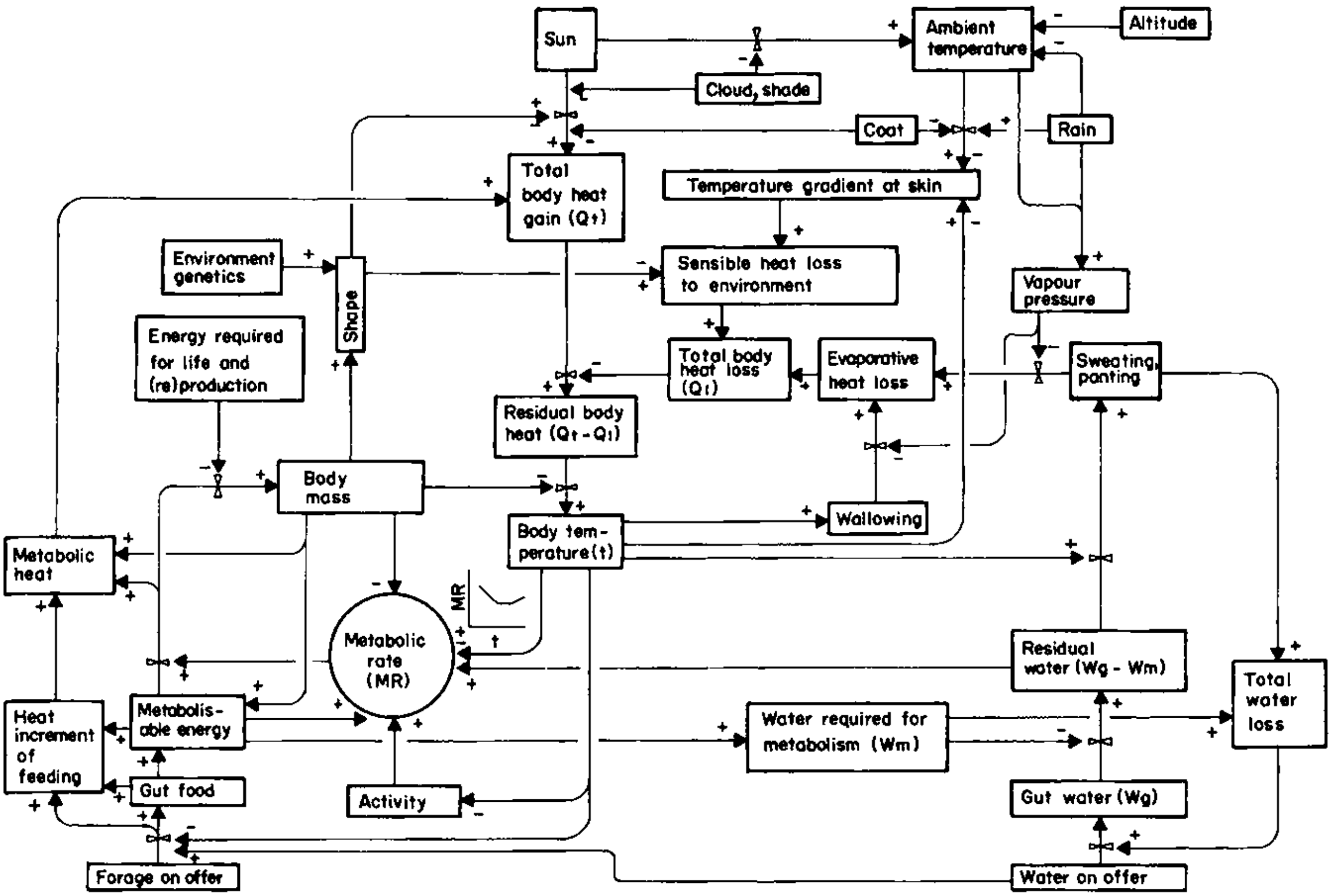
Donkeys are relatively unaffected by a water loss of 12 to 15% of their bodyweight. Food intake decreases by 27% at 15% dehydration, but this decrease is associated with an increase in apparent digestibility from 41 to 51% due to a longer retention time, particularly in the large intestine, which favours microbial digestion. Evaporative water loss also falls by about 50%, notably through the skin, and this is associated with an increase in respiratory rate and range of rectal temperature by 2 to 5.2°C. At between 15 and 30% dehydration, appetite is depressed and hence water loss through faecal output is decreased to 20% of the fully hydrated levels (Schmidt-Nielsen, 1965; Bullard et al, 1970; Maloiy, 1970; 1972).

4.4 Integration of energy metabolism, thermoregulation and water

Figure 19 provides a model of ungulate water needs in relation to climate and forage. It integrates the factors discussed above and illustrated in Figures 6,7 and 8.

The core of the model is the animal's body temperature, shown in the centre of the figure. This temperature must be maintained above a lower critical level to support respiratory function and metabolism, and below an upper critical limit to prevent heat death. The main source of heat gain at night is endogenous coming from intermediary metabolism, which is shown on the left half of the figure. The body temperature is above that of the environment and heat is lost from the skin by conduction, convection and radiation. This sensible heat exchange is illustrated in the middle of the right-hand segment of the figure. During the day, the sun heats up the animal and its environment, as shown at the top of the figure, causing a net inflow of heat to the body. Sensible heat loss may no longer be enough to control body temperature and the animal has to draw on residual water, surplus to metabolic requirements, for additional cooling. The body water cycle is illustrated in the bottom right-hand corner of the figure, and the contribution of sweating and panting to total heat loss is above it and to the left. A lack of residual water for cooling will cause a reduction in the contribution of sweating/panting to total heat loss, thereby allowing the body temperature to rise. The effect will be twofold: (a) to increase the temperature gradient at the skin and hence the sensible heat loss; and (b) to reduce activity and forage intake and hence the metabolic heat contribution to total body heat gain. The two feedback mechanisms combine to reduce residual body heat and hence body temperature.

Figure 19. Ungulate water needs in relation to climate and forage.



5. Energy and water use in pastoral systems

The purpose of this chapter is to relate the physiological aspects of water and energy turnover discussed in chapters 2 to 4 to the real-life situation as influenced by climate and livestock management. Emphasis will be placed on the dry season when water is scarce, and on the more important livestock species.

The effects of the different seasons on domestic herbivores are well illustrated in a traditional pastoral system because there is little opportunity to alleviate adverse conditions with supplements of food and water.

5.1. Analytical background

The way in which the energy use of the grazing animals is affected by different watering regimes can be simulated in simple tables. The level of detail is much coarser than that shown in Figure 19 and described in chapters 2, 3 and 4, but it is beyond the scope of this report to try and develop a complicated model. Instead, a number of assumptions have been made: the environmental heat load has been kept constant between watering regimes, and is assumed to be high. As a result, drinking water intake has been elevated by a constant related to temperature and varied primarily by DMI. The prediction of forage intake has not been discussed so far, and it must be established along with energy to allow the completion of simple energy budgets.

The zebu has been used in this illustration because it is the most important species of livestock in sub-Saharan Africa.

5.1.1 Energy units

Metabolism in the ruminant is currently expressed in one of two ways derived from different systems of analysis: one based on metabolisable energy (ME), proposed by Blaxter (1962), adopted by the UK Agricultural Research Council (ARC, 1965) and put into practice by the Ministry of Agriculture, Fisheries and Food (MAFF, 1975); the other, based on net energy (NE), proposed by Lofgreen and Garrett (1968) and adopted by the USA National Research Council (NRC, 1970). The relative merits of each system have been reviewed by Webster (1978), who points out that it does not matter which convention one uses provided that one recognizes that it is not possible to combine estimates of the energy value of foods from one system with estimates of the energy requirements of the other and get a sensible answer. The reason is that the expressions are based on different conventions.

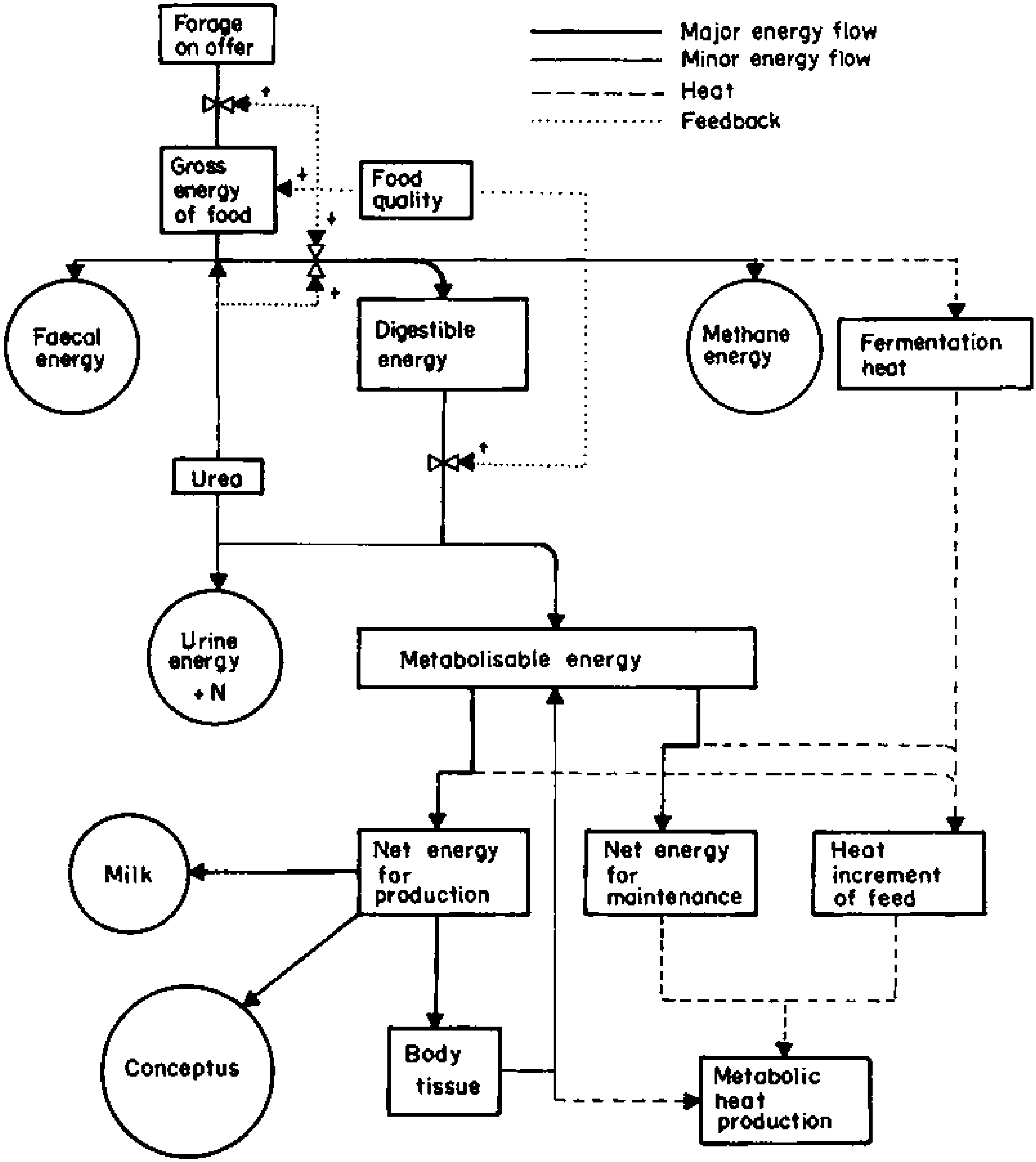
For the purposes of the present analysis, ME units have been chosen. Therefore other components of energy metabolism in the ruminant, which is illustrated in Figure 20, must be converted into ME, using coefficients which will be described in the text. Most of these coefficients have been taken from

Konandreas and Anderson (1982), and modifications from other sources have been cited.

5.1.2 Forage intake

Forage availability varies with season for a given set of soil and vegetation types and conditions. These seasons have different climatic characteristics in different parts of sub-Saharan Africa: in East Africa there are two dry seasons, one hot and one cool, each year; in West Africa there is only one dry season, which begins cool and becomes hot; and in central and southern Africa there is a single cool dry season. Such differences affect water turnover more than energy intake and use. Therefore, one can generalise by stating that at the start of the dry season conditions are uniformly good for food intake; there is usually an adequate crop of standing hay, and intake of nutrients is not depressed by lack of drinking water, by a high parasite challenge or by high THI. Thereafter there is increasing dessication of the vegetation and drying up of watering places as the dry season progresses. Thus there is a steady decline in the quality and quantity of herbage on offer, except where pastoralists exploit floodplain grazing, such as that of the inland delta of the Niger in Mali (Wilson et al, 1983).

Figure 20. Energy metabolism in the ruminant.



Within the animal, the process of conversion of feed sources of energy into animal products can be divided into the absolute capacity of the animal to ingest metabolisable energy, and the partial efficiencies of the conversion processes themselves. These are equally important (Blaxter, 1969b).

Before describing the way in which forage intake is currently predicted, it is worth mentioning the reservations that have been expressed about the approach, particularly in the tropical situation. These reservations have been summarised by Freer (1981) as follows: 'There are at least three areas where the simple model based on the amount of herbage and its digestibility avoids important complexities of the real situation.... Firstly it is probable that weight per unit area is an insufficient predictor of the availability of herbage to a grazing animal. Secondly it is certain that digestibility is an inadequate index of those quality changes in herbage wich affect its rate of disappearance from the gut. Van Soest (1982) found that there was a higher correlation between intake and plant cell wall content (- 0.76) than intake and digestibility (0.44) in 187 forage species tested. Freer (1981) continues: And lastly, little is known on how the two variables (weight and digestibility) interact with increases in energy demand, during growth and lactation for example, to increase intake. But he goes on to point out that more experimental information is needed before substantial improvements can be achieved.

In the meantime the amount and digestibility of the herbage on offer will continue to be the principal components of the model of forage intake, particularly as they have been studied comprehensively in an African situation (Elliot and Fokkema, 1961; Elliot et al, 1961). The general relationship obtained to determine intake has been developed by Konandreas and Anderson (1982) to give the following equation:

$I = m(d,t).\ m(Q).\ m(D).\ m(t).\ m(x,t)$

$m\ (p,t).a.W_e^{-0.73}$ (5.01)

Each variable is listed below with its range of values likely to be obtained for pastoral cattle in the dry season:

I = dry matter forage intake ($kg.d^{-1}$)

$m(d,t)$ = digestibility-of-forage-correction multiplier = $1/(1-d)$, where d = digestibility between 0.40 and 0.65

$m\ (Q)$ = quantity - of - forage - correction multiplier ($t.ha^{-1}$), with forage on offer (Q) varying from 0.7 - 2.1 with threshold for intake reduction (Q^x) 0.8. Thus

$m(Q) = 1$ at all values for $Q\ {}^{3}0.8$, and Q/Q^x below 0.8

$m(D)$ = grazing-time-correction multiplier, a function of the distance walked per day (D), which above 14 km (D^*) reduces forage intake by $1.0 - 0.05\ (D-D^*)$; otherwise $m(D) = 1.0$

$m(t)$ = age-correction multiplier = 1

$m(x,t)$ = sex-correction multiplier = 1

$m(p,t)$ = physiological-status-correction multiplier, which for dry females = 1, and for lactating cows = 1.15, partially due to an increase in chewing and ruminating (Dulphy et al, 1980)

a = intake coefficient ($kg\ DM.kg^{-0.75}.d^{-1}$) which is equivalent to the rate of pas sage, and taken as 0.042 for dry cows and 0.049 for lactating cows

W_e = expected liveweight (kg) for animal's age and sex.

The gross energy content of tropical pasture is relatively constant (17.2 to 18.7 $MJ.kg^{-1}DM$), giving a mean value of about 18 $MJ.kg^{-1}$, which is about 0.5 $MJ.kg^{-1}$ less than the mean for temperate pastures (Minson, 1981). As shown in Figure 20, portions of this energy are lost as faeces, urine, methane, and fermentation heat during the conversion to ME. Thus the energy (E) from a given intake (**I**) can be expressed as:

$E = \mathbf{I} \times 18 \times d \times 0.81$ MJ ME (5.02)

5.1.3 Energy use

Energy demands vary with the body functions for which energy is used. Thus the net energy (NE) demands of the product (e.g. lactation, growth) are converted back to ME using different coefficients. For maintenance the NE, or total metabolic heat production, is estimated from a specific variant (Table

24) of the general formula for fasting metabolism: 0.293 Wt $kg^{0.75}$ ($MJ.d^{-1}$), more familiar in its original form of 70 Wt $kg^{075}kcal.d^{-1}$ (Brody, 1945; Kleiber, 1947). The amount of ME used for maintenance in the zebu cow can be estimated from the equation:

$$E_m = 0.343\ Wt^{0.73}/k_m \text{ MJ ME} \quad (5.03)$$

where k_m is the efficiency with which ME is used for maintenance and

$$k_m = 0.55 + (0.3 \times 0.81 \times d) \quad (5.04)$$

To maintain bodyweight, the cow must also graze and walk to water, which increases energy expenditure above basal rates by 30-70% (Young and Corbett, 1972; Lewis, 1975).

The cost of prehension, tearing and eating coarse dry grass has been estimated at 40 $kJ.MJ^{-1}$ ME of ingested food, based on Webster (1980).

The energy cost of walking per horizontal km is similar for *Bos taurus* and *Bos indicus* cattle on a diet at or above maintenance. The most efficient speed is between 2.5 and 3.5 km. h^{-1} when the cost is 1.8 $kJ.kg^{-1}$ (Ribeiro et al, 1977; Finch and King, 1979). At faster and slower speeds the energy cost per metre increases.

Productive uses of energy include growth, pregnancy and lactation. The ME used for lactation is calculated from the NE required for milk, divided by the efficiency with which ME is conversed to NE for lactation. This efficiency (k_1) is less than for maintenance:

$$k_1 = 0.463 + (0.24 \times 0.81 \times d) \quad (5.05)$$

The NE requirements for milk are calculated from the milk yield ($kg.d^{-1}$) multiplied by its energy content (e_1). The energy content is given approximately by the following equation:

$$e_1 = 0.0386BF + 0.205SNF - 0.236 \quad (5.06)$$

where

BF = butter fat content ($g.kg^{-1}$), and
SNF = solids-not-fat content ($g.kg^{-1}$)

For the zebu, BF = 54 $g.kg^{-1}$ and SNF = 85 $g.kg^{-1}$ (Williamson and Payne, 1978 while e_1 = 3.6 $MJ.kg_{-1}$.

The efficiency with which surplus ME is converted into energy for weight gain (k_g) is lower than that for lactation. It is obtained by multiplying ME by k_g where:

$$k_g = 0.03 + (0.81 \times 0.81 \times d) \quad (5.07)$$

However liveweight gain during lactation is achieved at a similar level of efficiency as lactation, thus:

$$k_g = k_1 \quad (5.08)$$

The liveweight gain from the available NE derived from equation (5.07) or (5.08) is calculated as follows:

$$DW = Eg/(6.28+0.018W+0.3Eg) \quad (5.09)$$

where

DW = liveweight gain ($kg.d^{-1}$)
Eg = available NE ($MJ.d^{-1}$)
W = present liveweight (kg).

Table 24. Fasting metabolism of livestock.

Species	Weight (Wt) (kg)	Fasting metabolism ($MJ\ NE.\ d^{-1}$)		Equation	Source
		Predicted ($0.293Wt^{0.75}$)[a]	Measured		
Donkey	160	13.2	9.6	0.73 ($0.289Wt^{0.75}$)	CEEMAT(1972) Robinson and Slade (1974) BDPA (1974)
Horse	350	23.7	24.3	$0.289Wt^{0.75}$	CEEMAT(1972) Robinson and Slade (1974) BDPA (1974)
Bovine					
humped	350	23.7	24.7	$0.343Wt^{0.73}$	Rogerson (1968)
humpless					
N'Dama	260	19.0	-	-	
European	500	31.0	35.2	$0.376Wt^{0.73}$	Blaxter (1969a)
European	600	35.5	37.0	$0.305Wt^{0.75}$	Flatt et al (1969)
Camel	450	28.6	20.4	$0.209Wt^{0.75}$	Schmidt-Nielsen et al (1967)
Eland	300	21.1	30.2	$0.464Wt^{0.73}$	Rogerson (1968)
Goat	30	3.8	3.2	$0.251Wt^{0.75}$	Macfarlane and Howard (1972)
Sheep					
British	50	5.5	4.2	$0.243Wt^{0.73}$	Blaxter (1969a)

[a] Source: Kleiber (1947; 1969).

5.1.4 Energy budgets

Simple budgets can now be compiled to simulate real life situations, which are developed further in section 5.2.1. First the parameters listed in Table 25 are derived, in this case from sample data given by Konandreas and Anderson (1982).

The factors affecting energy intake and output can now be estimated separately. For example, forage intake (I) is calculated by inserting the values from Table 25 into equation (5.01):

$$I = 1/1 - 0.50.1.0\ .\ 8.1.1.1\ .\ 15.0\ .\ 049.250^{0.73}$$

which yields an intake of 5.08 kg $DM.d^{-1}$. This value is entered into the energy balance table (Table 26), where it is expressed as MJ ME, using equation (5.02).

5.1.5 Tissue mobilisation

It can be seen from the example given (Table 26), that feed intake is insufficient to meet the animal's total energy requirements. The deficit consists of 12.9 MJ ME for lactation and 0.7 MJ ME for maintenance, and is made good by mobilisation of body tissue. The energy value of the tissue mobilised is taken as 20 $MJ.kg^{-1}$ (MAFF, 1975), although the mean value for the meat in the carcass may be lower (Ledger and Sayers, 1977). It is used with an efficiency of 0.84 to produce milk energy (NE) (ARC, 1980).

The energy yield of milk from each kg of body tissue mobilised is:

$$20 \times 0.84 = 16.8\ MJ\ NE \quad (5.10)$$

This is equated to dietary ME by dividing by k_1 (equation 5.05):

$$16.8 \div 0.560 = 30\ MJ\ ME$$

The amount of tissue mobilised for milk production is therefore:

12.9 ÷ 30 = 0.43 kg

The same efficiency coefficient is assumed when energy released from body tissue mobilisation is used to meet maintenance requirements (Konandreas and Anderson, 1982). Therefore the amount of tissue mobilised for maintenance is:

0.7 ÷ 30 = 0.02

Thus, total daily tissue loss is 0.45 kg.

5.1.6 Response to chronic energy deficit

5.1.6.1 Drough

Table 26 illustrates the 'typical' energy status of a zebu cow about one third of the way through the dry season. Thereafter the quality and quantity of herbage will decrease still further, so that the estimated daily bodyweight loss will increase above 0.45 kg and one might expect the animal to be dead within 2 months. The fact that it is not can be explained by a number of changes that occur in its metabolism, and in its management by the herdsman. These changes must be quantified where possible.

Table 25. Basis for estimation of daily energy budget of a zebu cow watered daily.

Parameter	Absolute value	Unit	Functional form and value	
Forage digestibility	0.50	fraction	d	= 0.50
Herbage (DM) on offer	2.10	t.ha^{-1}	m(Q)	= 1.00
Distance walked	18	km	m(D)	= 0.80
Milk yield	2	kg	m(p,t)	= 1.15
Intake coefficient	0.049	fraction	a	= 0.049
Expected liveweight	250	kg	W_e	= 250

Source: Konandreas and Anderson (1982).

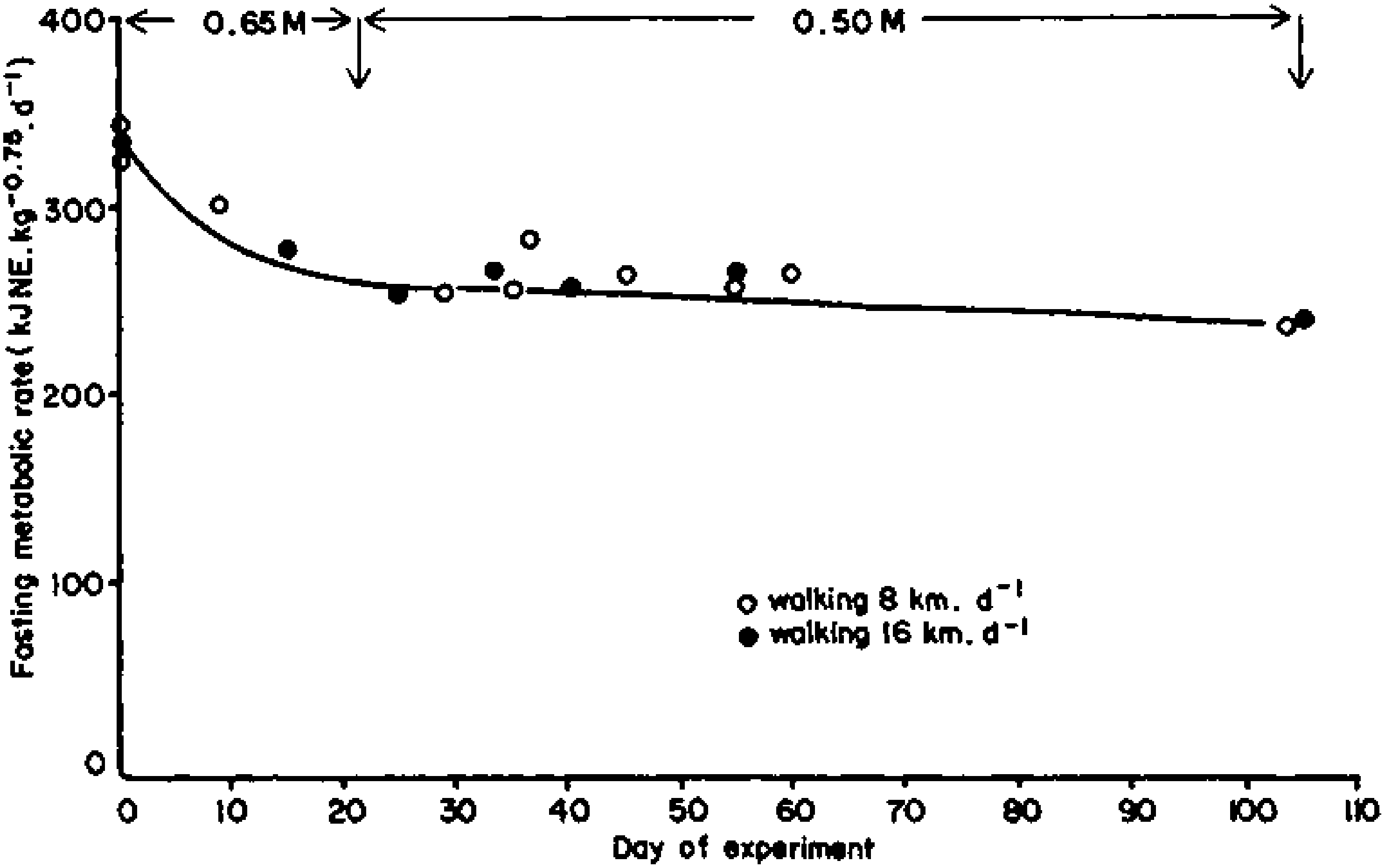
Table 26. Estimated daily energy of a zebu cow, based on Table 25.

Activity		Absolute value	Coefficient	Equation number	ME (MJ)
Forage intake		5.08 kg DM		(5.02)	37.0
Maintenance at rest		250 kg		(5.03/4)	28.8
Extra costs:					
	feeding	37.0 MJ ME	40kJ MJ^{-1} ME		1.5
	walking	18 km	1.8kJ.kg^{-1}.km^{-1}		8.1
	lactation	7.2 MJ NE		(5.05)	12.9
				Subtotal	50.6
Energy balance					-13.6

In their study of the response of zebu cattle to protracted periods of undernourishment caused by reduced intake of a high quality diet, Ledger and Sayers (1977) concluded that the 33% drop in maintenance requirements was partly due to increased conversion efficiency. But Finch and King (1979) found that the reduction in fasting metabolic rate of zebu steers, in response to a progressive reduction in food, was one third, thus accounting for all the difference observed by Ledger and Sayers. The drop in maintenance demands during the dry season will therefore be quantified using metabolic rate only (Figure 21).

Figure 21. Fasting metabolic rate change with reduction in ration below maintenance (M) of zebu

steers watered daily.



Further conservation of energy is achieved when the cow depresses its milk yield, and the herdsman decreases the distance walked by the animal per day by reducing the frequency of watering. Both these variables have already been quantified in section 5.1.3, but in the case of the undernourished animal there is a significant ($P < 0.01$) reduction in the cost of walking compared with the cow on a maintenance diet. For both classes of animal, the energy cost of horizontal walking, above that of standing still, has been plotted using data from Finch and King (1979) (Figure 22). For 220 kg zebu steers at maintenance the equation is:

$$E_w = 3.012x - 3.225 \ (r^2 = 0.82)$$

and for 200 kg steers on a half maintenance ration:

$$E_w = 2.068x - 2.122 \ (r^2 = 0.81)$$

where

E_w = energy cost of walking (kJ ME.kg^{-1}.h^{-1}),

and

x = speed of walking (km.h^{-1}).

At speed of between 2 and 5 km.h^{-1} the energetic efficiency (kJ ME.kg^{-1}.km^{-1}) of walking is higher in the undernourished zebu (Table 27). Energy saved by walking more slowly must be balanced against loss of grazing time.

There are two other energy and water saving mechanisms which have not been quantified but which should be mentioned, namely nitrogen recycling and thermolability.

As the diet becomes more fibrous and therefore less digestible, food intake is primarily limited by physical processes. The ruminant stops feeding when a certain level of fill is reached in the reticulo-rumen. Forage will be retained in the rumen until it has been reduced to small particles of mean length 0.5 mm for cattle and 0.25 mm for sheep. The reduction is achieved by microbial degradation and chewing. Low digestibility is correlated with low nitrogen content of the diet, which in turn depresses the cellulytic activity of rumen microorganisms (Dulphy et al, 1980). Konandreas and Anderson (1982) accounted for low digestibility by an additional multiplicative adjustment of voluntary intake at levels of crude protein <6% and digestibility <40%. But lack of crude protein is partly offset by recycling urea from the kidneys to the digestive tract via the bloodstream. This mechanism is present in ungulates employing either the rumen or the large intestine for microbial digestion, and is particularly well developed in species frequently exposed to low protein diets such as the zebu and the camel (Livingston et al, 1962; Schmidt-Nielsen, 1975). This source of non-protein nitrogen is incorporated into microbial protein, thereby increasing the microbial population and its digestion of cellulose before it in turn is digested.

The mechanism of thermolability allows the body temperature to drop below normal at night without increasing thermogenesis, and to rise above normal during the day by regulating sweating rates at a low level (section 4.2.6). The result is body conservation of water and energy. The mechanism of thermolability is initiated in response either to dehydration or to depressed food intake.

5.1.6.1 Drought

The extent to which the mechanisms, described in the previous section, come into play will depend on whether the season is a normal dry one or a drought.

The word drought tends to be used rather loosely. There is a need to distinguish between a dry year and a drought year, as well as drought conditions in a dry year, because the causes and effects can be different.

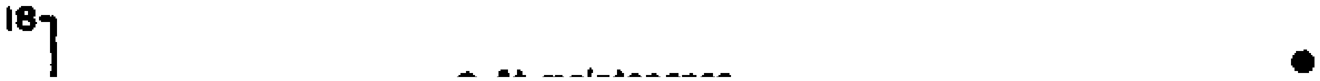
Drought means dryness. It is a serious deficiency of water for herbage production caused by the cumulative effect of above-average evaporation and/or below-average rainfall (Munn, 1970). In sub-Saharan Africa, rainfall is the more variable of the two components. The level at which low rainfall represents a drought and how it should be calculated is a matter of opinion. In the semi-arid areas of Kenya it has been found that the distribution of values for annual or seasonal rainfall is normal. Instead the probability curve is skewed by the inclusion of occasional very wet years. Thus the value for mean annual rainfall is higher than the median. For the purposes of range and animal management, rainfall expressed as a mean is less useful than median and quartile probabilities (Bille and Heemstra, 1979). It is suggested that a drought year is one in which the total annual rainfall is at or below the lower decile value on the probability curve. The effect of low rainfall on primary production will also depend on the amount of rain in each shower and the interval between showers, bearing in mind that about 25 mm of precipitation is required for growth of perennial grasses and shrubs and 40 to 60 mm for seed germination of annual grassland (J.C. Bille, unpublished).

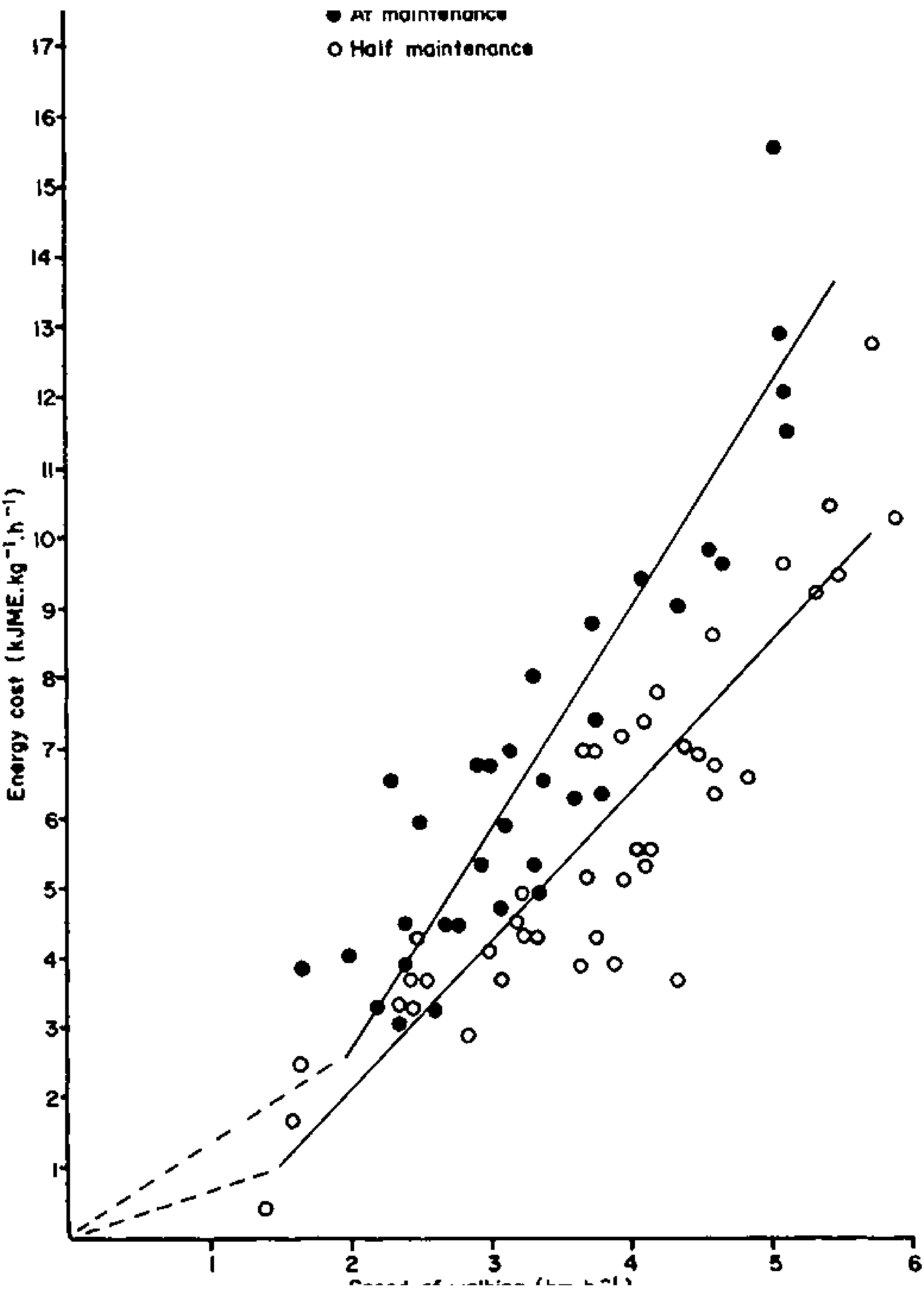
Table 27. The effect of sub-species and feeding regime in steers on the energetic efficiency of walking.

			Energetic efficiency (kJ ME. kg-1.km-1)			
Sub-species	**Weight (kg)**	**Feeding level**	**2km.h^{-1}**	**3km.h^{-1}**	**4km.h^{-1}**	**5km.h^{-1}**
Bos taurus	500	Maintenance and above	2.0	1.8	2.8	2.0
Bos indicus	220	Maintenance	1.4	1.9	2.2	2.4
Bos indicus	190	Half maintenance	1.0	1.4	1.5	1.6

Source: Ribiero et al (1977); Finch and King (1979).

Figure 22. The energy cost above standing still of horizontal walking at different speeds on a treadmill for 200 kg zebu steers.





● At maintenance
○ Half maintenance
Energy cost (kJME.kg⁻¹.h⁻¹)
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
1
2
3
4
5
6
Speed of walking (km h⁻¹)

Speed of walking (km.h^{-1})

The combined effects of sun, wind and feeding by invertebrate herbivores is gradually to remove the leaves from the herbage so that all that remains is a standing crop of stems. Thus the nutritive value of the rangeland will fall below the level for cattle maintenance whether or not it is grazed. On Galana ranch, Kenya, in March 1971, after only 170 mm of rain had fallen over 16 months, the standing crop of *Brachiaria* spp. had a crude protein content of 3.5%, while *Schoenfeldia transiens* had 4.5%. These two grasses comprised most of the diet of the grazing stock, which could not supplement their diet with browse because most of the palatable trees and shrubs had lost their leaves. Under such conditions, the response of different herbivores varied: Boran cattle lost so much condition that they had to be moved long before the grazing was exhausted, whereas domestic oryx in the same paddocks continued to grow (King and Heath, 1975). One of the reasons for the difference between the two ruminants appeared to be the ability of the oryx to select what was left of the more nutritious plant parts, whereas cattle with their broad mouths were ingesting a lot of grass stems (Field, 1975). The very fibrous diet of the cattle with inadequate nitrogen content to support normal rumen microbial activity obviously slowed digested passage rate and hence intake. Thus the cattle were starving in paddocks full of grass. Furthermore the provision of water daily, as is the case on a well-run commercial ranch, may have delayed the transition of the animals' metabolism to a 'siege economy'. As a result the body tissue reserves may have been depleted at a faster rate than if they had been forced onto a restricted watering regime earlier in the dry season. Eventually, in this type of situation, the quantity as well as the quality of the forage will become limited.

Drought conditions can also occur in a series of dry, but not drought, years. They occur as a result of overgrazing so that the quantity rather than the quality of the herbage is the main limiting factor. The use of the word 'drought' attributes the blame to the climate and obscures the fact that the conditions often arise because of a lack of range management.

5.1.7 Compensatory growth

Although the onset of the rains is greeted with relief, it may precipitate many deaths in a starving livestock population. At the end of a drought, animals have practically exhausted their energy reserves. The first heavy rain lowers the ambient temperature and soaks the animal's hair, thereby reducing the insulating effect of its coat. Heat loss from the animal exceeds heat gain and triggers off thermogenesis and shivering, albeit at a lower critical body temperature than in an animal in good condition (Finch and King, 1982). This waste of the last nutritional energy reserves is not immediately compensated for by improved energy intake. In the first place, unless there is a green flush following a fire which proceeded the rain, it takes a few days for the grass to grow after the first shower. Secondly the abrupt transition from sparse, dry grass stems to highly nutritious moist green grass causes the animal to scour (French, 1956b). In fact rainfall over a 21-day period always appears to have a negative effect on liveweight gain (Potter, in press).

For example:

$$LWG = 442.22 - 9.82a + 9.84b + 0.83c$$

$$(r^2 = 0.68)$$

where

LWG = liveweight gain (g/head/d)
a = rainfall within last 3 weeks (mm)
b = rainfall 3 to 6 weeks ago (mm)
c = rainfall 6 to 9 weeks ago (mm).

If the cow survives the dry to wet season transition, it usually starts putting on weight even more rapidly than would be estimated from its ingestion of green grass with a high digestibility (e.g 0.65 in ILCA, 1975). Part of this gain has been attributed to an increase in the weight of the alimentary tract. Gut contents have a water content of 85%, so that one might expect the total body water of the animal to increase from 70% to about 72%, whereas it has been found to drop to 65%, and on carcass analysis it was revealed that fat had been deposited (V.A. Finch and J.M. King, unpublished). An explanation for this phenomenon of compensatory growth is that the demands for maintenance form a much lower proportion of the diet in an emaciated animal than in one in good condition. This is so because the animal has an increased efficiency of food conversion, a smaller proportion of active tissue in the carcass and a depressed metabolic rate. During the weeks it takes to rehabilitate the animal there is therefore a larger surplus of ME available for body tissue deposition than might be expected.

Forage intake during the rains is not a constraint to animal production. Nevertheless there are a number of factors which are counter-productive. For example, the rainy season provides conditions favourable to the rapid multiplication of other forms of life, such as insects and helminths which irritate and sap the productivity of the herbivore. Ambient temperature is not at its highest, but the water vapour pressure of the air is. The combination of the two may produce peak THI readings - for instance at Tahoua, Niger in the Sahel (Figure 11) - and could conceivably cause discomfort even in zebu cattle. Humidity values of 75% r.h. may not be sufficient to reduce the efficiency of evaporative cooling, but the associated cloud cover, which insulates the earth and the animal from radiation to the night sky, may reduce heat loss. If the animal cannot dissipate the large amount of endogenous heat associated with maximum productivity, it will cut back its food intake and metabolic rate, whatever the state of the vegetation.

5.1.8 Body water turnover

In order to understand the effect of different management strategies in the dry season, total body water turnover (TBW_T) must be divided into the components for which it is used, and also the sources from which it comes. Very little work has been done on livestock under African ranching or pastoral conditions. I have had to rely on my own data on TBW_T in zebu steers on Galana ranch in Kenya and extrapolate from there.

The TBW_T of steers during the long dry season (June to October), when the mean ambient temperature is about 25ºC, is 150 $ml.l^{-1}.d^{-1}$ (Figure 9). Given a bodyweight (Wt) of 250 kg and a body pool size of 168 1 (67% Wt), then the absolute volume of TBW_T is 25.2 $l.d^{-1}$.

The two most important costs contributing to TBW_T are evaporative cooling of the heat load, and water for forage intake. Unfortunately these two costs have not been separated here, anymore than they have been in the information on farm animals in the British Isles (Table 19). However, a model on heat exchange is being developed (D.M. Swift, unpublished), which should allow separation in future. For the time being, the water cost of forage intake is related to a particular temperature which is assumed to remain constant for each example within a species (section 5.2). The forage intake (I) can be predicted from equation (5.01), assuming in this case a digestibility of 0.50:

$$I = 1/(1-0.50).1.1.1.1.1.0\ .\ 042.250^{0.73}$$
$$I = 4.73\ kg.d^{-1}$$

The energy value of this intake is 34.5 MJ ME according to equation (5.02).

Because the animal is not lactating, nor walking great distances, the TBW_T can be related entirely to forage intake at that temperature, assuming the animal is at maintenance. When metabolic water (W_M) and respiratory and cutaneous water (W_{RC}) have been deducted from TBW_T, the balance represents water from food (W_F) and drink (W_D) and the values are directly comparable with those in Table 19.

$$W_F + W_D = TBW_T - (W_M + W_{RC})\ (5.11)$$

Metabolic water can be estimated in two ways when energy intake or expenditure is known (section 3.3.5). For example:

$$W_M = 0.029 \times \text{total MJ ME}\ (5.12)$$
$$W_M = 0.029 \times 34.5 = 1.00\ l.d^{-1}$$

Alternatively W_M can be roughly estimated from TBW_T using the following equation from King at al (1978):

$y = 0.013k^{-0.783}$ ($r^2 = 0.86$) (5.13)

where

$y = W_M$ as fraction of total input, and

k = flux rate of body water pool (fraction of body pool.d^{-1}).

Respiratory and cutaneous water intake (section 3.3.4) is estimated as follows:

$W_{RC} = 0.11TBW_T$ (5.14)

$W_{RC} = 0.11 \times 25.2 = 2.77$ l.d^{-1}

Equation (5.11) can now be solved:

$W_F + W_D = 25.2 - (1 + 2.77) = 21.43$ l.d^{-1}

Thus the water cost, in food and drink, of forage intake is:

$I_w (W_F + W_D)/I$ (5.15)

$I_w = 21.43/4.73 = 4.5$ l.kg^{-1}DMI

This value for the coefficient I_w falls within the range- for cattle breeds in the British Isles (Table 19) although the environmental temperatures may have been calculated differently in the British and Kenyan situations. A lower value of 2.7 l. kg^{-1}DMI was calculated for zebu cattle in the semi-desert of northern Kenya based on measurements by IPAL (1982) of DMI and water drunk. The herd average for DMI was 2.9% bodyweight compared with 1.9% in the Galana example.

There is an extra water cost of walking (WK_W) in high solar heat loads (section 4.1.3):

$WK_w = 0.0014 \times Wt$ l.km^{-1} (5.16)

where Wt is the weight of the steer in kg

$WK_w = 0.0014 \times 250 = 0.35$ l.km^{-1}

In the hydrated animal at maintenance or above, this water cost is incurred between about 10.00h and 16.30h local time. If the herd leaves from and returns to the night enclosure at 08.00h and 18.30h respectively, then theoretically it can walk for 12 km (4 h at 3 km.h^{-1}) without increasing its water loss. In practice, cattle usually drink between 10.00h and 14.00h, so part of the 12 km (e.g. 6 km) will incur an extra water cost. Thus:

Water for walking = WK_w (WK - 6) (5.17)
where WK is distance walked (km).

It should be noted that in undernourished cattle, sweating rates remain high for a much shorter period of the day, namely from 11.00h to 14.00h (Finch and King, 1982). Therefore the water cost of walking must be adjusted to a lower estimate of the distance walked during those 3 hours.

Another extra water cost for the lactating cow is the water secreted in the milk (MY_w) which has been estimated from Table 19 as:

$MY_w = 0.87$ l.kg^{-1}MY (5.18)

The sources or inputs to TBW_T can be stated as:

$TBW_T = W_F + W_D + W_M + W_{RC}$ (5.19)

(The relation of water intake from forage (W_F) to forage moisture content is illustrated in Figure 4, and described by the equation:

W_F = (I × forage moisture)/(1 - forage moisture) (5.20)

Water drunk can be estimated in a number of ways, by solving equation (5.11) or (5.19) for W_D, by combining equations (5.15/16/17/18):

$W_D = (I \times I_w) + (WK \times WK_w) + (MY \times MY_w) - WF$ (5.21)

or by estimating the maximum volume the animal can drink during one visit to the watering point (section 4.3.1) and dividing by the number of days between drinks. The estimation of metabolic water (W_M) has already been given in equations (5.12/13) as has W_{RC} (equation 5.14); but where TBW_T has not been measured but its components have, W_{RC} can be estimated:

$W_{RC} = 0.12\ (W_F + W_D + W_M)$ (5.22)

Once the analytical background has been established it is possible to estimate the water costs and sources of TBW_T (Table 28), and use them to construct a table of daily water intake (Table 29). The example chosen is the zebu cow whose energy budget was shown in Table 26.

The values in Table 29 look realistic: the lactating cow is drinking 28 $l.d^{-1}$ compared with a practical guideline for the dry cow of 25 $l.d^{-1}$ (Table 10); adjusted body water turnover, by subtraction of metabolic and respiratory water, is 117 $ml.kg^{-1}.d^{-1}$ compared with a range of 51 to 150 $ml.kg^{-1}.d^{-1}$ (Table 13); TBW_T is 201 $ml.l^{-1}$ compared with a range of 97 to 274 $ml.l^{-1}.d^{-1}$ (Table 18).

The maximum values for TBW_T were associated with a daily watering regime in the hot dry season. Higher rates, or maintenance of the same rate on an alternate day watering regime, would result in severe dehydration. Therefore body water conservation mechanisms are assumed to become increasingly important at the expense of evaporative cooling which must give way to dry heat loss. The latter mechanism is assisted by a weather pattern of clear nights and substantial diurnal temperature fluctuation, which is from 22 to 35°C in parts of Kenya.

Table 28. Basis for estimation of daily water intake in a zebu cow.

Item	Symbol	Amount	Source	Application to equation
Forage intake	I	5.08kg DM	Table 26	(5.20)
Forage moisture	-	0.15 fraction	Table 14	(5.20/21)
Water cost of I	I_w	4.51.kg^{-1} DM	equation(5.15)	(5.21)
Distance walked	WK	18.0 km	Table 25	(5.16/17)
Cow weight	Wt	250 kg	Table 25	(5.16)
Water for walking	-	4.21	equation(5.16/17)	(5.21)
Milk yield	MY	2.0 kg	Table 25	(5.18)
Water in milk	MY_w	1.741	equation(5.18)	(5.21)
Total ME	-	50.6 MJ	Table 26	(5.13)
Body water pool	TBW	0.671.kg^{-1}	estimate	-

Table 29. Estimated daily water intake of a zebu cow.

Water source		Body water turnover		
Item	Equation	l	ml.kg^{-1}	ml.l^{-1}
Forage	(5.20)	0.9	4	5
Drink	(5.21)	27.9	112	166
Metabolic	(5.12)	1.5	6	9
Respiratory and cutaneous	(5.22)	3.6	14	21

Total input		33.9	136	201

Source: Table 28.

When a zebu cow stops maintaining a constant body temperature by evaporative cooling, and instead allows its body temperature to rise during the day and fall at night, its feed intake and hence its nutritional energy circuit is likely to be depressed (Figure 19).

5.2 Simulation by species

The purpose of this section is to show the effect of traditional management practices on water and energy budgets of the most important species of livestock in pastoral areas. Each simulation is preceded by a brief description of the role of each species in the traditional pastoral system. Because some sort of development has already occurred in much of Africa, traditional systems are defined as those not requiring large inputs of skills, equipment or money from outside (Sandford, in press).

5.2.1 Zebu cow

The management of cattle for subsistence dairy ranching is different from that for beef. On a commercial beef ranch it may be appropriate to dry off the cow as soon as possible in the dry season, whereas the opposite may hold true in the pastoral situation. The pastoral zebu cow may have to maintain her lactation despite a declining plane of nutrition, decreasing watering frequency, increasing distances between grazing and drinking water, and an increasing environmental heat load. The cow must be able to draw on body reserves for lactation when its nutrition is inadequate, and rebuild these body reserves when grazing improves, rather than increase the overall lactation (Lampkin and Lampkin, 1960b). Seasonal weight loss is also an important means of supporting a higher livestock population, and of achieving a higher productivity per ha, in an arid, water-limited environment than would be possible if bodyweight were maintained (Western, in press). When the rains come there is more than enough forage for the surplus livestock population. For instance, the carrying capacity of an area north of Lake Chad, in Niger, was estimated at 65 000 TLU in the dry season and 200 000 TLU during the rains (Rippstein and Peyre de Fabregues, 1972).

The race chosen for simulation is the Small East African Zebu, indigenous to Mausailand. It is a small cow with a mean adult female weight of only 250 kg (King et al, in press) and a peak daily milk yield of 3.5 kg 4 months post partum (Semenye, 1982). The energy budget and water turnover of this animal have been calculated at three phases of the long dry season associated with daily, 2-day and 3-day watering, assuming the following scenario: the animal calved in March just before the long rains, which were below average, so that its milk yield has been depressed, and by the beginning of July the daily yield is down to 2.0 kg, of which the family are only milking out 0.5 kg.

At this stage, the cow is still drinking every day and grazing on the way to and from the watering point. The *boma* is located 8 km from water and animal is walking 18 km per day. Up to now, the grazing has been adequate and the cow has lost only 10 kg of bodyweight, but forage will become scarce in the near future.

When it does, the *boma* will be moved to a second location 11 km from water and the cow watered every second day. On one day the cattle are herded away from water over adjacent peripheral grazing, which is adequate in quantity but has declined in quality. The cow walks about 11 km. The next day the herd is walked in an almost straight line to the watering point and returned home the same evening, covering a distance of 23 km (Western, 1975). The specific effect of 2-day watering reduces milk yield by <5% below the level of daily watering (Semenye, 1982). However the continuing energy deficit and declining plane of nutrition combine to reduce the daily yield to 1 kg.

If the dry season is particularly harsh or extended, or the area severely overstocked, the cattle may be placed on a 3-day watering regime. They then have to search for forage further away from the main *boma*, because the adjacent peripheral grazing areas have been denuded. Consequently they are unable to return home on the same day, and have to spend the night at a more distant temporary *boma*, returning to main *boma* on the second night. The first and second days are thus devoted to grazing, which involves walking about 10 km.d^{-1}.

On the third day the cattle have to get to water by the shortest route, i.e. 11 km, and after they have drunk there is usually only time to take the direct route home. On the third morning, the cattle could be in the desperate straits described by Classen (1977) (see also section 4.1.3) but according to French (1956a) 'this steady dehydration does not lead to unruly behaviour when the animals approach water-holes. In fact, it is a common dry-season sight in Maasailand to observe thousands of cattle waiting patiently in their turn to drink. On reaching the water, they drink steadily for several minutes during which they swell visibly and then stand for 10 to 15 minutes before taking a further short drink prior to the usual 10-mile return journey to their night quarters. Apparently the 3-day watering regime cannot be continued for long, but drinking on alternate days is a system which can be continued for weeks without apparent harmful effects on the animals.'

Three-day watering during the dry season is less common in Maasailand nowadays, because of water development. But it is still practiced elsewhere on the continent, for example in East Africa by the Borana (Helland, 1980) and the Turkana (N. Dyson-Hudson, unpublished), and in West Africa by the Maure (H. Breman, unpublished) and the Tuareg (Swift, 1979).

Assuming the above scenario, the changes in forage availability are listed in Tables 30, and the estimates of energy budget and water turnover in the cow in Table 31. The calculations required to convert the values from one table to the other have been shown in section 5.1, where Tables 25, 26, 28 and 29 give almost identical figures to those listed in the daily watering column of Tables 30 and 31.

Table 30. Basis for calculating daily energy budget and water turnover of a zebu cow on daily, 2-day and 3-day watering.

Item	Unit	Basis for energy budgets		
		Daily watering	2-day watering	3-day watering
Forage digestibility	fraction	0.50	0.45	0.40
Herbage on offer	tDM.ha^{-1}	1.8	1.6	0.8
Distance walked	km	18	17	14
Milk yield	kg	2	1	0
Intake coefficient	fraction	0.049	0.049	0.042
Expected liveweight	kg	250	250	250
Forage intake	kg DM	5.08	4.90	3.94
Actual liveweight	kg	240	230	215
Walking cost	kJ ME.kg^{-1}.km^{-1}	1.8	1.8	1.4
		Basis for water turnover		
Forage moisture	l.kg^{-1}	0.15	0.12	0.10
Walking in the sun	km	12	6	0
Body pool	l.kg^{-1}	0.67	0.68	0.70

Source: Tables 25, 26, 28 and 29.

Table 31. Estimated daily energy budget and water intake of a zebu cow on daily, 2-day and 3-day watering.

Item	Energy budget (MJ ME)		
	Daily watering	2-day watering	3-day watering
Forage intake	<u>37.0</u>	<u>32.1</u>	<u>23.0</u>
Maintenance at rest	27.9	27.6	17.9

Extra costs: feeding	1.5	1.3	0.9
walking	7.8	7.0	4.2
lactation	12.9	6.5	0
Total expenditure	50.1	42.4	23.0
Energy balance	-13.1	-10.3	0
	Water intake (1)		
Forage moisture	0.9	0.7	0.4
Drink	27.7	24.2	17.3
Metabolic	1.5	1.2	0.7
Respiratory and cutaneous	3.6	3.1	2.2
Total input	33.7	29.2	20.6

Source: Tables 25, 26, 28 and 29.

The first column in Table 30 relates to the beginning of July when the cow is still lactating and drinking daily, but at the expense of its own body tissue. The daily energy deficit is 13.1 MJ ME which, according to section 5.1.5, gives a weight loss of 0.45 kg.d^{-1}, 3.15 kg. week^{-1}, and 12.6 kg. month^{-1}. These figures are based on the status of the animal at the beginning of the month and do not take into account the daily decline in weight and milk yield and hence also the decline in energy demands for maintenance, walking and lactation as well as in forage quality, quantity and intake. Nevertheless, it is reasonable to suppose that, by the end of the month, the cow will weigh not more than 230 kg and a change in management will be required.

The change to 2-day watering in August has the effect of increasing forage accessibility by extending the grazing orbit away from the water point, but without increasing the distance walked daily. Nevertheless, there is still a daily energy deficit of 10.3 MJ ME despite the drop in milk yield, which is where the greatest energy saving is made. The deficit represents a weight loss of 2.36 kg per week which may be tolerated for another month. By September the cow weighs only 220 kg and has probably stopped lactating, so that weight loss is reduced to less than 1 kg per week.

As there is no sign of rain in October, the cattle are forced onto a 3-day watering regime because of the scarcity of herbage within the existing grazing orbit. The grazing that is now brought within range is nevertheless of poor quality because it is so late in the season. Consequently, energy intake is depressed to only 60% of the levels given for daily watering 3 months earlier. But the animal is in energy balance for the first time in about 4 months. The reason is that the chronic energy deficit coupled with intermittent partial dehydration has stimulated the conservation responses described in section 5.1.6.

The daily body water turnover follows a similar trend to that of energy declining from 210, to 187 and finally 137 ml.l^{-1} of body pool. The amount drunk on visits to the watering point at daily, 2- and 3-day intervals was 281, 181 and 521 respectively.

There are few field data with which to validate this modelling of different pastoral watering regimes. As far as weight loss is concerned, unimproved Boran cows under drought conditions in the Kenya highlands lost up to 15% bodyweight during the course of a 36-week lactation when supplied with water and hay supplement (Lampkin and Lampkin, 1960a; 1960b). Predicted values for the different components and sources of body water turnover look realistic. An exception could be the requirement to tolerate 21% dehydration (i.e. $2 \times W_D$), and still produce 1 kg of milk a day. The weakest link in the chain of calculation could be the water cost of forage intake (I_w).

It is concluded that the calculated values are near enough to the real values. They reveal the comparative effects of the different watering regimes, and their objectives. The change from daily to 2-day watering is an attempt to maintain production for man, whereas 3-day watering is a survival strategy for the cow. By then, the animal has practically exhausted its reserves of fat, having used about 12.5 kg. It has also used about 12.5 kg of its original 95 kg of muscle, liver and gut wall. Therefore whatever equilibrium it has achieved is extremely precarious. In this weakened state of ambulatory aestivation, an energy deficit of only a few MJ ME may cause the animal to collapse from exhaustion during the period of greatest stress in the management cycle. This period occurs on the third day without water when the cow has to walk the 22 km to water and back with scant prospect of finding forage. Thirst may keep the animal on its feet until it has drunk, but there may be little incentive to keep going after that.

5.2.2 Camel

The camel replaces the cow as the main milk producer at or below 200 mm mean annual rainfall (Western, in press). Its physiological adaptations have been referred to in many of the preceding sections. Briefly, they include slow absorption of water from the rumen, thereby reducing the amount excreted by the kidneys after drinking; good reabsorption of water from faeces and kidneys; reabsorption of nitrogen by the kidneys and its recycling in the body; and a diurnal range in body temperature which increases from 2°C in the hydrated animal to 6°C in the dehydrated state.

The camel has a tolerance of dehydration of at least 27% of its bodyweight (Schmidt-Nielsen, 1965). Its long neck enables it to reach the lower branches of most trees and, unlike the giraffe, it also has no difficulty feeding on dwarf shrubs at ground level. Camels also eat good quality standing hay (*Aristida* spp.), and salt bushes (*Sueda* spp.) to offset sweating when there is a salt defficiency in the diet (Gauthier-Pilters, 1974; Williamson and Payne, 1978; C.R. Field, 1978 and unpublished). The camel population in Africa appears to be increasing, possibly because desertification is extending into large areas south of the Sahara (UNEP, 1977) and opening up new habitats for the camel. There is also a growing demand for camel meat (C.R. Field, unpublished).

It follows that the staple food of pastoral people in arid regions of Africa is camel's milk. Among the Rendille in northern Kenya, for example, milk constitutes 60 to 90% of the diet, and 80 to 90% of this milk comes from camels (Schwartz, 1979). Young men herding camels away from the household may even have to rely on camel's milk to provide their water needs for up to 1 month at a time (G. Powys, unpublished).

Milk production is more important for these pastoralists than a high level of calf production. In fact, they compete with calves for milk, which is possibly why calf mortality rates of up to 40% are recorded (Bremaud, 1969; Spencer, 1973; Dahl and Hjort, 1976; Williamson and Payne, 1978; Wilson, 1978a).

The male camel is also important in the pastoral way of life as a water carrier for the household. The number of baggage camels dictates the amount of water that can be fetched and hence the distance a settlement can be from water; the further it is away, the more forage there will be available and hence the more productive the livestock will be, particularly the lactating females (Table 32). Despite the important role of male camels, short-term human needs take precedence over the longer term interests of the settlement to raise healthy stock. Male camel calves are first deprived of milk; then as juveniles they are bled to the point of exhaustion, providing up to 35 l of blood per annum, presumably mainly at the end of the dry season; and at 3 to 4 years they are castrated to make them more amenable. If they survive to become water carriers they are attached to the settlement and work long hours before being let out to browse in the immediate environment, which may have been stripped of vegetation (Schwartz, 1979). The same problem of water carrying does not occur in cattle-herding communities because the grazing must be better to support cattle, and the distance to water shorter. Donkeys can therefore be used as water carriers, and rarely have to supply an additional nutritional role.

Table 32. Relation between number of loading camels per household, maximum settling distance from a single water source and potential area of utilisation in northern Kenya.

No. of loading camels per household	nil	0.25	0.5	1
Frequency of water transport	daily	daily	2 days	4 days
Maximum settling distance (km)	2.5	5	12.5	27.5
Potential area of utilisation (km^2)	177	314	962	3318

Source: Schwartz (1979).

Even less information is available on the camel than on the zebu cow, so extra groundwork has to be done and assumptions made before the energy and water economy of the animal can be modelled.

As far as the energy budget is concerned, forage DMI has been found to vary between 1.4 and 2.5% of bodyweight (C.R. Field, unpublished); the gross energy and metabolisability of the camel's diet, which is mainly browse, has been calculated using the same coefficients as for grass. The following assumptions have been made about energy expenditure: cost of feeding and lactation are the same as for cattle, but camels are faster and more efficient walkers.

The components of TBW_T can be built up in much the same way as for cattle (section 5.1.8), once the three coefficients, MY_w, WK_w and I_w have been estimated. The water cost per kg of milk (MY_w) is taken as the same as for cattle, namely 0.87 $l.kg^{-1}$. The likelihood of an extra water cost from walking in the sun (WK_w), apart from that incurred foraging (I_w), has been disregarded in the management situations which will be illustrated. Therefore the only remaining, and most important, coefficient to be determined is the water cost per kg DMI (I_w) at specified environmental temperatures. No specific experiments have been designed to discover the value of I_w, but two pieces of fieldwork in Kenya can be used to arrive at estimates from which a mean figure can be taken.

Table 33. Data for estimate of water cost of forage intake in camels.

Item	Unit	n	Mean	S.E.
C				
Mean ambient temperature	°C	3	25.4	1.00
Moisture in diet	fraction	3	0.36	0.003
Water drunk (W_D)	$l.d_{-1}$	8	12.9	0.86
Total body water turnover (TBW_T)	$l.d^{-1}$	8	20.2	0.86
Water turnover rate constant (k)	fraction	8	0.006	0.0026
Bodyweight	kg	8	430	19
K				
Period between drinks	days		17	
Bodyweight	kg		500 (est.)	
Maximum amount drunk	l		100 (est.)	
Water drunk (WD)	$l.d^{-1}$		5.9 (est.)	
Milk yield(MY)	$kg.d^{-1}$		6 (est.)	
Moisture in diet	fraction		0.7 (est.)	
Forage intake(I)	kg		12.5(est.)	

Source: J.M. King et al (unpublished); C.R. Field (unpublished).

In the first trial, on Galana ranch, tritiated water turnover and related measurements were made on eight camels during June and August, the long dry season. The animals were male or dry non-pregnant females and so were treated as one group. The equation to be solved is (5.15), for which only W_D has been measured (Table 33):

$$I_w = (W_F + W_D)/I \ l.kg^{-1}DM.d^{-1}$$

However water from food (W_F) can be roughly estimated from equation (5.19):

$$W_F = TBW_T - (W_D + W_M + W_{RC}) \ l.d^{-1}$$

where

TBW_T = 20.2 (Table 33)
W_D = 12.9 (Table 33)
W_M = 2.2 (Table 33 and equation 5.13)
W_{RC} = 2:2 (Table 33 and equation 5.14)

Food intake (I) can be even more roughly estimated from equation (5.20) rewritten as:

$I = W_F$ (1- forage moisture)/forage moisture
$I = 2.9 (1 - 0.36)/0.36$
$I = 5.16$ kg DM.d^{-1}

Equation (5.15) can now be solved:

$I_w = (2.9 + 12.9)/5.16$
$I_w = 3.06$ l.kg^{-1}DM.d^{-1}

The value for I_w could be an overestimate because it is based on a forage DMI of only 1.2%, whereas at the minimum DMI measured (C.R. Field, unpublished) the value for I_w would be 2.6.

In the second trial near Mount Kulal in northern Kenya, lactating camels walking 2 km.d^{-1} in dense green vegetation went without drinking for 14 to 20 days (C.R. Field, unpublished). Given this information a number of assumptions can be made based on measurements of the assumed values in that or similar environments (Table 33). The equation to be solved for I_w is, in this case, (5.21)

$I_w = (W_D + W_F) - (WK \times WK_w) - (MY \times MY_w)/I.$

Figures for some of these variables can be substituted directly from Table 33:

$I_W = (5.9 + W_F) - 0 - (6 \times 0.87)/I$

Values for intake of very green vegetation by lactating camels are likely to be at the top of the recorded range, namely 2.5%. Given this information, W_F can be solved (equation 5.20):

$W_F = (12.5 \times 0.7)/(1 - 0.7)$
$W_F = 29.2$ l.d^{-1}

Reverting to equation (5.21):

$I_w = (5.9 + 29.2) - (6 \times 0.87)/12.5$
$I_w = 2.4$ l.kg^{-1}DM.d^{-1}

The mean figure for I_w from the two studies is 2.7 l.kg^{-1}DM.d^{-1}, and this will be used in the following illustrations.

The purpose of the examples is to demonstrate the effect of the application and removal of constraints on energy and water use in the lactating camel. In the first situation the camel is being kept in a poor settlement, 5 km from water, to provide milk for the women, children and old people. In the second, the same animal has been released to complete the second half of its lactation in the mobile herd, which is managed by boys and young men (Dahl and Hjort, 1976).

The basic data required to model the energy budget and water turnover of the animal are given in Table 34.

Table 34. Basis for calculating the daily energy budget and water turnover of a camel in two different situations.

Item	Unit	Settlement 5 km from water	Mobile herd
	Energy budget		
Expected liveweight (W_E)	kg	500	500
Forage intake	$\%W_E$	1.9	2.4
	kgDM	9.6	11.8
Forage digestibility	fraction	0.45	0.55

Actual liveweight	kg	500	460
Distance walked	km	16	16
Walking cost	$kJ.kg^{-1}.km^{-1}$	1.0	1.0
Milk yield	kg	5.0	4.0
Milk energy	$MJ.kg^{-1}$	3.5	3.5
Water turnover			
Forage moisture	$l.kg^{-1}$	0.35	0.64

Source: Nutritional analysis by University of Hohenheim of dietary grab samples collected by C.R. Field, who also measured DMI, distances walked and daily activity; Schmidt-Nielsen et al (1967); Dahl and Hjort (1976); Knoess (1977); Williamson and Payne (1978); King (1979).

Table 35. Estimated daily energy budget and water intake of a camel in two different situations.

Item	Energy budget (MJ ME)	
	Settlement 5 km from water	Mobile herd
Forage intake	63.0	94.6
Maintenance at rest	33.5	30.4
Extra costs: feeding	2.5	3.8
walking	8.0	7.4
lactation	31.8	25.5
Total expenditure	75.8	67.1
Energy balance	-12.8	+27.5
	Water intake (l)	
Forage moisture	5.2	21.0
Drink	25.1	14.3
Metabolic	2.2	1.9
Respiratory and cutaneous	3.9	4.5
Total input	36.4	41.7

Source: Table 34, section 5.1.

The results of the calculations are presented in Table 35. Looking down the first column of figures, it can be seen that the camel attached to the settlement is losing weight at 2.9 kg per week. Any energy deficit that the animal might be expected to have during the first half of its lactation is accentuated by the lack of forage accessible to the camel from the settlement. At this proximity to permanent water, the vegetation will almost certainly be overused by livestock. It is, of course, man and not the animal who has to stay near water; the camel only needs to drink every 4 days. After 3 months at the settlement the animal will have lost about 40 kg, i.e. 8% of its bodyweight, and might then be moved to the mobile herd.

The mobile herd provides most of the food and water needs of the herdsmen, and so it is not tied to the watering place by man's drinking water requirements. The herd therefore can exploit the more inaccessible parts of the country where the vegetation is of better quality and greener, unless the herding range is restricted by intertribal fighting (Field, 1978). The camel, introduced to this herd from the settlement, is able to revert to a positive energy balance. The rate of weight gain is calculated from equations (5.08) and (5.09) as 0.8 kg per week, so that within approximately 7 weeks it will have regained its original weight. At the same time its water turnover rate has increased, but its drinking requirement has decreased due to the moisture content of the forage. It would need to drink once in 7 days.

The above calculations of the rate of water use by camels can be compared with data from C.R. Field (unpublished) who found that camels drank 100 to 1351 of water every 6 to 7 days when attached to a settlement.

5.2.3 Smallstock

Sheep and goats are the 'petty cash' of livestock capital, and are used by man to fulfill a variety of different social and religious obligations. They are also an insurance against a dry year because smallstock, and in particular goats, may outsurvive cattle. Even if it is not so dry that cattle survival is in doubt, it is likely that cows' milk will have dried up and people will have resorted to bleeding male animals and using smallstock (Dahl and Hjort, 1976). Sheep and goats will be slaughtered for food, or sold to buy maizemeal. Goats, in particular, will be expected to give milk under the driest conditions (A.C. Field, 1978).

Smallstock exploit a broader spectrum of natural bushed grassland, and a wider range of rainfall than cattle (Knight, 1965; Topps, 1967). Sheep and goats are usually herded by women and children nearer to the homestead than zebu cattle and camels, but they can cover considerable distances when required to do so (Dahl and Hjort, 1976). Bedouin goats often walk 17 km.d^{-1} for grazing and return to the encampment every evening to suckle their kids. The encampment may be 25 km from the watering point (A. Shkolnik, unpublished). Australian sheep covered 15 km.d^{-1} at 2 to 2.5 km.h^{-1} when food and water were separated (Squires and Wilson, 1971). As the distance of separation increased, food intake decreased almost linearly; at first water intake remained the same, but then it declined; the distance walked per day increased to a peak and then dropped to the initial level, and frequency of watering decreased (Squires, 1978).

Although the two species are herded together, that is where the similarity ends. They are kept for different purposes, and their products are not entirely interchangeable: for instance, sheep are kept for their fat and goats for their lean meat. They have different susceptibilities to different diseases (BVA, 1976), so by keeping both the pastoralist is spreading the risk. In arid areas, both species will take more than one third of their annual diet as browse and browse litter, but the composition of the diet differs.

In the lowlands of northern Kenya it was noted that sheep seldom raise their heads above 20 cm from the ground when feeding, and goats normally do not lower their heads below 20 cm (IPAL, 1983). Goats can extend their feeding range by standing on their hindlegs (A.C. Field, 1978), or even climbing trees. Consequently they can ingest a higher proportion of trees and shrubs than sheep (Table 36). In fact the presence of goats is frequently associated with overgrazed, degraded areas. It has been pointed out that goats may not have been the cause of the original overgrazing (Devendra and Burns, 1970; Joubert, 1973). They are merely delivering the coup de grace: for example, Turkana people with goats can survive after Rendille and Gabra have grazed out an area with their camels and cattle (C.R. Field, unpublished).

Water balance is unaltered during the first 2 days of water deprivation in sheep, with water drawn from the digestive tract; only after that does physiological dehydration develop (Hecker et al, 1964). It reaches a critical level only when desert sheep have lost 30% of their bodyweight (More and Sahni, 1978), and at an even later stage in desert milking goats (Shkolnik et al, 1972). When deprived of water, sheep and goats reduce water loss by the excretion of sodium in concentrated urine (Macfarlane et al, 1961; Taneja, 1965; Schoen, 1968). Faecal water loss is also limited, particularly by breeds originating from arid areas (Slagsvold, 1970).

Differences in food selection and water requirements between breeds of the same species are nearly as large as differences between the two species in different parts of Africa: for example, compare Gihad (1976) and King (1979). Nevertheless the practice of grouping sheep and goats together under the heading of smallstock should be discontinued as more field data become available.

From the foregoing remarks it is apparent that it will be difficult to generalise from one chosen example. And data on water and energy budgets are so sparse that differences between species and breeds cannot be illustrated with confidence.

Table 36. Difference in the diet of sheep and goats in the dry season in northern Kenya.

		Per cent of diet	
Plant species	**Type**	**Sheep**	**Goats**

Cordia sinensis	Large shrub	0	3
Acacia nubica	Large shrub	0	13
Indigofera spinosa	Dwarf shrub	21	39
Indigofera cliffordiana	Dwarf shrub	1	1
Hermannia kirkii	Herb	1	9
Leptothrium senegalense	Grass	14	7
Kohantia caespitosa	Herb	6	1
Total		43	73

Source: A.C. Field (1978); C.R. Field (unpublished).

One animal which has been and is being studied, is the Small East African goat, which is common to all but the coldest or driest parts of the region.

The forage intake of the goat has been taken as 2.5% of bodyweight, based on a range of 2.1 to 3.2% (Devendra and Burns, 1970; A.C. Field, 1978). The gross energy and metabolisability of the diet has been calculated using the same coefficients as for grass; the cost of feeding has been made the same as for cattle; walking cost was taken as higher and cost of lactation as lower than for large stock, but based on a higher nutritional value (Dahl and Hjort, 1976) than that shown in Table 9.

The water cost of each kg of milk has been taken as the same as for cattle, and the extra water used in walking as negligible. The water required per kg DMI (I_w) at a given environmental temperature has been calculated from data on Small East African goats at Galana ranch, which were included in the field trials with the camels (Table 37).

Table 37. Data for estimate of water transactions in Small East African goats.

Item	Unit	n	Mean	S.E.
Mean ambient temperature	ºC	4	25.4	0.66
Moisture in diet	fraction	4	0.53	0.118
Water drunk (W_D)	$l.d^{-1}$	12	2.20	0.295
Total body water turnover (Tsw_T)	$l.d^{-1}$	12	3.86	0.187
Water turnover rate constant (k)	fraction	12	0.155	0.0075
Bodyweight	kg	12	36.6	1.67

Source: J.M. King et al (unpublished).

Water from food has been derived from equation (5.19):

$$W_F = TBW_T - (W_D + W_M + W_{RC})\ l.d^{-1}$$

where

$TBW_T = 3.86$ (Table 37)
$W_D = 2.20$ (Table 37)
$W_M = 0.22$ (Table 37 and equation 5.13)
$W_{RC} = 0.42$ (Table 37 and equation 5.14)

Hence W_F was 1.02 $l.d^{-1}$. The mean value for forage intake (I) during the period from June to August was taken as one third of the way up the range of observed values, namely 0.90 $kg.d^{-1}$. The forage moisture content was then calculated as 53% from equation (5.20).

The water intake in relation to forage intake is estimated from equation (5.15) as follows:

$I_w = (W_F + W_D)/I$
$I_w = (1.02 + 2.20)/0.90$

$I_w = 3.61.kg^{-1}DM.d^{-1}$

This value compares reasonably well with the value for growing sheep under hot conditions, namely 3 $l.kg^{-1}DM.d^{-1}$ (Table 19), because the goats on Galana were not particularly arid-adapted, and the temperature was higher.

The application of the values derived above to the energy and water turnover of the goat is shown in Table 38. It can be seen that the animal' would have an energy deficit of 1.64 MJ $ME.d^{-1}$, resulting in a weight loss of 0.38 kg per week. Such a rate of loss could be tolerated for about 3 months, assuming that forage intake was also decreasing. It is more likely that the animal would dry off before then and eliminate the reason for the deficit, which is the energy cost of lactation. Frequency of watering would need to be at least every third day to avoid depression of appetite and lactation (section 4.3.1).

The Small East African goat is not as desert-adapted as the Somali sheep or Galla goat, which only need to drink once a week when cattle are being watered every second day (Mares, 1954). Furthermore the goat has a higher TBW_T than the zebu cow (Table 13). Nevertheless it possesses, in some degree, the attributes which allow smallstock to outsurvive cattle in times of drought. It requires less water per kg DMI than zebu cattle in the same environment. Its food intake is higher because of its superior ability to select nutritious food, except during the rains when there is adequate forage anyway. As a browser it obtains more water from forage than do grazers. Nevertheless in a severe drought, when the leaves turn brown and fall off even the deep-rooted shrubs, smallstock may lose their edge over cattle when faced with the same indigestible diet. They may be able to find natural supplements such as browse litter. For example, acacia flowers rich in protein and soluble carbohydrates are shed at the end of the dry season (Schwartz and Said, 1980).

Table 38. Daily energy budget and water intake of a Small East African goat.

Item	Value	Unit	Coefficient	Equation number	Energy (MJ ME)
Forage intake	0.90	kg DM	d = 0.50	(5.02)	6.40
Maintenance at rest	35		$0.251\ W^{0.75}$	(5.04)	5.38
Extra costs:					
feeding	6.40	MJ ME		-	0.26
walking	8	km	$1.9\ kJ.kg^{-1}.km^{-1}$	-	0.53
lactation	0.35	kg	$3.0\ MJ.kg^{-1}$	(5.05)	1.87
Total expenditure					8.04
Energy balance					-1.64
					Water intake (l)
Forage moisture	0.50	fraction	-	(5.20)	0.88
Drink	-	-	$I_w = 3.61.kg^{-1}$ DM	(5.21)	2.40
Metabolic	8.04	MJ ME	-	(5.12)	0.23
Respiratory and cutaneous	-	-	-	(5.22)	0.42
Total input					3.93

Source: Clapperton (1961); Young (1966); Graham (1964); Corbett et al (1969); Devendra and Burns (1970); McDonald et al (1976); A.C. Field (1978); Webster(1978); King(1979); nutritional analysis by University of Hohenheim of dietary grab samples collected by C.R. Field.

5.2.4 Donkey

The donkey has been described as the ubiquitous beast of burden in southern Sudan (Wilson, 1978b); a role that it also fulfills in much of sub-Saharan Africa. In subsistence societies which value multipurpose animals, the retention of a specialist animal is surprising. Equines are no longer milked in Africa as they are in Asia (Jarrige, 1980), and donkeys are eaten only as a last resort. The animal owes its survival to the following attributes: it can carry a heavier load in relation to its bodyweight than other baggage and riding animals (Table 39); it is more efficient at walking than man, or even than the mule

(Yousef and Dill, 1969); it appears to thrive on neglect; and it can withstand droughts better than most species of livestock, as was illustrated in Niger in the early 1970s (Eddy, 1979). The characteristics which enable it to survive are summarised below.

Table 39. Daily performance figures of baggage and riding animals.

Animal	Bodyweight (kg)	Job	Load to bodyweight ratio	Load (kg)	Natural speed ($km.h^{-1}$)	Distance travelled (km)
Donkey	125[c]	Pack	0.60[b]	75	3.2[g]	16[e]
	160[c]	Ride	0.50	80[e]	4.0[g]	20[e]
Horse	350[b]	Ride	0.23	80[e]	8.0[e]	30[e]
Camel	450[a]	Pack	0.51	230[d]	4.0[d]	24[d]
	450[a]	Ride	0.27	120[d]	10.0[d]	48[d]
Ox	350[b]	Pack/Ride	0.31[f]	110[e]	5.5[b]	20[e]

Source: [a]Wilson (1978a); [b]CEEMAT (1972); [c]Wilson (1978b); [d]Williamson and Payne (1978);[e]estimate; [f]Ishizaki et al (1961); [g]E.M. Wathuta (unpublished).

African equines exploit the rangelands in a very different way from the ruminant. Their food intake is not depressed by a low protein, high fibre diet (Robinson and Slade, 1974), and so the donkey remains productive with little loss of condition. The concomitant demands for water for cooling and for intermediary metabolism are high. The working donkey uses water at much the same rate as man (Dill, 1938), but the water that it carries back to the *boma* is for the household and not for itself. Fortunately the animal is more adept than man at maintaining its plasma volume at the expense of other extracellular and intracellular fluids. Its appetite is not depressed until dehydration is severe, by which time the donkey is back at the watering point where it rapidly re-hydrates without risk of intoxication (Schmidt-Nielsen, 1965; Maloiy, 1970; Maloiy and Boarer, 1971). When the animal is not working, minimum water expenditure could be as low as 2.5% (Dill, 1938), which would allow the animal to go without drinking for at least 10 days, because it can tolerate 30% dehydration. But donkeys in northern Kenya appear to water more frequently than smallstock (C.R. Field, unpublished).

Donkeys are used to carry grain, forage, firewood, people, household possessions and water, as well as to pull carts. In Maasailand, the animal usually weighs about 120 kg and carries a load of 35 to 45 kg. In the dry season the location of a *boma* may, in part, be determined by the distance a donkey can walk to a source of drinking water and back to the household. The journey should be completed during daylight, i.e. within 13 h at speed of about 3 $km.h^{-1}$ (Table 39). Thus a settlement can be up to 20 km from a source of drinking water, and a donkey will be expected to make the trip there and back every second or third day during the dry season (D. Western, unpublished). On the days it is not working the donkey may follow the cattle out to graze, but go less far, and be brought back to the vicinity of the *boma* in the evening. It is not enclosed at night unless there is a high risk of predation.

The example chosen is less extreme than the limits of endurance credited to the donkey would permit and is more in line with the 2-day watering regime of zebu cattle, where the *boma* was located 1 km from water (section 5.2.1). When the animal is being used to collect water on alternate days, its daily TBW_T and energy budget will be approximately as shown in Table 41, based on the coefficients and equations listed in Table 40.

The first point to note is the high estimate of forage intake (2.7% of bodyweight) despite the fibrous diet. The donkey being a simple-stomached herbivore, achieves microbial digestion of plants in its large intestine, which has several functional similarities to the rumino-reticulum, including the synthesis and digestion of microbial protein (Stevens et al, 1980). The efficiency of cell-wall digestion of forages is 30% less in Equidae than in ruminants, while the apparent digestibility of the cell contents is similar. The digestibility (d) of forage can be predicted from either of the following equations, or preferably the mean of the two:

$$d = 0.31 + 1.45 CP \quad (5.23)$$

where CP = crude protein fraction, or

$$d = 1.45 - 2.82\ CF \quad (5.24)$$

where CF = crude fibre fraction.

The reduced breakdown of cell-wall carbohydrates in the large intestine of Equidae is primarily due to a shorter retention time than in ruminants. The latter must retain fibrous vegetation in the rumen until it is small enough to pass through the reticulo-omasal orifice and between the leaves of the omasum. This process may be so delayed that food intake falls below the level required for maintenance regardless of the quantity of herbage on offer. No such depression of intake occurs in the equine which compensates for its less efficient digestion with a 30% longer feeding time than the ruminant. The conclusion is that caecal digestion is in fact a superior adaptation for dealing with high fibre content herbage, provided that intake is not limited by the actual quantity of herbage available. Amongst the Equidae, the donkey appears to have a higher capacity for crude fibre intake than the horse (Robinson and Slade, 1974; Jarrige, 1980). For example, the donkey is one of the few species that can use the short spiky leaves of *Sporobolus spicatus*, a common grass of alkaline flats in Africa (Pratt and Gwynne, 1977).

The metabolisability of the food digested is slightly higher (0.90) than for ruminants, so that the energy derived (E) from a given intake (I) is predicted with a different equation than equation (5.02). For equines:

$$E = I \times 18 \times d \times 0.90 \text{ MJ ME} \quad (5.25)$$

The efficiency (k_m) with which ME is used for maintenance has been derived from an adaptation of equation (5.04):

$$k_m = 0.55 + (0.3 \times 0.90 \times d) \quad (5.26)$$

Table 40. Estimates of daily energy budget and water turnover of a donkey carrying water on alternate days.

Item	Coefficient or equation	Value	Unit
	Energy budget		
Bodyweight (Wt)	-	120	kg
Forage intake (I)	0.027 Wt	3.2	kg DM
Crude protein (CP)	-	0.06	fraction
Crude fibre (CF)	-	0.42	fraction
Forage digestibility (d)	(5.23/4)	0.33	fraction
ME intake	(5.25)	17.1	MJ ME
Efficiency of ME use (k_m)	(5.26)	0.639	fraction
Maintenance cost at rest	(5.26/7)	12.0	MJ ME
Feeding cost	53 kJ.MJ ME	0.9	MJ ME
Walking unloaded (including grazing)	1.0 $kJ.kg^{-1}$ $bodyweight.km^{-1}$	11.5	km
Walking loaded	1.4 $kJ.kg^{-1}$ $bodyweight.km^{-1}$	5.5	km
	Water turnover		
Forage moisture	(5.20)	0.1	fraction
Water cost relative to food intake (I_w)	3.6 $l.kg^{-1}DM$	11.5	l
Walking speed	-	3.2	$km.h^{-1}$
Distance between water and *boma*	-	11	km
Time walking loaded and hot	-	1:8	h
Water cost, walking loaded and hot (WKL_w)	0.0133 Wt	1.6	$l.h^{-1}$
Metabolic water	(5.12)	0.5	$l.d^{-1}$
Respiratory and cutaneous water	(5.22)	1.6	$l.d^{-1}$

Source: Dill (1938); ARC (1965; 1980); Fonnesbeck (1968); Vander Noot and Gilbreath (1970); Wooden et al (1970); Hintz et al (1971); Vander Noot and Trout (1971); CEEMAT (1972); Robinson and Slade (1974); Schmidt-Nielsen (1975); Pratt and Gwynne (1977); E.M. Wathuta (unpublished).

Thus the amount of ME used for maintenance by the donkey is given by the equation:

$$E_m = a.Wt^{0.75}/k_m \quad (5.27)$$

where a = 0.211 (Table 24).

The energy costs above maintenance are feeding and walking with and without a load. Feeding costs per MJ ME have been increased by one third to account for the extra feeding time. Walking costs have been based on the assumption that the donkey walks only 3 km while grazing on the day it is carrying water but 9 km on the day it is not. To this total must be added the 11 km journey to water carrying empty containers. The load on the 3.5 h return journey has been estimated at 45 kg, i.e. less than 40% of the animal's bodyweight, which is not hard work for a donkey. Larger loads and longer working hours will increase energy requirements by two to four times that of maintenance (CEEMAT, 1972; BDPA, 1974).

Water intake from forage is low, because the grass is dry. Drink therefore accounts for most of the animal's water intake. It is calculated using a variation of equation (5.21), namely:

$$W_D = (I \times I_w) + (WKU \times WKU_w) + (WKL \times WKL_w) - W_F \quad (5.28)$$

where the water required per kg DMI (I_w) has been taken at the same value as for the light horse at a moderate ambient temperature (15°C) (Table 40).

The water cost of walking unloaded (WKU_W) has been taken as negligible, for two reasons. Because the donkey is an efficient walker it generates relatively little heat and there is no marked increase in sweating in response to exercise, as there is in man. Speed of walking is dictated by the animal's ability to maintain thermoregulation, and it will not be driven any faster. Thus the inherent stubborness of the animal enables it to avoid working at a rate exceeding its thermoregulatory capacity (Yousef and Dill, 1969; Bullard et al, 1970). Secondly, the animal will have covered the distance to water before the day heats up.

There is a water cost of walking back loaded (WKI_w) during the heat of the day of about $1.6 l.h^{-1}$ (Table 40). If the return journey is not delayed until the afternoon this cost will be borne by the animal for 3.5 h, which must be divided over 2 days. Equation (5.28) can be solved:

$$W_D = 11.5 + 0 + 2.8 - 0.4$$

$$W_D = 13.9 \ l.d^{-1}$$

Estimates of metabolic and respiratory and cutaneous water input have been made using equation (5.12) and (5.22) respectively.

Table 41. Estimated mean daily energy budget and water intake of a donkey carrying water on alternate days.

Activity	Energy budget
	MJ ME
Forage intake	17.1
Maintenance at rest	12.0
Extra costs: feeding	0.9
walking unloaded	1.4
walking loaded	0.9
Total expenditure	15.2
Energy balance	+ 1.9

	Water intake (l)
Forage moisture	0.4
Drink	12.4
Metabolic	0.5
Respiratory and cutaneous	1.6
Total input	14.9

Source: Table 40.

The final picture of energy and water turnover in the donkey (Table 41) is very different from that in cattle belonging to the same household, also on a 2-day watering regime (Table 31). The donkey has an energy surplus whereas the cow has a deficit. The reason appears to be that the donkey has a high ME intake, which in the ruminant would be associated with high energy demands, for example in lactation, whereas in fact the donkey's maintenance requirements are very low.

However, water expenditure (ml.l^{-1}) is similar in both animals. There are two reasons for this: firstly, although the water cost per kg DMI (I_w) is lower in the donkey, food intake must be higher for a given ME intake; secondly, the evaporative water needs of the donkey walking in the heat of the day are nearly three times those of the cow walking unloaded and more than offset the cow's extra water need for lactation.

The rate of water loss in the donkey is particularly marked at the outset of the 2 days between drinking, because of the sweat lost carrying the water back to the *boma*. This loss must not reach a level which will depress the animal's appetite during the next grazing day, even though it may be able to graze during the first night. On the morning after work, the degree of dehydration will be approaching 13% and by the afternoon 15%. At this stage the person who has walked with the donkey, and sweated nearly as much, would be in a coma if he or she had not drunk. However, donkeys are relatively unaffected by a water loss of 12 to 15% of their bodyweight; appetite is not depressed until the level of dehydration reaches in excess of 15%, or as high as 23% in Sinai donkeys (A. Shkolnik, unpublished). By the time the animal returns to drink on the second day it will have lost 21% of its body water, but will rapidly and completely rehydrate (section 3.3.1).

The foregoing examples and equations have been based largely on data and situations in Kenya. Nevertheless, the approach is readily transferable to other parts of Africa. For example, given baseline data of the sort provided by Swift (1979) on the Tuareg in Mali (Table 42), water and energy turnover of four species can be simulated.

The value of the model is that the behaviour of livestock throughout the year can be illustrated and related to a variety of options for water development, whereas practical guidelines for development were formerly based on a single conservative estimate of daily drinking water requirements (Table 10).

Table 42. Distribution of nomadic flocks and herds in relation to water during dry seasons in arid Mali.

Species	Water frequency (d)	Distribution of flocks and herds (%)			
		Distance between pasture and wells (km)			
		10-19	20-29	30-39	40+
Camels	5 - 6	25	23	39	13
Cattle	2 - 3	19	66	15	0
Sheep	3	30	54	16	0
Goats	- 2	54	46	0	0

Source: Swift (1979).

6. Water and livestock development

Modern strategies of livestock production require exogenous inputs of skills, equipment and money. A fundamental element of these strategies is the new ability to place water points where one wants them to be, rather than where they occur by accidents of nature. Unfortunately these technological innovations are entirely dependent for their success on the human organisation and management of livestock and grazing resources. In pastoral systems, where the traditional organisation has collapsed and has not been replaced by an alternative, overgrazing becomes a certainty and the provision of extra water a liability. However, water development makes such an immediate improvement to the quality of life of pastoral people that its provision can hardly be denied. Having accepted the social and political obligations to provide water, the emphasis must be on minimising its deleterious effects.

6.1 Rangeland

In theory, the objective of water development in pastoral areas is similar to that for commercial ranching areas, but in practice it is quite different because of this lack of grazing control and the resultant range degradation around watering points. The extent of this degradation has been described by Jarrige (1980) relying largely on information from Le Houérou (1977):

"The quality, productivity and surface of the arid and semi-arid pastures of Africa (and the Middle East) have deteriorated at an alarming rate over the last decades as a result of overstocking and the increasing pressure of human population. Production is currently one third to one fifth of its potential and sometimes even as low as one tenth in the arid zone of Africa. The numbers of livestock have increased sharply (38% in all of Africa between 1950 and 1973; 53% for cattle) as a result of better sanitary protection and increased rainfall in the 1950s and 1960s, sometimes helped by unsound water development projects. Heavy and continuous overgrazing have resulted in the replacement of perennial grasses by annual grasses and of forage shrubs and trees by undesirable ones. At the end of the 1968-1973 drought in the Sahel, the vegetation cover was 32% less than 30 years ago. Tens of thousands of hectares are converted to desert by wind erosion every year. The human population explosion has led to more and more pastures being turned into cereal cropping and fallow being reduced or suppressed. This periodical cereal cropping with modern ploughs eliminates the perennial forage species. Destruction of woody species for fuel around the cities not only suppresses some browse species but also results in the disappearance of valuable forage species that grow in the shade."

The prospects for the future are not encouraging. Food problems in tropical countries are well known. The rise in food production will have to exceed population growth in order to remedy present-day shortages, which cause half a billion people to suffer from undernutrition or malnutrition. There is little chance of this happening in the near future, because the population has been growing and continues to rise at an unprecedented rate (>2% p.a.). This population explosion is expected to last several more decades. In the intertropical zone by the year 2000 the population will probably reach 2950 million people, or 47% of the world's population and 60% more than at present (Jarrige, 1980).

If pastoralism in any form is to survive, the range resources must be protected above all else.

6.1.1 Uncontrolled grazing

The most conspicuous effects of range degradation are to be found around permanent wells and boreholes. For example the man-made desert round the settlement at Kom in northern Kenya is nearly 8 km in radius and 200 km^2 in area (IPAL, 1982). In Niger, Rippstein and Peyre de Fabregues (1972) estimated that proper exploitation of a circle of 8 km radius around a pumping station, with overexploitation during 9 months of the dry season, allowed a maximum of 3000 TLU on pastures having an annual primary productivity of 700 kg $DM.ha^{-1}$. The actual biomass of stock was usually more than 10 000 TLU. The authors made a number of standard recommendations on how water could be used to improve range management. The system of transhumance was to be maintained and the time spent in the wet season dispersal area was to be increased by increasing the number and depth of temporary ponds. The early return of transhumant herds to dry-season grazing grounds was to be discouraged by delaying the date at which the borehole pump starts operating. The number of pumping hours per day were to be varied to deliver the daily water needs for the correct stocking rate. This daily ration was carefully calculated for each month, and varied from 24 l in January to >42 l in October. In addition, dry-season grazing reserves were to be created particularly from wooded pastures and firebreaks were to be introduced. Control of permanent water points, stocking rates and livestock distribution was to be placed in the hands of the nomads who traditionally use the area.

However, it should be noted that the effectiveness of such plans can be limited by: isolated and sporadic rainstorms which may not fill all the ponds in the wet season; pump attendants and range management officials may be bribed or coerced into operating pumping stations (Sandford, in press); the committees set up to manage the rangeland may not be very effective; and fuel delivery and maintenance of pumps and engines in remote areas may be difficult at best.

Further water development in areas of uncontrolled grazing may temporarily alleviate overstocking. However, it will merely postpone the day of reckoning when the rangeland will be a desert unless limited extent of range management in Africa is recognized. The emphasis in water development must be on the continuing use of traditional watering practices for which the labour and social organisation required act as a constraint on range utilisation (Helland, 1980). An example of such a development plan is given by King et al (1983) using carefully spaced hand-dug wells. The preference for wells rather than ponds was based on their reliability and water quality, compared with the unreliability, high evaporation rate, as well as erosion, silting and polluted water, associated with ponds (IPAL, 1982).

6.1.2 Controlled grazing

In certain situations grazing is controlled. For example, in parts of Kenya Maasailand with an annual rainfall >600 mm individual ranches have been created which are a natural extension of the Maasai practice of reserved grazing areas. Most households have reserved grazing areas for their calves (called *olepolole*), and some have reserved areas for grazing in the early to mid dry season (*dokoya unkishu*), as well as reserves (*enkaroni*) for the final period of the dry season. Households associated with a specific reserved area do not have exclusive rights to that area, but they do collectively decide when livestock may enter for grazing. A meeting of men from a particular neighbourhood makes this decision, and disputes about entry often occur. Nevertheless, collective action may be taken against any person herding prematurely in the reserved area, whether they are from the controlling neighbourhood or from elsewhere (Peacock et al, 1982).

In such cases, water development should be largely a question of economics, which means that a watering point would be required to support the equivalent of 1250 adult zebu cattle (Classen et al, in press). Conventional range management practices may be applied (Pratt and Gwynne, 1977), but these are unlikely to include expensive improvement of natural pastures until research has shown that new interventions (e.g. forage legumes) are a realistic proposition. Food and mineral supplements can be considered, provided they are cheap enough. For example, the provision of urea when forage digestibility is low has increased the milk yield of Merino ewes (Stephenson et al, 1981).

Consequently the protein and fibre content of the diet may place a ceiling on ruminant DMI particularly by bulk grazers such as cattle. Crude protein levels of less than 7% markedly reduce the intake of natural grasslands in the tropics (Osbourn, 1976), and are considered the major limiting factor to liveweight gain, for example in Botswana (Pratchett et al, 1977). Therefore one can apply the old adage that 'water can be limited when forage is short' (in quality or quantity).

Earlier in the dry season, water should be accessible enough to allow the lactating cow to satisfy its appetite and maintain energy balance. That situation is illustrated in Table 46 where the lactating zebu cow is in energy balance, walking about 9 $km.d^{-1}$. The distance itself is not critical because the water and energy costs of walking are relatively small. Long distances (estimated at >14 km by Konandreas and Anderson, 1982) are nevertheless associated with a loss of grazing time, which is probably a more important factor. Daily watering is necessary for maximum productivity when grass digestibility is above 50% but moisture content below 50% or thereabouts. The conclusion reached is that doubling the density of watering points in an underdeveloped area produces a spectacular improvement in productivity, but that there is a rapid diminution in the return with each doubling in density thereafter (Sandford, in press).

6.2 Woodland

The contribution of trees, particularly acacias, to pastoral systems is considerable. Besides providing green leaves for browsing, all the litter which falls on the ground, in the form of dead leaves, flowers and seedpods, is eaten. Dead wood is used for firewood and live branches for *bomas*. This last practice results in the destruction of woodland in the vicinity of *bomas*. Tree regeneration is prevented by overbrowsing particularly by goats which should be excluded from an area for 5 years to allow young trees to grow out of the animals' reach (IPAL, 1982). The destruction is exacerbated by the likelihood of traditional watering places being located where ground water is at or near the surface and trees are concentrated. Careful spacing of new watering points away from some areas of woodland may reduce destruction, but is unlikely to eliminate it because smallstock can forage up to 20 km and *bomas* can be located up to 15 km from water.

6.2.1 Tree shade

Tree shade provides a shelter for nutritious plants and the resultant green vegetation acts as a heat sink for radiant heat from the animal. Its value for pastoral production in semi-arid rangelands is unquestioned but unquantified. It may be less important for indigenous stock, such as Boran cattle, in more humid less water-limited environments but tree shade is needed to maintain high levels of production if there are high solar heat loads (Fuquay, 1981). Thus shade from mature coconut palms significantly increased the milk yield of Friesian × Boran cows (+18%) on the Tanzanian coast (Macfarlane and Stevens, 1972).

6.3 Livestock

Water development projects which take into account the need to minimise range degradation from uncontrolled grazing will clearly need to limit the number and size of water points. The attributes of indigenous livestock in energy and water conservation show them to be better suited to such pastoral production systems than are exotic breeds and crosses.

6.3.1 Beef versus milk

The main reason for the existence of 100 million of the 135 million cattle in sub-Saharan Africa (FAO, 1977) is to provide a staple diet of milk under conditions which are harsh for both man and beast for much of the year. The amount of milk produced is, of necessity, only a few litres per day but is usually shared between the household and the calf, so that there is scope for marketing immature animals. Furthermore, the high percentage of females in the herd (55 to 60%) provides scope for rapid population recovery after a drought (King et al, in press).

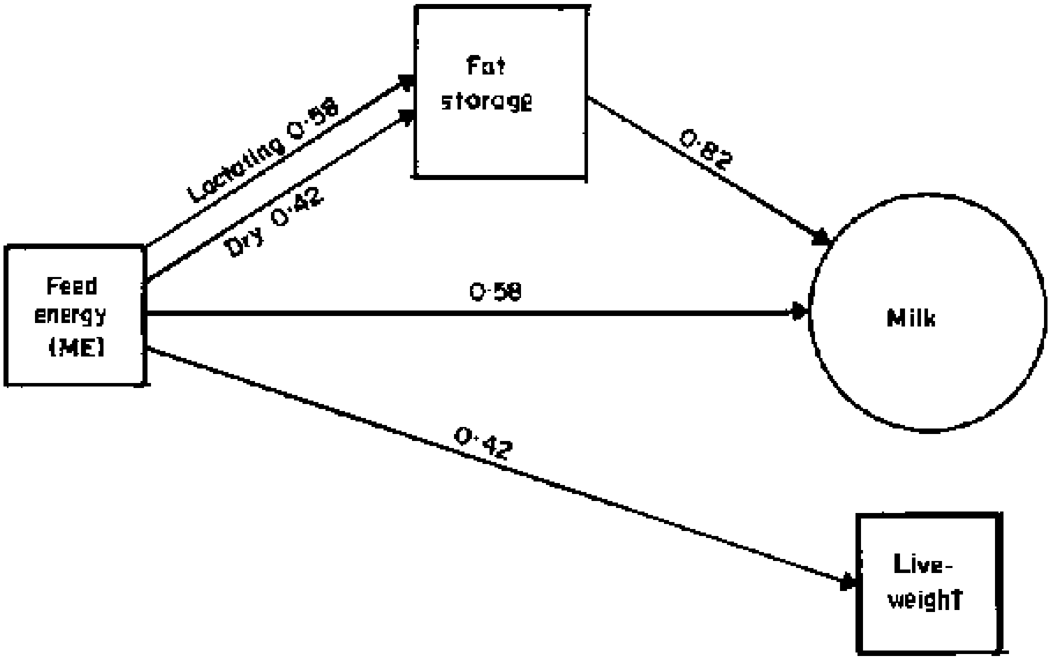
The dependence of pastoralists on milk may be decreasing with the trend towards smallstock, dryland farming and a more cash-oriented economy. Nevertheless, the transition from pastoral milk to commercial beef production is not the logical extension of this trend because it fails to provide a livelihood for the vast majority of the pastoral community. The slums and shanty towns around most African cities bear witness to the hopelessness of trying to find alternative employment for these people.

Furthermore, there is nothing inefficient about dairy ranching versus beef. The value, in terms of human nutrients, of a kg of milk is much the same as that of 1 kg of liveweight gain. The efficiency of conversion of feed energy (ME) to milk is much higher than to meat and fat. Lactation also enhances the conversion efficiency of fat deposition. The actual conversion coefficients vary with the digestibility of the diet, which has been fixed at 60% for the purposes of the example (Figure 23). The comparative water content may also be relevant in the dry season when water intake is limited. At that time fatty tissue, containing only 0.451.kg^{-1}, is unlikely to be deposited and the water content of milk (0.87 l.kg^{-1}) and lean meat (0.75 l.kg^{-1}) are quite similar.

6.3.2 Cattle improvement

The African cattle breeds which are most frequently improved are zebu and Sanga. Compared with European breeds, zebu cattle are generally more tolerant of the heat, parasites and diseases of the African environment. They require less water per kg bodyweight and per degree rise in ambient temperature, but this is mainly due to a smaller food intake and a lower metabolic rate. The threshold ambient temperature at which they start to sweat is higher (28°C as opposed to 17°C), but they sweat at a higher rate once they have started (Winchester and Morris, 1956; Horrocks and Phillips, 1961; Brown and Hutchinson, 1973). Zebu cattle digest low-quality grass hay slightly better than Herefords and show less depression of appetite when water is restricted (Phillips, 1960; 1961a; 1961b). The N'Dama, an indigenous *Bos taurus* breed found in the humid areas of West Africa, is reputed to have an even lower water requirement than the zebu (Pagot, 1974).

Figure 23. Relative efficiencies of metabolisable energy use for cattle production, at a digestibility of 0.60.



Source: Moe and Flatt (1969); Konandreas and Anderson (1982); Van Soest (1982).

The improved breeds are usually exotic to Africa and come from Europe, North America or Asia. Their introduction is often not questioned because, at the level at which decisions are made, both the donor and the recipient are familiar with the exotic animal in its original environment. For example, attempts to establish the Red Sindhi × Jersey as a dairy breed in the southern United States were abandoned in favour of existing European breeds (Branton et al, 1966). The reason was that it was more economic to ameliorate the environment with cool buildings and reduce the heat increment of feeding with a low fibre, high protein and energy ration than replace high yielding European cattle with more robust zebu crossbred cattle of lower productivity. Since the early days of domestication, 'invaders have persisted with the introduction of livestock to which they are accustomed, even when the habitat was inappropriate' (Bökönyi, 1969).

In many parts of the tropics, for example in Queensland and East and central Africa, there is only limited opportunity for improving the environment and zebu crosses have proved superior to pure European breeds (Lampkin and Kennedy, 1965; Redfern, 1968; Sacker et al, 1971; Frisch, 1972; Brown and Hutchinson, 1973; Trail and Gregory, 1981). In such situations, the genetic potential for higher productivity of the pure European breed is less important than the superior ability of the zebu to rear a calf without losing too much condition, so that it conceives again.

In the pastoral or subsistence dairy ranching situation it is the relative stability of the small milk yield under fluctuating environmental conditions which is all important. The zebu achieves this stability because it lays down tissue reserves during the rains, whereas high-yielding European cows divert a greater proportion of dietary energy into milk (Trigg and Topps, 1981). As a result the European crossbred cow fails to provide a reliable milk supply in the dry season, because of lower tissue reserves as well as higher metabolic demands. Futhermore in European breeds of cattle, milk yield is depressed by water restriction (e.g. Little et al, 1976), whereas the admittedly smaller milk yield of zebu cattle is largely unaffected by alternate day watering by the time range conditions demand it. The conclusion is that if crossbred cattle produce more milk during the rains, when there is a surplus anyway, and less during the dry season when it is really needed, then they should not be considered an improvement, even if their overall lactation yield is higher.

In Kenya Maasailand, there is a trend with increasing group ranch development towards using introduced zebu bulls, notably the 'improved' milking Sahiwal and 'improved' beef Boran, on the Small East African Zebu. It also happens that the most developed group ranches have the highest rainfall, and it will be interesting to see how far down the aridity gradient the practice of crossbreeding is taken before it becomes counter productive (King et al, in press).

Both the Sahiwal and Boran are bigger than the Small East African Zebu, as well as being more productive. But when forage is scarce the small animal may prove to be the better milker, because it will walk and feed at much the same rate as the larger ones but have a smaller maintenance requirement. Livestock appear to get smaller as the average THI increases (Table 21). The phenomenon appears to apply to wild as well as domestic African ungulates (Dorst and Dandelot, 1970). While poor nutrition, high parasite loads and disease challenge may be contributory factors, dwarfism may be the physiological response to a humid, hot environment. Having accepted the general principle of using small indigenous animals because of their adaptation to a hostile environment, it is inconsistent to still select for bigger size.

The main objection to the use of 'improved' livestock in pastoral areas is their inability to realize their genetic potential in the absence of some improvement in management. At present livestock in much of pastoral Africa do not need to have a high production potential, because the low nutritive value of forage, supplied by grasslands and crop byproducts, allows but a limited yield if not supplemented with arable crops, which is unlikely (Jarrige, 1980).

6.3.3 Breeding cattle for pastoralism

It has been suggested that the amount of exotic blood in livestock should decline, as the productivity of the pastoral system declines, but the suitability for pastoralism of the genetic material in 'improved' breeds has so far not been questioned. Under conditions of heat, water or nutritional stress the exotic genes may be working at cross purposes with the objectives of the system.

It has also been suggested that pastoral cattle should remain reasonably independent of water. But emphasis on water conservation efficiency means that the criteria evolved in the developed tropics for livestock selection cannot be strictly applied. In the southern United States and northern Australia, research has been concerned with identifying livestock, particularly cattle, which exhibit the least rise in rectal temperature in response to heat stress. This attribute is described as heat tolerance, and has been related to higher growth rates, lower embryo mortality and higher birth weights (McDowell, 1972; H.G. Turner, unpublished). Heat tolerance is primarily due to efficient heat dissipatory mechanisms, notably sweating, but it could also be due to a depression in endogenous heat production which is why heat tolerance tests are not particularly sensitive indicators of productivity (Branton et al, 1966). Lower heat production implies a lower metabolic rate and consequently lower growth potential. The basis for selection has therefore been refined to that of maintaining a normal rectal temperature without a reduction in food intake (Vercoe, 1976; Frisch and Vercoe, 1977; 1978).

If sweating is to be kept at a minimum in the pastoral cow then either high heat loads must be avoided and dry heat loss increased, or the body temperature must be allowed to fluctuate (Figure 8 and section 4.2).

The value of a light or medium coloured, dense coat to reduce solar radiation reaching the skin surface is generally recognized, as is the disadvantage of a 'woolly' coat in cattle which has been negatively correlated with weight gain and milk production in the tropics, probably because it reflects a physiological imbalance (McDowell, 1972).

The best shape for reducing radiant heat load is that of the camel, with its long legs, short, slab-sided body and razor-back. The sale of immature steers may be an important component of production and the objectives of beef production may be in conflict with those for water conservation. For example, the Boran beef breeder is looking for a long, broad, straight back, avoiding rangy animals because they are indicative of slow maturity and stocky ones because they lack the more extensive and expensive back joints.

There is some debate about the efficacy of beef breeding selection programmes in changing the shape of the animal. For example, McDowell (1972) noted that the effect of zebu genes in a crossbreeding programme in the USA was to shorten the length of the back. In a crossbreeding programme in western Uganda, Trail et al (1971) found that at the same weight, there was no difference in side and leg length between Boran, zebu and Redpoll crosses. Ankole crossbreds, which are a Sanga type, were both longer and taller. The only crossbred that was longer backed and shorter legged was the Aberdeen Angus crossbred, reflecting the more intensive selection for blockiness which has gone on in this breed. The equable climate in western Uganda did not seem to favour one crossbred more than another. More extreme climates might have done so, and also altered the shape an-d size of the growing animals (section 4.2.5).

The role of appendages has not been completely clarified and there is not enough evidence to promote them at the expense of other characteristics. Thus skin folds should not extend into pendulous sheaths, nor should horns be retained just for their possible thermoregulatory function. On the other hand there may be good reasons not to dehorn animals in a pastoral situation, where horns may be highly prized. For example the size, shape and colour of the horns of the Ankole cow, which may be up to 85-90 cm long and weigh 7 kg or 1.7% of bodyweight, are second in importance only to coat colour in the eyes of their breeders, the Abahima people (Mackintosh, 1938). Horn disbudding had no significant effect on growth rates from birth to 3 years (Trail and Sacker, 1966), and it is possible that horns would act as radiators in hotter, drier environments.

There are also other behavioural responses to be encouraged, apart from shade-seeking. Camels are adept at exposing the minimum surface area to solar radiation under conditions of water deprivation. When the herdsman notices that all the camels have turned to face the sun, it is time to take them to water (C.R. Field, unpublished). Schmidt-Nielsen (1965) describes how the dehydrated camel sits on the ground with its legs under its body facing the sun, and how groups huddle together couched on the ground to reduce heat flow from the environment during the hottest hours of the day in the Sahara.

The alternative of allowing the body temperature to fluctuate was addressed by Thigh (1972) who suggested that the benefits which thermolability bestows on the camel could apply equally well to cattle, sheep and goats. As has already been indicated (section 4.2.6), smallstock probably do not have a large enough mass to store a significant portion of the day's radiant heat load to make thermolability worthwhile. Cattle are big enough and at least one breed, the N'Dama, allows its body temperature to fluctuate. The mechanism has been associated with trypano-tolerance, but it has also been noted that the N'Dama has low water requirements. Furthermore thermolability does not seem to have affected the N'Dama's productivity compared with other indigenous breeds of cattle (Table 45). Selection for thermolability runs contrary to the philosophy behind the heat tolerance tests mentioned earlier in this section.

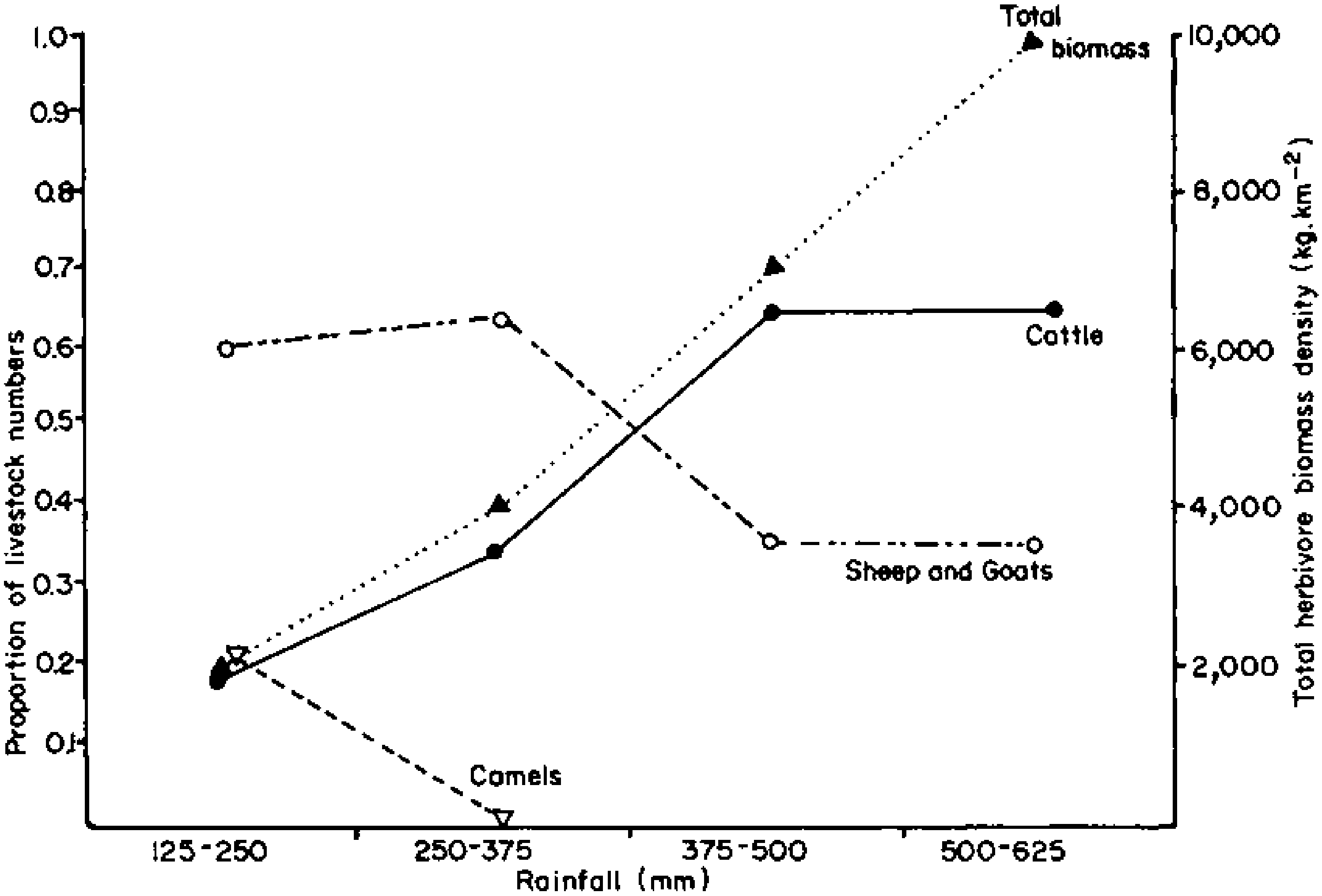
Because of the relatively small milk yield of the pastoral cow, it may be tempting to replace it with a beef animal. But the criteria for selecting a pastoral cow are slightly different from those for the beef cow, which may be selected on the basis of her calving interval, ability to maintain bodyweight while suckling a calf, and on the calf's viability and weight at weaning. Admittedly the 'improved' Boran is only a few generations away from its role as a pastoral cow, and may retain the pastoral characteristics. To support this last suggestion it has been shown that 'beef' Brahman cattle imported into tropical Australia, milked more than Herefords and used feedstuffs and nutrients from body stores to lactate at the expense of reproduction (Turner, 1980).

6.3.4 Species mix

Despite the attributes of the pastoral cow discussed above, pastoralists cannot rely on cattle milk throughout the dry season, and in arid areas they may not be able to keep cattle at all. Thus a mix of species is kept, related to the rainfall in the area (Figure 24). This mix is also affected by such factors as sedentarisation, range trends and exposure to new markets (King et al, in press).

The ratio between the species varies with the rainfall since it is partly related to heat tolerance and water needs. Attributes in water conservation efficiency are normally thought to be traded off against productivity, but enough evidence has been produced in this report to show that this relationship is not constant. In a direct comparison of the water cost of production between species on Galana ranch, it was found that the growth rate of domestic oryx, eland and cattle was of the same order, but that oryx had about one third of the water requirements of the other two (Table 43).

Figure 24. The relative composition of pastoral livestock holdings under various rainfall regimes in Kenya (total herbivore biomass figures include wildlife).



No similar work has been done in the pastoral situation, but one can make a preliminary assessment of whether or not big discrepancies in the water cost of production are likely to occur. The first step is to obtain a measure of the productivity of different species on natural rangeland.

A useful index was developed by ILCA (1979a) which measured productivity in terms of the weight of the yearling calf and the calf equivalent of milk taken by the herdsmen, divided by the weight of the dam maintained annually. The same sort of index was applied to sheep and goats, with the difference that the weight of the progeny was taken at weaning (5 months), although production was still expressed on an annual basis. In order to compare large and small stock in the same index, production has been expressed on an annual basis in terms of what the female weans. Weaning age is taken as 12 months in camels (Bremaud, 1979), 9 months in cattle and 5 months in smallstock. Thus yearling calf weights given in ILCA (1979a) have been corrected to weight at 9 months using the following equation:

9-month weight = 12-month weight - (12-month weight - birth weight)/7 (kg) (6.01)

a

Table 43. Comparison of daily growth and water turnover in domestic oryx, eland and Boran cattle.

Species	Water turnover (ml $l^{-0.82}$)	Growth ($g\ kg^{-1}/W_{¥}^{0.75}$)	Water cost of growth ($ml.g^{-1}$)
Oryx	68	3.2	21
Eland	202	3.1	65
Boran cattle	188	3.4	55

[a] From birth to 98% of asymptotic weight (W¥).

Source: Carles et al (1981).

Table 44. Annual productivity estimates for the camel.

Parameter	Unit	Code	Calculation	Value
Calving	%	A		50
Calf viability to weaning	%	B		60
Calves weaned	%	C	A × B ÷ 100	30
Calf weaning weight	kg	D		150
Total weight of weaners	kg %	E	C × D	4500
Milked out yield	kg	F		1460
Liveweight equivalent of milk	kg	G	F ÷ 9	162.2
Female viability	%	H		95
Females maintained	%	I	H + [(100 - H) ÷ 2]	97.5
Female weight	kg	J		420
Female metabolic weight	$kg^{0.75}$	K	$J^{0.75}$	92.8
Per cow maintained				
Weight of weaner	kg	L	E ÷ I	46.2
Liveweight equivalent of milk	kg	M	G × (A ÷ 100) ÷ 1	83.2
Productivity index[a]	kg	N	L+M	129.4
Productivity index[a]	$g.kg^{-1}$		N × 1000 ÷ J	308.1
Productivity index[a]	$g.kg^{-0.75}$		N × 1000 ÷ K	1394

[a] Defined as the total weight of weaned calf plus liveweight equivalent of milk produced per annum.

Source: Mason and Maule (1960); Bremaud (1969); Spencer (1973); Dahl and Hjort (1976); Williamson and Payne (1978); and Wilson (1978a).

Camel productivity traits have had to be derived from a variety of sources (Table 44). The low calf viability to weaning (60%) is a reflection of the demands made by the household. These needs can hardly be reduced: in times of drought the Rendille of northern Kenya let the male camel calves die first, then their own children, and then the female calves (H.J. Schwartz, unpublished).

The values of the productivity index for species and breeds from all over sub-Saharan Africa have been brought together in Table 45.

When the productivity index is expressed in Table 45 as g of weaner produced per kg of dam maintained per year, it can be seen that goats are more productive than sheep, and sheep more than cattle and camels. However, when size is discounted, there is no difference between the 20 kg West African Dwarf goat and the 420 kg camel. It is difficult to know if differences between breeds within sheep or goats are real or due to a paucity of data, compared to cattle. The mean values for sheep, goats, cattle and camels are remarkably similar with a range of 1085 to 1395 $g.kg^{-1}W^{0.75}$. $year^{-1}$ (30%). In contrast the values for mean daily water turnover are remarkably different, with a twofold difference between the Small East African goat (at 300 $ml.l^{-0.82}$) and camel (at 150 $ml.l^{-0.82}$) in the same environment (Galana).

The conclusion is that differences in the water cost of production between species, if not breeds within species, are worth more study, particularly in the context of pastoral water development.

6.3.5 Centripetal watering

This management practice involves herding livestock as far from water as possible at the start of the dry season, when the vegetation is green and the days are cool, and gradually bringing them closer as the vegetation dries out and the days become hotter. It is commonly practiced with camels and smallstock, for example by the Rendille and Gabra of northern Kenya (IPAL, 1982), but not with cattle. Herders of cattle normally adopt a practice of centrifugal watering, which involves grazing near water first and extending their range as the dry season progresses. The reason for the different practices probably relates to the lower water requirements of camels and smallstock and their higher water intake from forage, compared to cattle.

Nevertheless, the observation of cattle in Niger suffering fatigue and weight loss but walking maximum distances at the end of the dry season and at the hottest time of year, prompted Rippstein and Peyre de Fabregues (1972) to recommend centripetal watering. The practice was adopted by Klein (1981) in an experiment to determine the optimum stocking rate on Sahelian pastures in Niger. A traditionally managed herd was included as a control, but the comparison of the two systems of watering was confounded by the fact that the animals on the centripetal system were in paddocks, and may even have grazed at night.

The value of centripetal watering in maintaining bodyweight at the end of the dry season may be negated in the pastoral system if it depresses lactation at the beginning. The milk yield will be at its peak at the end of the rains when the cow will be expected to walk as far away from water as possible. An energy budget for that period suggests that the animal should not walk more than about 10 km.d^{-1} (Table 46).

Table 45. Comparison of the productivity index in different breeds of livestock under subhumid to semi-arid ranching conditions, and low to no tsetse fly challenge.

		Weaner per dam per year	
Species		**(g kg^{-1})**	**(g kg^{-1}W$^{0.75}$)**
CAMEL		308	1395
CATTLE			
Humpless:	N'Dama	325	1310
	West African Shorthorn	334	1215
Humped:	Boran	349	1530
	Small East African Zebu	319	1295
	Sokoto Gudali	274	1175
	White Fulani	394	1690
Humpless × humped:	Africander	256	1180
	Ankole	284	1230
	Tswana	338	1540
Species mean:		316	1375
GOATS			
Dwarf:	West African	648	1390
Intermediate:	Small East African	428	975
Long-legged:	Sahel	363	840
	Sudan Desert	618	1495
Species mean:		514	1175
SHEEP			
Thin-tailed:	West African Dwarf	639	1405
	Sahel	434	1095
	Sudan Desert	530	1335
Fat-tailed:	Maasai	297	710
	Tswana	370	890

Species mean:		454	1085

Source: Adapted from ILCA (1979a) and Table 44 for the camel.

Table 46. Estimated daily energy budget of a zebu cow on centripetal watering.

Item	Absolute value	Coefficient	Equation number	Metabolisable energy (MJ)
Forage intake	6.34 kg DM	d = 0.50	(5.02)	46.3
Maintenance at rest	250 kg		(5.03/4)	29.0
Extra costs: feeding	46.3 MJ ME	40 kJ.MJ^{-1}ME		1.9
lactating	2.0 kg	3.6MJ.kg^{-1}	(5.05)	12.9
walking	9.5 km	1.8kJ.kg^{-1}.km^{-1}		4.3
Total expenditure				48.1
Energy balance				- 1.8

The estimated energy deficit of 1.8 MJ ME. d^{-1}, or 0.4 kg weight loss per week, is unlikely to depress lactation. However the *boma* can only be located a maximum of 5 km from the watering point. Therefore the cow must be watered every second day so that it can graze away from water on alternate days, thereby increasing the radius of the grazing area from the watering point to about 9 km. The problem with the implementation of 2-day watering when the cow's water needs are still high (due to high DMI and milk yield) is that the animal may become severely dehydrated. This will become apparent if it drinks more than 50 l every second day, i.e. it has a daily drinking requirement of 25 l. The degree of dehydration represented by 50 l every second day in a 250 kg cow is 20%. Any further water needed to offset the demands of DMI and milk yield must come from water in forage, which can be calculated using equation (5.21):

$$W_F = (I \times I_W) + (WK \times WK_W) + (MY \times MY_W) - W_D$$
$$= (6.34 \times 4.5) + (0 \times 0.35) + (2 \times 0.87) - 25$$
$$= 5.3 \text{ l.d}^{-1}$$

The moisture content of the grass which will achieve this water intake is obtained from equation (5.20):

$$\text{Forage moisture} = W_F/(I + W_F)$$
$$= 5.3/(6.34 + 5.3)$$
$$= 0.46$$

The conclusion reached is that lactating zebu are unlikely to maintain full productivity on a centripetal watering system when the grass moisture falls below 0.46. This value is based on a mass of assumptions which need to be validated. However, the example illustrates the principles involved and one of the main constraints to the innovation.

The other major constraint in Niger, and of course elsewhere, is how to destock around the pumping stations so that centripetal watering can be adopted. The pasture within a radius of 8 km of these pumps is about 20 000 ha and should support <3000 TLU, whereas in practice it carries >10 000 TLU (Rippstein and Peyre de Fabregues, 1972).

6.3.6 Restricted watering

When the rains have failed and it is likely to be a difficult dry season the transition to 2- and 3-day watering should be made earlier in order to precipitate a 'siege' condition in the animals. The value of reducing cattle maintenance requirements to two thirds of normal, is that it allows the grazing to last one third longer or carry one third more animals. There is also a saving in tissue reserves compared with an animal on a daily watering regime, which could be in the region of 95 MJ ME (Figure 18). This saving does not look much compared with a daily maintenance requirement of 23 MJ ME until one realizes that the cow with a depressed metabolic rate is approximately in energy balance (Table 31). The decision to change from a production to a survival strategy is normally associated with lack of grazing, but it should also be taken when the *quality* of the forage is low. As Rogerson (1963) showed and has been mentioned in section 4.3.2, cattle on a roughage diet with a low protein content are better able to maintain energy balance if water intake is reduced.

The trend of decreasing frequency of watering is usually associated with increasing distance of the *boma* from the watering point, which puts added strain on the water supply to the household. This constraint can be overcome with the provision of baggage animals. In the semi-arid areas donkeys appear to be in plentiful supply, but in the deserts where camels are used there is not enough slack in the system to rear an adequate number of males (section 5.2.2). Consequently there may be a case for providing mature baggage camels to poor settlements to allow them to get away from water into better browsing areas, thereby breaking the vicious circle in which they have neither milk nor forage enough to rear their own males. In fact this is one of the recommendations of the resource management plan for the Rendille area of northern Kenya (IPAL, 1982).

Another category dependent on carried water are young, unweaned livestock in the hottest pastoral environments. For example, in the northern Sahel, the Tuareg keep their camel calves in camp for the first 4 months and give them 5 to 10 l water from a waterskin every 3 to 4 days, and goat kids are kept in camp for 6 months and drink 1 to 21 every day (Swift, 1979). The provision of inadequate water to compensate for the milk taken by man could be one more factor contributing to the high mortality rates in young stock.

6.3.7 Night grazing

Except where intense sun forces herdsmen to let their livestock out before dawn, night grazing is not practiced in pastoral Africa. The main reason is that it is very labour intensive, and also dangerous for the stock (predators) and the herdsmen (snakes). A prerequisite for night grazing is fencing and predator control, both human and animal. The value of night grazing is that it provides extra time to eat vegetation with a higher moisture content at low environmental heat loads. It is practiced by many wild herbivores in desert areas, and makes them largely independent of drinking water (section 3.3.3). In cattle, its most important contribution is to the high yielding dairy cow which can be identified by the extent of its foraging at night (Stobbs, 1975). Good night paddocks are desirable for optimum dairy production on tropical pastures. At the other end of the scale, it was found in Tanganyika that Small East African Zebus allowed to graze at night were only 3 kg heavier after 72 weeks than their counterparts which were penned at night (Meyn, 1970). In a similar comparison, Boran zebus put on an extra 23 kg with night grazing. It was concluded that a small breed of zebu can satisfy its nutritional requirements under traditional pastoral management whereas a larger breed, like the Boran, cannot. In another trial in Tanganyika with Boran and Angus × Boran steers, the 5 to 6% improvement in liveweight of 24 h grazing over night penning was offset by the loss of 2 steers killed by lions (Wigg and Owen, 1973). The same authors noted one benefit of night grazing, not previously mentioned, namely the manure the pasture receives which would otherwise accumulate in the night enclosure. This extra fertilizer visibly assisted the spread of a most useful perennial star grass (*Cynodon dactylon*).

From the foregoing, it can be seen that the value of night grazing to small breeds of indigenous livestock is not automatic; it also varies with environmental and pasture conditions. For example, when West African Shorthorn cattle were left out during the whole 24 h in Ghana, the amount of time they chose to spend grazing at night was found to vary with the environmental conditions (Rose Innes, 1963). In Uganda, Joblin (1960) found that the restriction of night grazing led to a significant decline of 30% in liveweight gain in zebu oxen, but the difference was largely attributed to periods of moderate grass shortage, when those animals with the longer grazing period were able to select a diet of superior quality and quantity. Under good or very bad grazing conditions the provision of night grazing made no difference. In many areas of Maasailand the nights can be clear, cold and windy, particularly towards the end of the dry season. Crowding cattle together in a thorn *boma* for the night must reduce their heat loss and their need to waste limited body energy reserves on thermogenesis.

7. Research implications

Successful livestock management in a pastoral production system is the art of balancing production objectives against highly unpredictable and variable forage and water resources. Such a scenario is difficult to recreate on a research station and the scientist must be prepared to extend his experiments into the herds and flocks of the pastoralists.

7.1 Modelling and hypothesis

The value of a modelling approach is that it disciplines the scientist to piece together scattered facts from isolated experiments and ideas into a coherent form (Figure 19). It may be difficult to define the units of a model. For example, there was a strong case for adding considerations of protein and mineral metabolism, but this has been excluded.

The consideration of an overall model also has the benefit of indicating factors in need of investigation (Van Soest, 1982). Simple models are the first step in providing scenarios for a range of conditions in applied situations (for example, Table 32 on daily, 2-day and 3-day watering), enabling better management decisions to be made (Christian, 1981). Governments and aid agencies need the most sophisticated projections they can get, if for no other reason than an insurance against expensive failures.

7.2 Component research

A study of almost any section of this report reveals opportunities for component research, either in the field, the research station or the laboratory. The research priorities outlined below are based on the most important topics and species and are biased towards the pastoral situation rather than the laboratory.

7.2.1 Priority topics

There is a need to improve the precision of the estimates in the following components of energy production, heat exchange and water turnover.

The most important and yet weakest link in the research chain of energy production is the measurement of forage intake. The fibre component of the diet may prove to be a more useful predictor of intake (e. g. Thornton and Minson, 1972; Van Soest, 1982) than digestibility and crude protein which are more frequently used at present (Konandreas and Anderson, 1982). The fasting metabolism or at least the maintenance requirements of the wide variety of breeds of African livestock need to be measured. The biggest drain on the pastoral cow is probably lactation, not walking, despite the cow's small milk yield. The energy expended (MJ ME) in producing 1 kg of milk was estimated to be the same as walking 14 km (section 5.1.3).

More work on heat exchange between the animal and its environment needs to be done in the field. Up to now much of it has been done in the laboratory and the calorimeter. The value of the work is unquestioned but it still has to be translated into the field or pastoral situation. The main difference between the two environments is of course the sun, but solarimeter readings are probably of less general value than temperature recordings in sub-Saharan Africa. The reason is that the heat load on the animal decreases with increasing altitude whereas solar radiation may increase. The overall vertical decrease in temperature (lapse rate) is between 0.5°C and 1.1°C per 100 m of altitude in the tropics, depending on the season, with a relatively constant rate of 0.6°C per 100 m in the highlands of eastern Africa (Barry and Chorley, 1971; Brown and Cochemé, 1973). Measurements of environmental heat load can be obtained from standard meteorological sites, but a more accurate picture of the microclimate affecting the animal is required.

A number of different indices of the thermal environment are discussed in the textbooks, each requiring different recording instruments (Kerslake, 1972; McDowell, 1972; Mount, 1979). Ideally these should integrate solar radiation, ambient temperature, wind velocity and air water vapour pressure. A simple index which has proved useful for reducing heat casualties in man during army training is the wet bulb: globe temperature index' (WBG T_g). If the normal wet bulb temperature (T_{wb}) is used, from a forcibly ventilated wet bulb not exposed to radiation:

$$\text{WBG } T_g = 0.7\, T_{wb} + 0.3\, T_g \quad (6.02)$$

Tritiated water studies of TBW have increased our understanding of animal water transactions under field conditions. The most important intake is drink but water intake from forage requires further study. The separation of evaporative water loss (Maloiy, 1973) from that required for intermediary metabolism might be the next requirement of the model, if, indeed, the extra precision justifies the effort.

Work on nutrition heat load and body water turnover should proceed in parallel, otherwise it is very difficult to integrate the three components.

7.2.2 Priority species

The zebu cow remains the most important animal in the pastoral system (Table 2), but priorities for research may be modified slightly towards other species for a number of reasons. There is a trend towards pastoralists keeping more smallstock, at least in certain areas such as Maasailand. The value of camels is becoming increasingly apparent, notably because more areas are being made available for them by the desertification process and also because their exploitation of fragile habitats is less destructive than that of goats, cattle and sheep. The donkey may thrive on neglect, but that does not mean that a small research input would not improve the lot of this much abused animal.

7.3 Field methods

Field work on the priority topics already discussed (section 7.3.1) is not as difficult as it used to be; technical equipment is becoming increasingly compact and rugged so that samples can be collected, processed, preserved or even measured in the field. Communications by 4 wheel drive vehicles, light aircraft and scheduled air services provide ready access to advanced laboratory facilities.

Studies of the nutritional value of the diet are complicated by the difficulties of herding fistulated animals in a pastoral environment. Fortunately, where the preponderance of shrubs threatens to dislodge the fistula plug, the herbivore changes from a grazer to a browser and simulation of the diet by hand-plucking becomes more realistic. Similarly, while bagging techniques may be applied to free-ranging cattle (Dicko, 1981), the faeces produced by herbivores in dry, thorn scrub are often pelleted and easy to collect. One advantage of the nutritionist in Africa compared with colleagues in some other parts of the world, is that labour-intensive methods can be employed. The high ratio of good herdsmen to livestock also means that the animals are easy to catch and handle. There remains the problem of obtaining a representative sample of the herbage on offer from natural grassland.

Measurements of energy balance are frequently done using a portable weighscale. Such scales may not be accurate to more than 2% of bodyweight (e.g. 5 kg on a cattle weighbridge), which may mean that 20% of the body fat reserves may be missed. Similarly, it is easy to obtain a rough measure of milk yield and distance walked (e.g. Semenye, 1982) but difficult to get an accurate one.

Measurement of heat exchange in the animal in the field is the province of the specialist, but the general animal scientist should at least understand the principles involved and be able to describe the microclimate of the free-ranging herbivore. Whether or not an index such as WBG T_g is applied, two of the most useful portable instruments are: the whirling hygrometer which can measure shaded dry bulb temperature as well as wet bulb depression for calculations of total heat of evaporation, and the globe thermometer which measures the combined effect of radiation and convection.

Much useful information can be obtained from field observations of drinking, such as the physical limits to the volume that can be drunk and the time taken to completely replace lost body fluid. Is water intoxication really a problem in indigenous ruminants adapted to semi-arid environments, or are the symptoms caused by distension of the rumen, discomfort and weakness? What is the level of dehydration which will depress appetite and lactation in each breed and species under field conditions? The forage moisture content of the diet must be estimated as accurately as possible using hand-grab samples of the observed diet. Accuracy is most important when forage moisture is above about 35% when its contribution to total water intake starts to increase rapidly (Figure 4). Tritiated water studies should be continued, provided the potential size of the discrepancies between predicted and actual water input under intermittent watering regimes are recognized and precautions taken to minimise them (King and Finch, 1982).

7.4 Conclusion

An important contribution that the developer, and hence the scientist, can make to the productivity of pastoral systems will be to increase the efficiency with which scarce water and energy resources are used. As much as possible of the research should be undertaken in the environment in which the pastoralist is living so precariously, in order to understand the realistic possibilities for improvements in livestock production in pastoral systems.

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Abbreviations used in the text

ABA	Animal Breeding Abstracts, CAB, U.K.
ARC	Agricultural Research Council, U.K.
BDPA	Bureau pour le Développement de la Production Agricole, France
BVA	British Veterinary Association, U.K.
Bwt	bodyweight
CAB	Commonwealth Agricultural Bureaux, U.K.
CEEMAT	Centre d'Etudes et d'Expérimentation du Machinisme Agricole Tropical, France
CNRA	Centre National de la Recherche Agronomique, France
d	day
DDT	pp'-dichlorodiphenyltrichloroethane
DM	dry matter
DMI	dry matter intake
FAO	Food and Agriculture Organisation of the United Nations, Rome, Italy
HMSO	Her Majesty's Stationery Office, U.K.
IAEA	International Atomic Energy Agency, Vienna, Austria
IEMVT	Institut d'Elevage et de Médecine Vétérinaire des Pays Tropicaux, Paris, France
IFS	International Foundation for Science, USA
ILCA	International Livestock Centre for Africa, Addis Ababa, Ethiopia
IPAL	Integrated Project on Arid Lands, Kenya
LU	livestock unit
MAFF	Ministry of Agriculture, Fisheries and Food, U.K.
m a.s.l.	metres above sea level
ME	metabolisable energy
mosm	milliosmole
NE	net energy
NRC	National Research Council, USA
OAU/STRC	Organisation of African Unity/Scientific and Technical Research Council
Pa	Pascal
r.h.	relative humidity
TBW_T	total body water turnover
THI	temperature-humidity index
TLU	tropical livestock unit = 250 kg
TOH	tritiated water
UNESCO	United Nations Educational, Scientific and Cultural Organisation, Rome, Italy
Wg	water in gut
Wm	water for metabolism
$W.m^{-2}$	Watts per square metre
Wt	weight

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