Feeding and Working Strategies for Oxen used for Draft Purposes in Semi-arid West Africa

*A. Fall**

With the collaboration of

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List of Abbreviations

ADF	Acid-detergent fibre
AFRC	Agricultural and Food Research Council
ATP	Adenosine triphosphate
°C	Degree Celsius
Cr	Chromium
CO_2	Carbon dioxide
CTVM	Centre for Tropical Veterinary Medicine
d	Day
DM	Dry matter
DMD	Dry matter apparent digestibility
DMI	Dry matter intake
E_f	Efficiency of doing work = work done / energy used
E_w	Energy cost of walking
FAO	Food and Agriculture Organization of the United Nations
g	Gram
GE	Gross energy
h	Hours
H	Heat production
HEM	Hemicellulose
IBC	Initial body condition
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
ILCA	International Livestock Centre for Africa
ILRI	International Livestock Research Institute
J	Joule
k_1	Rate-constant, rate of passage of digesta in the rumen
k_2	Rate-constant, rate of passage of digesta in the lower tract
kg	Kilogram
kJ	Kilojoule
km	Kilometre
M	Liveweight mass
m	Metre
ME	Metabolisable energy
MIRT	Maximum increase in rectal temperature
min	Minute
mm	Millimetre
mmol	Millimole

MJ	Megajoule
MRT	Mean retention time
n	Number of observations
N	Newton
NDF	Neutral-detergent fibre
NE	Net energy
nmol	Nanomole
No.	Number
NS	Not significant
O_2	Oxygen
OM	Organic matter
PUN	Plasma urea-nitrogen
RAM	Rest in the morning
RPM	Rest in the afternoon
RH	Relative humidity
RR	Respiration rate
RT	Rectal temperature
s	Second
SAS	Statistical Analysis Systems
SE	Standard error
SMR	Standing metabolic rate
T_3	Triiodothyronine
T_4	Thyroxine
THI	Temperature humidity index
TT	Time of first appearance of the marker
W	Watt
WAM	Work in the morning
WPM	Work in the afternoon

Glossary of Units

Calorie (cal)	The amount of heat required to increase the temperature of one gram of water by one degree centigrade (from 14.5 to 15.5°C in physiological studies) when the specific heat of water is 4.184 J/g.
Joule (J)	Work done when a body is moved 1 m against an opposing force of 1 Newton. 1 calorie = 4.184 joules; 1 kJ = 1000 J; 1 MJ = 1 000 000 J.
Kilogram-force (kgf)	1 kgf = 10 Newtons.
Newton	The SI unit of force that, acting on a mass of one kilogram, increases its velocity by one metre per second every second along the direction that it acts.
Watt (W)	1 W = 1 joule per second.

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1
Introduction

Draft animal power has been harnessed for agricultural purposes for thousands of years. Although tractors have superseded draft animals for farming in the developed world during the last 50 years, draft animal technology remains a relevant farm technology in many parts of the developing world mainly for economic and agro-ecological reasons. Purchase and maintenance costs of tractors are high in many countries in sub-Saharan Africa. These factors confer a comparative advantage on draft animal technology, which is less expensive than tractor power for small-scale farmers who make up the majority of rural communities. In addition, certain fields such as those on steep or terraced hillsides and in muddy river valleys are often inaccessible to tractors. Draft animals are therefore the only means, other than hand labour, farmers have for cultivating these lands.

Draft animal power was introduced in sub-Saharan Africa during the last 70 years and its use is spreading (Panin and Ellis-Jones 1994; Starkey 1994). However, the contribution of draft animals to the power requirements for agriculture is still limited in this area. Agricultural production in sub-Saharan Africa continues to rely primarily on human power. Statistics in 1987 suggested that 89% of power was provided by humans while draft animals supplied 10% of the farm power input (FAO 1987).

Draft animal technology has been qualified as an ecologically sustainable means of increasing agricultural production, reducing human drudgery and improving the quality of rural life (Starkey 1994). There is a need to promote the use of draft animals in sub-Saharan Africa to fill the gap between the deteriorating level of food production and the increasing demand for food. This is particularly true in semi-arid areas where timeliness in cropping operations is fundamental for successful cropping because of the short growing season. The low and erratic rainfall regime constrains land preparation and timely planting at the onset of the rainy season. In these situations, draft animal power becomes critical to supplement human energy so that field operations can be done at the right time to reduce the risk of crop failure and to secure a stable yield. Draft animal power has also proved effective in this zone in increasing agricultural production by enabling an increase in the area of land that can be cropped.

The supply of satisfactory levels of draft animal power at the right time for crop production requires sound management of draft animals throughout the year. Relevant features of draft animal management include adequate feeding, health care and appropriate use of animals to ensure their sustained use on-farm. Adequate feeding to meet the nutrient requirements of draft animals is a major constraint facing farmers using animal power in semi-arid areas. Livestock productivity in these areas is greatly influenced by the seasonal variation in the availability and the quality of naturally occurring feed resources and of crop residues. Reasonable levels of animal productivity can be expected from natural pastures during the rainy season. However, during the long dry season feed resources become increasingly scarce and their nutrient content is low. The resulting feed shortage causes dramatic losses of live weight in draft oxen. For example the minimum live weight of draft oxen at the start of the cropping season was found to be only 73% of the maximum live weight at the beginning of the dry season in Mali (Wilson 1987). These animals are therefore in poor condition at the start of the cultivation season when the energy demand for cropping is at its peak. This is often thought to be the single most important technical factor constraining the adequate supply of draft animal power to cropping operations in semi-arid areas.

In addition, nutrient supply to draft animals for work may be constrained by the limited time available for these animals to eat and comminute feeds. This may adversely affect the intake and digestibility of feeds. Furthermore, the high ambient temperatures prevailing in semi-arid areas may also combine with the increased metabolic heat due to work to cause severe heat stress on the working animal. This may depress work output and feed intake. The logical solution to the problems of feed deficit and nutrient deficiencies is to supplement the diet of draft animals with high quality feeds. However, many farmers who keep draft animals in semi-arid areas do not have easy access to good quality feeds because such feeds are scarce and expensive. Farmers generally prefer to exploit the cycles of nutrient deposition and mobilisation in the management of their draft animals. Cattle in semi-arid areas have adapted to the seasonality in feed supply by building up body reserves during periods of plentiful food. These reserves are drawn upon during periods of feed deficit for work, foetal growth and calf feeding.

The identification of feeding and management strategies for draft animals in a farming system requires information on the availability and the nutritive value of existing feed resources over the year, knowledge of the utilisation of these feeds by draft animals and information on the nutrient requirements of draft animals for work. There is little information on the energy requirements of draft oxen working on sandy soils under hot conditions in semi-arid areas. Neither have the patterns of nutrient supply to draft oxen for maintenance and work through intake of feeds and through the mobilisation of body reserves and the relationship between these factors and work output been investigated in the semi-arid areas in West Africa. In 1992, the Centre for Tropical Veterinary Medicine (CTVM) and the International Livestock Centre for Africa (ILCA), now the International Livestock Research Institute (ILRI), began a joint three-year research project aimed at the development of feeding and working strategies for draft oxen in semi-arid areas.

This research project, funded by the Overseas Development Administration (ODA), UK, was implemented by the CTVM and ILRI research team based at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Sahelian Center in Niger. The objectives of this project were to:

- determine the energy expenditure of draft oxen working on sandy soils, performing common agricultural tasks, so that their energy requirements could be determined
- establish the relationships between work and intake and digestibility of roughages by draft oxen
- investigate the effect of body condition before work and liveweight losses during work on work performance
- investigate the implications of heat stress on draft oxen in semi-arid areas.

This information will allow informed decisions to be made on the feeding and management of draft animals in semi-arid areas. Four experiments were conducted. Experiment 1 investigated the energy costs of walking on soils of different consistencies and the efficiencies of doing work. Experiments 2 and 3 were designed to establish the effect of work on intake, digestibility and rate of passage of feeds (millet stover) in the digestive tract. Experiment 4 looked at the effect of body condition before work and weight losses during work on work performance. The effect of heat stress on work performance was also investigated in experiments 2, 3 and 4. This report gives details of these experiments, the results obtained and, based on these, the recommendations made regarding feeding and working strategies for draft oxen in semi-arid areas.

2
Energy expenditure by oxen working on soils of different consistencies

Introduction

Three major research components are crucial to the formulation of feeding strategies for draft animals. These are the evaluation of the availability and the nutritive value of existing feed resources, the utilisation of the feeds by animals, i.e. how much of these feeds they can eat and how efficiently these feeds are converted into useful products and finally the determination of the nutrient requirements of these animals. Until the mid-1980s, research on nutrient requirements for working cattle received less attention than that on other classes of farm livestock. This was because little interest was attached to these animals and because of the difficulties associated with the determination of their energy expenditure. As a result, until 1986 few original data were available to form an information base on the nutrition of draft cattle. Fortunately, during the last decade a great deal of research has been geared towards the elucidation of some fundamental aspects of the nutrition of draft animals.

The adaptation of portable gas analysers to measure oxygen (O_2) consumption by draft animals and the design of instrumentation to measure work performance contributed to the accumulation of a body of knowledge that can form the basis of sound predictions of the work performance and the nutrient requirements of draft animals. For instance, it is now recognised that the estimation of energy expenditure of draft animals as 2.7 times the maintenance expenditure (FAO 1972; Goe and McDowell 1980) was an overestimation and that values between 1.3 and 1.8 times maintenance (Lawrence 1985; Barton 1987; Pearson 1989) are more realistic estimates. Although draft animal science has progressed from its infancy state in the 1970s to a more adolescent stage (Lawrence and Zerbini 1993), there are still areas that need more research if sound feeding strategies of draft oxen are to be developed. The determination of the energy costs of different activities occurring during work is one of the topics that needs further investigation (Lawrence and Becker 1994).

In the absence of direct measurement of oxygen consumption, the extra energy used to perform different activities can be estimated using the factorial method developed by Lawrence and Stibbards (1990). This method integrates, additively, the energy cost of walking, carrying and pulling loads. The energy cost of pulling is fairly constant when expressed in relation to tractive effort and distance. Therefore, this can be accurately predicted if work output is known. Energy cost of walking, which can account for 50% or more of the total energy expended for work (Lawrence and Becker 1994), is more difficult to predict because it is dependent on ground surface and needs to be determined directly. For instance, Dijkman (1993) found in the subhumid zone of Nigeria that the energy cost of walking (E_W) in cattle ranged from 8.58 J/m/kg M on ploughed waterlogged rice fields to 1.47 J/m/kg M on unploughed upland soils. The objective of this study was to investigate the energy cost of walking (E_W) and ploughing on sandy soils and of carting in semi-arid areas. This information is needed to estimate the energy requirements of draft oxen working on sandy soils.

Material and methods

Animals and feeding

This experiment was conducted from October to November 1994 at ILRI's research site at the ICRISAT Sahelian Center, Sadoré, Niger. The ages and weights of the seven animals used in this experiment are listed in Table 1. These animals had been previously trained and used for work and proved suitable for experimental purposes. The animals were fed to about maintenance level by grazing natural pastures supplemented with wheat bran and a mineral mixture (in total about 9–10 g/kg $M^{0.75}$ per day). The animals had access to water *ad libitum* during the periods they were not working. Mean ambient temperature and relative humidity were 30.1°C and 62.7%, respectively, when animals worked in the morning and 36.5°C and 24.2%, respectively, when work took place in the afternoon.

Table 1. *Ages and weights of cattle used in the experiment on energy expenditure.*

Animal	Weight (kg)	Age (years)
4a	341	6.5
9b	525	7
10a	282	5
13a	294	5
16a	354	5
21a	365	5
24a	364	5

a = non-castrated; b = castrated.

Experimental methods

Oxygen consumption was measured using the Oxylog (Plate 1), a portable breath-by-breath analyser. This instrument, manufactured by P.K. Morgan Ltd, Kent, England, was originally designed for use with people and was modified for oxen in a manner similar to that described by Lawrence et al (1991).

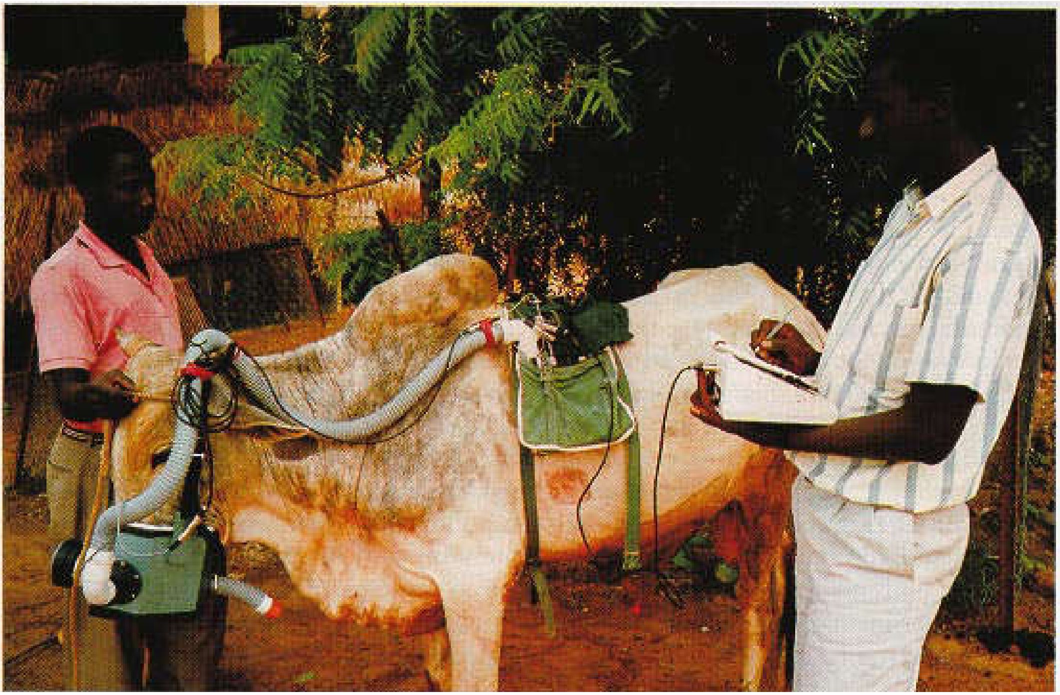

Plate 1. *Measuring the standing metabolic rate (top picture) and the energy cost of walking (bottom picture) of an ox in Niger using an Oxylog.*

The apparatus consists of an airtight face mask with inlet and outlet valves and an analysis and display unit. Air is sucked into the mask through a cylinder 80 mm long 100 mm diameter mounted on the right side. At the end of this tube near the mask a plate was fitted with three 25 mm diameter inlet valves. At the other end there was a similar plate which contained the original Oxylog turbine flow meter (Humpfrey and Wolff 1977) and three `dummy' flow meters. The dummy flow meters had the same diameter and turbine stator as the original flow meter, but no rotor or electric connections. They therefore had the same resistance to air flow as the original flow meter and by uncovering one or more of them, the range of the flow meter could be increased from its original value of 0–80 litres/min to 0–160, 0–270 or 0–360 litres/min. The range used in a particular experiment depended on the expected maximum respiration rate. The flow meter was calibrated over all four ranges using a reciprocating air pump as described by Dijkman (1993). Expired air passed from the mask via three 25-mm diameter outlet valves into a flexible tube attached to the analysis and display unit fixed to the animal's back. The Oxylog was used to take samples of inspired and expired air at every breath, and determined the difference in oxygen concentration using two matched polarographic electrodes. This was multiplied by the volume of air inspired to give oxygen consumption. The apparatus makes corrections for atmospheric pressure, temperature and humidity and displays the results as litres of oxygen consumed and air inspired corrected to standard temperature and pressure. In this experiment these values were recorded every minute from an auxiliary display panel connected by cable to the Oxylog which enabled data to be read more easily.

Work output, distance travelled and time spent working were measured using either an ergometer (Plates 2 and 3) for work and distance, or an odometer for distance only (Lawrence and Pearson 1985).

The animals used in this experiment were already well trained for work. Further training was, however, necessary to accustom them to carrying the instruments. Animals were trained for three weeks to wear the face mask and to carry the backpack containing the ergometer and the Oxylog while performing common farm activities.

Two trials were conducted. The first trial was designed to determine the energy cost of ploughing sandy soils using a mouldboard plough. The second trial measured the energy cost of carting. Light carts with pneumatic tyres were used. In both trials the standing metabolic rate and the energy cost of walking were determined. The treatment applied for the measurement of the energy cost of walking was the consistency of the surface: unploughed wet sandy soils, ploughed wet sandy soils and firm laterite tracks. To determine the efficiency of carting, the treatment was load applied (300, 600 and 900 kg). The experimental design for both trials consisted of a random assignment of treatments in sequence to each ox (block) with repeated measures.

During the first trial the work routine of the six animals included the following sequence of activities: standing for 15 min in the shade (SMR), walking unloaded for 15 min on unploughed soils, walking unloaded for 15 min on previously ploughed soils and ploughing for 20 min.

For each activity measurements were taken when animals had reached a steady rate of oxygen consumption after having worked for at least 5 min. The Oxylog was alternately attached to each animal during each work routine. During the walking

Plate 2. *A pair of oxen pulling a Nikart tool bar at the ICRISAT Sahelian Center in Niger with an ergometer attached to measure work output.*

sessions, the odometer of the ergometer was wheeled behind the animal to measure distance walked and time spent walking. Animals were allowed to rest for 15 min between bouts of work.

In the second trial the work routine involved the following sequence of activities: standing for 15 min (SMR), walking unloaded around a flat laterite circuit of 1000 m, pulling a two-wheeled cart with pneumatic tyres loaded with 300 kg around the 1000 m circuit, pulling a cart loaded with 600 kg around the 1000 m circuit and finally pulling a cart loaded with 900 kg around the 1000 m circuit.

Oxen were paired for both carting and ploughing. During the ploughing trials, one ox in each pair walked on unploughed soil and one walked on ploughed soil. However, the position of oxen in the pair was changed during other ploughing sessions so that by the end of the ploughing trial each ox had walked on both ploughed and unploughed soils.

Heat production (H) was estimated using the equation:

$$H = 16.18\ O_2 + 5.02\ CO_2 \text{ (Brouwer 1965)}$$

where O_2 is the volume of oxygen consumed and CO_2 is the volume of carbon dioxide produced. Methane and urinary nitrogen were omitted from the equation to calculate heat production proposed by McLean and Tobin (1987) because they would have quantitatively little influence on the estimation of H (see Lawrence et al 1991).

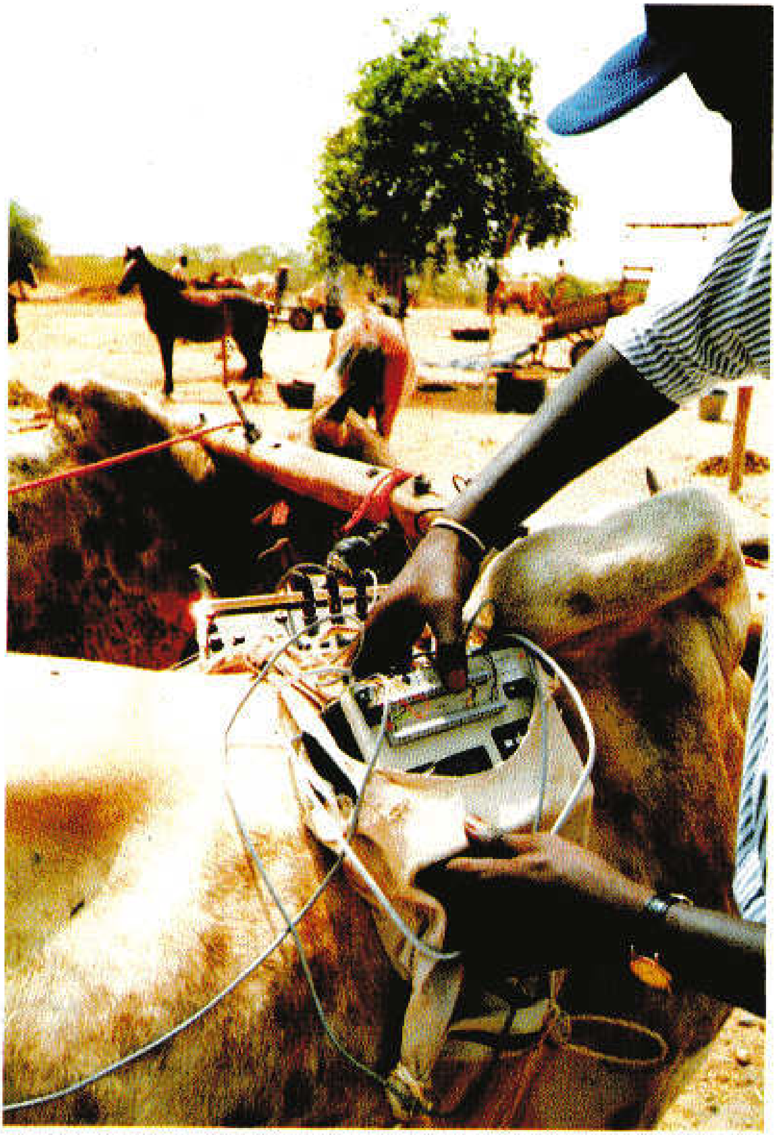

Plate 8. *An oxygen meter integration and display unit (left pocket) and a data logger (right pocket) contained in a backpack attached to an ox.*

Assuming a value of 0.9 for the respiratory quotient (the ratio of carbon dioxide produced to oxygen consumed), the energy expenditure of animals was estimated from oxygen consumption alone, assuming 20.7 kJ per litre of O_2 consumed (Lawrence and Stibbards 1990).

The energy cost of walking (E_w J/m walked per kg M) was calculated as:

$$E_w = (\text{energy used while walking} - \text{energy used while standing still}) / (\text{distance walked (m)} \times \text{M (kg)})$$

The energy cost of doing work was defined as an efficiency factor (E_f) according to Lawrence and Stibbards (1990):

$$E_f = (\text{work done (kJ)})/(\text{energy expended when loaded (kJ)} - \text{energy expended (kJ) to walk the same distance at the same speed but unloaded})$$

The information obtained from this experiment was incorporated into a factorial formula (Lawrence and Stibbards 1990) to predict the extra net energy required for ploughing sandy soils for one to six hours per day:

$$E = A\ F\ M + B\ F\ L + W/C + 9.81\ H\ M/D$$

where E = extra energy used for work (kJ), F = distance travelled (km), M = live weight (kg), L = load carried (kg), W = work done whilst pulling loads (kJ), H = height climbed (km), A = energy used to move 1 kg of body weight 1 m horizontally (J), B = energy used to move 1 kg of applied load 1 m horizontally (J), C = efficiency of doing mechanical work (work done/energy used), D = efficiency of raising body weight (work done raising body weight/energy used).

The energy cost of ploughing was estimated assuming the average draft force (1047 N for the team or 524 N for each animal) and the average walking speed (0.81 m/s) found in this study. This draft load would be equivalent to 0.16 of the live weight of animals in the pair weighing 300 kg each, 0.12 for animals weighing 400 kg and 0.10 for animals weighing 500 kg. Net energy requirements for maintenance (EM) were estimated as:

$$EM = 1.15(0.53[M/1.08]^{0.67})$$

according to AFRC (1993). The energy cost for maintenance was increased proportionally by 0.10 to account for the higher metabolic rate after work than on non-working days (Lawrence et al 1989a) and for the higher underlying resting metabolic rate during work than during the same time of day on non-working days (Lawrence et al 1989b).

Data analysis

The following statistical model was used to analyse E_w:

$$Y_{ijk} = \mu + O_i + S_j + \alpha\ (x_{1ij} - x_1) + \beta\ (x_{2ij} - x_2) + E_{ijk}$$

where:

Y = k^{th} observation of E_w for i^{th} animal and j^{th} surface

μ = mean

O_i = effect of animal, i^{th} ($i = 1...7$)

S_j = effect of ground surface, j^{th}, (j = 1: unploughed sandy soil; j = 2: ploughed sandy soil; j = 3: firm laterite track)

α = regression coefficient of Y on the speed of walking (x_1)

β = regression coefficient of Y on the live weight of the animal (x_2)

E_{ijk} = random error

The model used to analyse E_f during carting included the main effects of oxen and load. The main source of variation for the analysis of E_f for ploughing was the effect of oxen. In both analyses of E_f for carting and ploughing, speed of travel and the live weight of the oxen were included as covariates. Since repeated measurements were taken on animals over several days, animal was used as the error term to test the effect of ground surface on the energy cost of walking and on the efficiency of doing work. Mean values are reported ± SE.

Results

Standing metabolic rate

Mean daily energy cost of standing was 5.63 ± 0.12 W/kg $M^{0.75}$.

Energy cost of walking

Ground surface affected E_w and walking speed (P<0.01, Table 2). The energy cost of walking was lowest when the oxen walked on firm laterite tracks. Energy expenditure also was lower when animals walked on unploughed soils than on ploughed soils (Table 2). The regression of E_w on M was significant. The heavier the animal the higher the energy cost of walking was. Each extra kg of M was associated with an increase of 0.013 J/m/kg M in the energy cost of walking. Changes in walking speed were not associated with changes in the energy cost of walking. Speed was higher when animals were walking on laterite tracks than when they were walking on sandy field soils (Table 2).

Table 2. *Energy cost of walking (E_w) and speed of oxen walking on ploughed soils, on unploughed soils and on laterite tracks.*

	No. of animals		E_w (J/m/kg)		Walking + speed (m/s)	
Ground surface		n	Mean	SE	Mean	SE
Unploughed sandy soils	6	21	1.59[a]	0.069	0.95[a]	0.029
Ploughed sandy soils	6	20	2.15[b]	0.084	0.86[a]	0.029
Laterite track	6	19	1.00[a]	0.100	1.26[b]	0.033
Significance			*		**	

[ab] Values in the same column with different superscripts are significantly different.
* = P<0.05; ** = P<0.01; SE = standard error of the mean.

Energy cost of working

The average draft force required to plough sandy soils in this experiment was 1047 (±43) N. Ploughing was performed using a mouldboard plough at an average depth ranging from 12.9 (±0.68) to 17.1 (±0.73) cm. Soil moisture content was 2.2, 2.7, 2.9 and 3.0% at 0–5, 5–10, 10–15 and 15–20 cm depth, respectively. Teams worked at an average speed of 0.81 (0.024) m/s. The efficiency of ploughing was 0.31 (±0.008).

The load during carting, M, draft force and walking speed did not influence working efficiency (Table 3). The efficiency of doing work during carting was only affected significantly ($P<0.01$) by individual animals, suggesting large variability between animals (Table 4). The effect of individual oxen on the efficiency of doing work during ploughing was, however, not significant (Table 4).

Table 3. *Draft force, walking speed and efficiency (work done/energy used for work) of carting by oxen working in pairs.*

Load (kg)	No. of animals	n	Efficiency of working		Draft force (N)		Walking speed (m/s)	
			Mean	SE	Mean	SE	Mean	SE
300	5	18	0.32	0.03	310	8.0	1.23	0.02
600	5	17	0.32	0.03	409	8.1	1.23	0.02
900	5	16	0.33	0.03	503	8.3	1.19	0.02

Table 4. *Efficiency of doing work during ploughing and carting by individual oxen.*

Animal number	Efficiency of carting		Efficiency of ploughing	
	Mean	SE	Mean	SE
10	0.25	0.14	0.27	0.08
13	0.30	0.09	0.31	0.05
16	0.28	0.03	0.32	0.04
21	0.46	0.05	0.32	0.05
14	0.33	0.05	0.34	0.04

Quantification of the extra energy requirements for ploughing

The net energy required for maintenance, and for ploughing sandy soils for each animal in the team, one walking in the furrow and the other walking on the unploughed soil, is shown in Table 5. Depending on the live weight of the animal and the number of hours worked, the extra daily net energy expended for ploughing varied between 0.10 and 0.8 times the energy cost for maintenance.

Table 5. *Live weight, draft force for ploughing as a proportion of live weight (DF/M), daily net energy required for maintenance (EM) and for ploughing (multiple of maintenance) sandy soils for each ox in the pair, one walking on ploughed soil (A) and the other walking on unploughed soil (B).*

Live weight (kg)	DF/M	Daily EM (MJ)	Ploughing time (h/day) 1 h		2 h		3 h		4 h		5 h		6 h	
			A	B	A	B	A	B	A	B	A	B	A	B
300	0.16	34.75	0.15	0.13	0.29	0.25	0.44	0.38	0.59	0.50	0.74	0.63	0.89	0.75
400	0.12	43.12	0.14	0.12	0.28	0.23	0.43	0.35	0.57	0.47	0.70	0.59	0.84	0.70
500	0.10	50.99	0.12	0.10	0.24	0.19	0.36	0.30	0.48	0.40	0.60	0.50	0.72	0.59

Discussion

Standing metabolic rate

The standing metabolic rate (SMR) in this study (5.63 SE 0.12 W/kg $M^{0.75}$) was higher than that recorded by Becker et al (1993) in zebu oxen in Niger (4.75 W/kg $M^{0.75}$), but lower than that calculated from oxygen uptake in resting Bunaji bulls in Nigeria (7.59 W/kg $M^{0.75}$, Dijkman 1993) and resting crossbred cows in Ethiopia (9.32 W/kg $M^{0.75}$, Zerbini et al 1992). Differences in these results may be attributed to differences in breeds used, climatic conditions, altitude and in the time of day and measuring techniques used in the different experiments. For example in this experiment, SMR was measured before work started whereas SMR values reported by Dijkman (1993) and Zerbini et al (1992) were averages of SMR values before work and between bouts of work (Zerbini et al 1992) and during recovery periods.

Lawrence et al (1989b) found that the rate of energy expenditure of well-trained oxen fed at maintenance and standing still between bouts of work was proportionally 0.26 higher than the average rate during the same time of the day when the oxen were in a respiration chamber. The high value of 9.32 W/kg $M^{0.75}$ reported by Zerbini et al (1992) may be related to the *Bos taurus* × *Bos indicus* crossbred dairy cows they used. Those animals may have a higher metabolic rate than the *Bos indicus* breeds used in this and the other experiments (Becker et al 1993; Dijkman 1993). The SMR reported in all these studies, including ours, is related to total M and not to empty body mass and the energy expenditure measured while the animal was standing still includes heat increment.

Energy cost of walking

The significant effect of ground surface (unploughed and ploughed sandy soils and laterite tracks) on the energy cost of walking agrees with results reported by Dijkman (1993). The E_W of 1.59 J/m/kg M on unploughed sandy soils found in this experiment is close to the E_W of 1.47 J/m/kg M on unploughed upland and the E_W of 1.76 J/m/kg M on unploughed dry valley bottom soils found in Nigeria (Dijkman 1993). As might be expected, E_W on ploughed land was lower on the sandy soils in our study (2.15 J/m/kg M) than on ploughed land on the heavier soils with a higher clay content in valley-bottoms in Nigeria (3.76–8.58 J/m/kg M, Dijkman 1993).

The energy costs of walking on firm surfaces (unploughed land and laterite tracks) found in this study were similar to other measurements made in the field. Becker et al (1993) reported an E_W of 1.34 J/m/kg in zebu cattle in Niger and Clar (1991) found an E_W of 1.00 J/m/kg also for zebu cattle in Niger; these results were similar to the E_W measured on laterite tracks in this study. Field values recorded on firm surfaces were usually lower than values determined on treadmills such as: 1.9 J/m/kg (Brody 1945), 2.1 J/m/kg (Lawrence and Stibbards 1990) and 2.6 J/m/kg (AFRC 1993). Discrepancies between laboratory and field values of E_W can be explained by the artificial conditions of the laboratory. When oxen walk in the field they travel at their own speed and are likely to be more at ease than on a treadmill in a laboratory, where they have to walk at a set speed on a moving treadmill surface. This illustrates the value of conducting field measurements to establish the true energy requirements of working animals.

In this experiment the energy cost of walking was independent of the walking speed. The energy cost of walking increases as speed decreases if the rest-maintenance component of the cost is included (Brody 1945). However, if the maintenance cost is excluded from the total energy cost, as was done here in the calculation of the E_W, then the energy cost of walking is independent of speed. Lawrence and Stibbards (1990) also found that when oxen were walking at a comfortable speed, i.e. neither forced to walk very slowly nor very fast, but at a speed they might choose naturally, then the energy cost of walking was no longer influenced by speed.

Energy cost of doing work

In this experiment the efficiency of working was not affected by the type of work performed (ploughing versus carting with varying loads) or the draft force exerted. The efficiency of ploughing (0.31) was consistent with average efficiencies of pulling loads reported elsewhere (Lawrence and Stibbards 1990; Dijkman 1993). The efficiency of working in this study was unaffected by walking speed. This again agrees with the observations of Lawrence and Stibbards (1990) who did not find any significant effect of speed of walking on efficiency when animals were walking at a comfortable speed.

In this experiment a mouldboard plough was used for the ploughing trial. Results showed that an average draft force of 1047 N would be required to till at an average depth of 15 cm. The same implement could be used for direct ridging on untilled sandy soils. On sandy soils in semi-arid areas in Mali, the draft force required for ploughing (825 N) was similar to that for ridging (835 N, Khibe and Bartholomew 1993). In Zimbabwe, when ridges are already established, re-ridging moist sandy loam at the beginning of subsequent seasons required draft forces comparable to or slightly less than those for ploughing (Stevens 1994). Therefore, results from the ploughing trial in this experiment may also be applicable to direct ridging of sandy soils using a mouldboard plough. Goe and McDowell (1980) suggested that oxen can sustain work over a working day provided the draft force does not exceed about 11 kgf/100 kg M. This implies that a team totalling at least 950 kg is the ideal live weight for ploughing and ridging sandy soils in these semi-arid areas.

Lawrence (1985) estimated the energy expenditure of cattle working in land preparation for 5.5 h a day to be 0.42–0.67 times maintenance requirements. Pearson (1989) reported estimated extra daily energy requirements of 0.74–0.78 times maintenance energy requirements for cattle pulling carts for 5 h/day. Over a shorter working day (3 h) Mahardika et al (1995) estimated the extra energy expenditure of water buffaloes working at draft forces equivalent to proportionally 0.10 and 0.15 of M to be 0.42 and 0.48 times maintenance energy requirements, respectively. The values for E_W and the efficiency of working obtained in this study were used to estimate the extra net energy used for work according to the method described by Lawrence and Stibbards (1990). These calculations gave values for the extra energy for work ranging from 0.10 to 0.89 times daily maintenance energy requirements, depending on the number of hours worked, and the size of the animals used. The estimated energy expenditure during 5 to 6 h of ploughing sandy soils varied between 0.50 for oxen weighing 500 kg to 0.89 times maintenance for oxen weighing 300 kg. The energy expenditure during work of the 500 kg ox was comparable to that seen in the other studies (Lawrence 1985; Pearson 1989; Mahardika et al 1995). However, energy expenditure during work by the 300 kg ox was higher than that generally found, suggesting that it is better to use the larger animal (500 kg) for ploughing in semi-arid areas.

The findings of this study can be used to accurately estimate the energy requirements of draft oxen in semi-arid areas by applying the factorial method (Lawrence and Stibbards 1990) provided work output (draft force (N) $\times$ distance (m) travelled) during the working day is known. Functional activities such as locomotion and standing can contribute a great deal to daily energy budget in the extensive livestock production systems prevailing in semi-arid areas. The energy cost of these activities can be estimated by monitoring the daily activities of animals. This would allow a more precise calculation of the complete daily energy budget of draft animals for these areas.

3
Intake, digestion and rate of passage of feed through the gastro-intestinal tract in oxen working under hot conditions

Introduction

Ideally, draft oxen must eat sufficient feed before and during the cropping season so they can start work with a reasonable live weight. However, the scarcity and poor quality of available feeds before and during the early part of the cropping season in semi-arid areas often limit nutrient intake by oxen. Feed intake can be influenced positively or negatively by work through direct or indirect mechanisms. Direct effects of work on feed intake occur through physiological changes resulting from exercise. Muscular activity induces a higher metabolic rate in working animals than in animals at rest (Preston and Leng 1987). This leads to the depletion of circulating energy substrates. With sustained exercise, muscles draw energy-yielding substrates from body reserves. Work therefore imposes a higher energy demand which would be expected to stimulate intake to supply energy to muscle and to replenish depleted body nutrients (Weston 1985). Fatigue is a natural result of sustained muscular activity. The desire to eat and ruminate may be suppressed by fatigue (Pearson and Lawrence 1992). Physiological changes in working animals also include increased body temperature due to heat gained from solar radiation and increased metabolism during work. The resulting heat stress could depress feed intake in working animals (Collier and Beede 1985).

One indirect effect of work on intake stems from the reduced time animals have access to feed. Limited time available to eat and ruminate is a major constraint to increased feed intake in working ruminants (Pearson and Lawrence 1992). Time of feeding also affects feed intake. Bakrie and Teleni (1991) reported reduced feed intake by animals fed roughages before work as compared with animals fed after work.

Work also has the potential to affect digestibility of feeds by oxen directly and indirectly through changes in a range of factors including increase in body temperature, feed particle residence time in the gastro-intestinal tract, and effectiveness of mastication on particle breakdown (Weston 1985). Positive effects of work on feed digestibility may stem from the enhancement of microbial fermentation through greater mixing of rumen contents due to exercise (Matthewman and Dijkman 1993) and higher but moderate body temperatures resulting from work. Detrimental effects of work on feed digestibility may result from the shift of blood flow from the gut to muscles and peripheral tissues, reduction in meal frequencies (Matthewman and Dijkman 1993), and the less thorough mastication of feed because of limited time to ruminate (Pearson and Smith 1994). A clear understanding of the relationship between work and digestive physiology is necessary for the feeding management of draft oxen to be improved. This study investigated the relationships between feed intake and the efficiency of utilisation of feeds and work performance.

Material and methods

Experiment 2

Animals and feeding

This experiment was conducted from July to September 1993 at ILRI's research site at the ICRISAT Sahelian Center, Sadoré, Niger. Eighteen oxen, aged 4–8 years, bought in the local livestock markets, were used (Table 6). All the cattle were dewormed and vaccinated against rinderpest, anthrax and pasteurellosis. They were housed in individual concrete floor pens roofed with zinc sheets. Each pen was fitted with a halved empty oil drum as a feed trough and a graduated metal bucket for water. Individual pens were separated with wooden planks to prevent mixing of feed and feed spillages.

Table 6. *Age (years), initial body weight (kg) and initial body condition score of oxen used in Experiment 2.*

Ox no.	Age (years)	Castration	Initial live weight (kg)	Initial body condition score
1	5	Non-castrated	256	3
2	5	Castrated	246	2
3	4	Non-castrated	227	3
4	6.5	Non-castrated	294	2
6	6.5	Non-castrated	273	5
8	4	Non-castrated	202	2
9	7	Castrated	279	4
10	4	Non-castrated	253	3
11	7	Castrated	288	4
12	4.5	Non-castrated	274	3
13	4.5	Non-castrated	257	3
14	6.5	Castrated	266	2
16	4	Non-castrated	288	6
17	4	Non-castrated	327	6
69	8	Castrated	433	6
88	8.5	Castrated	448	6
89	8	Castrated	416	6
100	8	Castrated	422	6

Oxen were trained to pull common farm implements and 55 kg metal sledges. They were fed chopped millet stover *ad libitum* except during the working periods. Millet stover was supplemented with a concentrate mix made up of wheat bran (600 g/kg), groundnut cake (300 g/kg) and bone meal (100 g/kg) at a rate of 21.3 g/$M^{0.75}$/day (Table 7). The concentrate was fed when animals returned from work in the morning at about 1100 hours. Millet stover was given when oxen finished eating the concentrate, and at 1600 and 1800 hours. Feed troughs and buckets were withdrawn from all the pens when oxen on an exercise schedule were working. Therefore all animals had equal time of access to feed but assuming work restricted rumination, they did not have similar time available to ruminate. Refusals were regularly removed from troughs. Oxen at rest were tethered out of the pens under the sun when other teams were working.

Table 7. *Chemical composition of millet stover and concentrate feed given during experiments 2 and 3.*

	Millet stover		Concentrate	
Feed component	Expt 2	Expt 3	Expt 2	Expt 3
Dry matter (%)	90.2	94.0	90.5	93.5
Crude protein*	33	36	293	177
Gross energy (MJ/kg DM)	17.5	18.0	18.1	14.7
Organic matter*	964	973	898	756
Neutral-detergent fibre*	789	781	293	197
Acid-detergent fibre*	539	519	131	72
Hemicellulose*	274	261	162	125

* = g/kg DM.

Experimental design

A Latin square cross-over design with repeated measures was adopted for this experiment. Treatment consisted of the number of hours worked per day: 0, 2 and 4 h/day pulling a loaded sledge along a flat circuit or performing common field operations (cultivation). Oxen were divided according to their initial body weights into three groups with average weights of 245, 273 and 390 kg for groups 1, 2 and 3, respectively. Oxen in groups 1, 2 and 3 were allotted to squares 1, 2 and 3, respectively, so that each square had animals of similar live weight. Rows of each square were formed by ox teams whereas columns represented experimental periods. The experiment lasted nine weeks, which were divided into three-week periods. Treatments were applied in sequence to teams during experimental periods. During each period three teams were idle, three teams were working 2 h/day and three teams were working 4 h/day. Each team worked 3 days/week. Teams working for 4 h/day worked 2 h in the morning and 2 h in the afternoon.

Measurements

Work output, distance travelled and elapsed working time were continuously measured using an ergometer (Lawrence and Pearson 1985). Weekly blood samples were taken to determine plasma urea-N (PUN), thyroxine (T_4) and triiodothyronine (T_3). Body weight was measured every week. Feed offered and refusals were weighed every day. Refusals on the floor and feed left in troughs were collected separately because of contamination of floor spillage by urine and water.

Laboratory analysis

Daily feed samples were pooled each week. A sample was taken and dried in a forced-air oven to constant weight at 55°C and ground to pass through a 1 mm screen. The following determinations were made on the weekly pooled samples of feeds: acid-detergent fibre (ADF), neutral-detergent fibre (NDF), nitrogen (N), gross energy (GE), ash and organic matter (OM) using methods described by AOAC (1990).

Plasma T_4 was analysed using the fluorescence polarisation immunoassay technique with an Abbot TDx Analyser (Abbot laboratories, USA). The analysis for plasma T_3 used the IMx total T_3 assay based on the Microparticle Enzyme Immunoassay Technique (Abbot Laboratories, USA). Plasma urea-N was assayed by an enzymatic method using a Bayer Diagnostic RA-2000 Random Access Chemistry Analyser (Bayer Diagnostics, Basingstoke, Hants, UK).

Data analysis

The following statistical model was used to analyse feed and water intake, weight change, plasma thyroid hormones and PUN concentrations:

$$Y_{ijklm} = \mu + S_i + T(S)_{(i)j} + P(S)_{(i)k} + A_l + W_m + W * P_{mk} + W * A_{ml} + W * T(S)_{(i)jm} + E_{ijklm}$$

where:

Y = dependent variable (feed intake, water intake, M change, plasma thyroid hormones concentration, urea-nitrogen concentration)

μ = overall mean

S_i = effect of i^{th} square, i=1..3

$T(s)_{(i)j}$ = effect of the j^{th} team nested within i^{th} square, j=1, 2, 3

$P(S)_{(i)k}$ = effect of the k^{th} experimental period nested within i^{th} square , k=1, 2, 3

$A_{(l)}$ = effect of the l^{th} work level, l=1:0 h / day, l=2:2 h / day and l=3:4 h / day

W_m = effect of the m^{th} week, m=1, 2, 3

$W * P_{mk}$ = interaction between the m^{th} week and the k^{th} period

$W * A_{ml}$ = interaction between the m^{th} week and the l^{th} work level

$W * T(s)_{(i)jm}$ = interaction between the m^{th} week and the j^{th} team in the i^{th} square

E_{ijklm} = effect peculiar to the j^{th} team in the i^{th} square subjected to the l^{th} level of work in m^{th} week of the k^{th} period

The term $T(s)_{(i)j}$ was used as the error term to test the effect of work. The sums of squares for treatment and week were further partitioned into single degrees of freedom using polynomial contrasts (i.e. A_l). Weekly liveweight changes were estimated by regression analysis and were further subjected to analysis of variance using generalised linear models (SAS 1985). Mean values are reported ± SE.

Experiment 3

Animals and feeding

This experiment was conducted from December 1994 to February 1995 at the ILRI research site in Niger. Twelve oxen, aged 4–7 years, with an average weight of 288 (±11) kg at the start of the experiment were used. They were housed as in Experiment 2. All oxen were fed chopped millet stover *ad libitum* except during the working hours. The stover was chopped by hand to lengths of 12–20 cm. The millet stover was supplemented with a concentrate mix made up (g/kg) of wheat bran (400), groundnut cake (300), rock phosphate (100), crushed bone (100) and common salt (100) (Table 7). The concentrate was given at a daily rate of 10 g DM/kg $M^{0.75}$ at 1200 hours after the morning working session. Daily feed allowance was adjusted so that refusals were at least equal to a proportion of 0.50 of feed offered.

Treatments

Treatments consisted of levels of work performed: 0, 2.5 and 5 h/day achieved by walking 0, 6 and 12 km/day, respectively. Each team in an exercise treatment pulled a metal sledge loaded with weights so that the draft force exerted was equivalent to 0.10 of the team's live weight. Work was performed continuously, seven days a week, pulling the sledge around a flat circuit. Work stopped when the set distance or set time was completed or when one of the oxen in the team was unwilling to continue.

Experimental design

A Latin square cross-over design was used. Twelve oxen were assigned to the three treatment groups, two teams in each group. The rows of the squares represented individual oxen, whereas columns were experimental periods. The experiment lasted 10 weeks divided into five two-week periods. Observations were repeated every week in periods 1, 3 and 5. No treatment was applied during periods 2 and 4 to dissipate carry-over effects from previous periods. Each square included oxen of similar live weight. Treatments were applied in sequence during experimental periods so that during each period four oxen were idle, four oxen were working 2.5 h/day and four oxen were working 5 h/day.

Measurements

Sampling, measurements and laboratory analyses were as in Experiment 2 with the amendments and additions listed below.

Work. An ergometer was used only during the preparation phase of this experiment to measure work performed, distance travelled and elapsed working time for different known work loads. A regression analysis of force on work load was derived and used to determine the load required for each team so that the draft force exerted was equivalent to 0.10 of the team live weight The time taken to travel around the circuit was measured with a stop watch.

Intake and digestibility of feed. Each day a sample of millet stover was taken before chopping the stover. At the end of each week the daily millet stover samples were pooled and plant parts were separated and weighed to determine proportion of leaves in the stover.

Three digestibility trials were conducted, one in each two-week period. Total faecal collection was carried out for seven-day periods using faecal bags harnessed to oxen throughout the collection period. The faecal bags were emptied regularly and the faeces weighed and placed into a bucket and stored in a cool place. At the end of each day, faeces were mixed and a sample (proportionately 0.05) was taken and frozen. At the end of each seven-day collection period, daily samples were thawed, mixed and a sub-sample (1 kg) was taken and oven dried at 55°C.

Rate of passage of feed. Sixty grams of chromium (Cr) mordanted fibre were given on day 7 of the first and second periods (Mathers et al 1989). On that day feed was withdrawn at 1400 until 2300 when the markers were fed. Faecal samples were collected at regular intervals as follows: 9, 11, 13, 15, 17, 19, 21, 24, 33, 37, 39, 41, 43, 47, 57, 61, 65, 71, 81, 85, 89, 95, 105, 109, 113, 119, 129, 137, 153, 161, 177 and 185 h after dosing. Individual faecal samples were thoroughly mixed and a sample was taken for the determination of DM and Cr concentration. Gastro-intestinal mean retention time was estimated using Grovum and Williams (1973) mathematical procedures, after a single dose of marker.

Feeding behaviour. Six oxen, two oxen in each treatment group, were selected for the observation of feeding behaviour during the first period of the experiment. The behaviour of each animal was monitored during a 3-h observation period every 5 min. Two or three 3-h observation sessions were carried out each day. At the end of the fourth day, the combination of the 3-h observation periods yielded a 24-h composite behaviour pattern of the animals. This scheme was applied three consecutive times. During each 5-min observation period each of the six animals was observed. The time spent doing a particular activity (eating, ruminating, standing and lying) was estimated as the product of the number of times this activity was observed and the interval between observations (5 min).

Statistical analysis

Data were analysed using SAS GLM procedures (SAS 1985). The statistical model used to analyse daily intake of millet stover, daily water intake, liveweight change, plasma thyroid hormones and PUN concentrations included as main factors: square, ox nested within square, experimental period nested within square, treatment (number of hours worked), week and the interactions between these terms. Sources of variation for the analysis of digestibility coefficients were square, ox nested within square, period nested within square and treatment.

Orthogonal linear and quadratic polynomials were used to test the effect of treatment. A regression analysis of dry matter intake (DMI) and dry matter apparent digestibility (DMD) on the proportion of leaf in the stover was performed. Sources of variation for the analysis of time spent eating and ruminating were treatment, oxen within treatment and time of observation.

Results

Experiment 2

Climate and physiological responses to work

Minimum, maximum and mean ambient temperatures were 23.0, 35.0 and 29.3°C, respectively, when animals worked in the morning and 24.0, 36.0 and 31.7°C, respectively, when work took place in the afternoon. Minimum, maximum and mean relative humidities were 40.0, 93.0 and 67.4%, respectively, during the morning working sessions and 44.0, 96.0 and 60.0%, respectively, during the afternoon working sessions.

Plasma T_4 and T_3 concentrations were not affected by level of work (Table 8). There was a significant ($P<0.01$) linear increase in PUN as level of work increased (Table 8).

Feed and water intakes and live weight

Daily DMI of millet stover was not affected by number of hours worked per day. There was a significant linear increase over the weeks in daily DMI expressed in kg DM ($P<0.01$), in g DM/kg $M^{0.75}$ ($P<0.01$) and in g DM/kg M ($P<0.05$). The interaction between treatment and week was significant for DMI-g/kg M and close to the significant levels ($P=0.07$) for DMI-g/kg $M^{0.75}$. Table 8 shows daily work characteristics, feed and water intake and weekly liveweight changes. Feed intakes of animals working 2 and 4 h/day include feed consumption on non-working and working days. High intensities of work (4 h/day) depressed intake in working oxen during the first days of work. However, these animals were then able to increase their intake in the following days such that they could eat as much as oxen at rest or oxen working lightly.

There were no significant differences due to work in water consumption expressed in litres/day, litres/kg M, litres/kg $M^{0.75}$ or litres/kg DMI (Table 8). In this experiment, oxen at rest were tethered in the sun while other teams were working. Change in body weight was significantly affected by work ($P<0.05$, Table 8).

Experiment 3

Physiological responses to work

There was a significant ($P<0.05$) linear increase in PUN concentration as work level increased (Table 9). The effects of week and the interaction between work level and week were also significant ($P<0.001$). Increases of PUN over weeks were greatest as work level increased.

Table 8. *Daily work output, load and power and intake of millet stover and water, liveweight changes, plasma thyroid hormones (T_4, T_3) and plasma urea-nitrogen (PUN) concentrations for oxen working 0, 2 and 4 h per day (Experiment 2).*

Variables	Work						Significance
	0 h/day		2 h/day		4 h/day		
Work characteristics							
Daily work output (kJ)	0		3233	(22)	6763	(33)	
Load (N/kg M)	0		0.89	(26)	0.88	(23)	
Power (W)	0		583	(11)	616	(10)	
Power (W/100 kg)	0		90	(28)	92	(18)	
Daily intake of millet stover	Mean	SE	Mean	SE	Mean	SE	
kg DM	4.72	0.045	4.78	0.049	4.60	0.049	NS
g DM/kg M	15.46	0.17	15.94	0.19	15.50	0.19	NS
g DM/kg $M^{0.75}$	64.40	0.65	66.06	0.72	64.04	0.72	NS
Daily water intake							
litres	30.5	0.47	30.2	0.51	30.3	0.51	NS
litres/kg M	0.099	0.001	0.099	0.002	0.101	0.002	NS
litres/kg $M^{0.75}$	0.41	0.007	0.42	0.008	0.42	0.008	NS
litres/kg DMI	6.45	0.09	6.32	0.09	6.58	0.09	NS
Plasma thyroxine nmol/litre	56.3	1.2	52.7	1.2	52.3	1.2	NS
Triiodothyronine nmol/litre	0.95	0.03	0.94	0.03	0.98	0.03	NS
Plasma urea-nitrogen mmol/litre	4.0	1.14	4.5	0.14	4.83	0.14	Linear**
Liveweight change (kg/week)	3.72	0.76	1.58	0.84	–2.19	0.82	*

Values in parenthesis are coefficients of variation; NS = not significant; * = P<0.05; ** = P<0.01.

Table 9. *Least square means for intake of millet stover and water, live weight and plasma urea-nitrogen (PUN) concentrations of oxen working 0, 2.5 and 5 h/day (Experiment 3).*

	0 h/day	2.5 h/day	5 h/day	SE
Intake of millet stover				
g/kg M	15.13	16.22	16.15	0.20 NS
g/kg $M^{0.75}$	61.36	65.82	65.51	0.83 NS
Water intake				
litres/day	21.35[a]	25.20[b]	28.51[c]	0.380
litres/kg M	0.08[a]	0.09[b]	0.11[c]	0.014
litres/kg $M^{0.75}$	0.32[a]	0.38[b]	0.43[c]	0.050
litres/kg DMI	5.37[a]	5.83[b]	6.44[c]	0.120
Plasma urea-nitrogen (mmol/litre)[1]				
Before work	4.37	3.68	3.90	0.31
Week 1	3.02	3.42	4.30	0.31
Week 2	3.17	4.53	5.78	0.31
Live weight (kg)[1]				
Week 1	597	610	615	3
Week 2	599	602	597	3

1. See text for the significance of factors (work and week) included in the analysis of variance.
NS = not significant; values in the same row with different superscripts are significantly different, P<0.05.

Plasma T_4 concentration decreased as work level increased (Table 10). There was a significant (P<0.01) linear decrease in plasma T_3 concentrations as work load increased and over weeks (P<0.001).

Feed and water intakes and live weight

Intake of millet stover was not significantly influenced by work. Table 9 shows mean DMI, water intake and live weight over two-week experimental periods for oxen working 0, 2.5 and 5 h/day. The relationship between intake and the proportion of leaf in the stover (PLS) is described by the following regression equations that show an improvement in feed intake as the proportion of leaves increased:

$$\text{DMI (g/kg M)} = 12.8(\pm 1.09) + 5.4(1.18) \times \text{PLS} \qquad P<0.01 \qquad R^2 = 0.30$$

$$\text{DMI (g/kg } M^{0.75}) = 52.5(\pm 4.44) + 20.8(7.65) \times \text{PLS} \qquad P<0.01 \qquad R^2 = 0.28$$

There was a significant increase in water intake as work level increased (Table 9). Work caused liveweight losses whereas oxen at rest were able to maintain their body weight (Table 9).

Table 10. *Effect of work on feed apparent digestibility, gastro-intestinal rate of passage of solid particles, plasma thyroxine (T_4) and triiodothyronine (T_3) concentrations, and feeding behaviour parameters in oxen (Experiment 3).*

	Work			SE	Significance
	0 h/day	2.5 h/day	5 h/day		
Digestibility coefficient					
Dry matter	0.42	0.43	0.43	0.011	NS
Organic matter	0.45	0.46	0.45	0.012	NS
Acid-detergent fibre	0.54	0.54	0.55	0.010	NS
Neutral-detergent fibre	0.57	0.57	0.58	0.009	NS
Hemicellulose	0.63	0.63	0.65	0.009	NS
Energy	0.49	0.49	0.51	0.009	NS
Plasma thyroxine (nmol/litre)[1]					
Before work	48.6	45.3	48.0	2.6	
Week 1	49.0	44.4	38.7	2.6	
Week 2	45.5	34.6	27.7	2.6	
Triiodothyronine (nmol/litre)[1]					
Before work	0.77	0.69	0.64	0.04	
Week 1	0.69	0.64	0.62	0.04	
Week 2	0.60	0.49	0.39	0.04	
Time spent eating (min/day)	375	385	455	45	NS
Time spent ruminating (min/day)	339	400	344	42	NS
Time spent eating and ruminating (min/day)	715	785	799	49	NS
Eating rate (g DMI/min)	14.1	10.9	15.3	2.6	NS
Rumination rate (min/g DMI)	88.3	108.1	78.7	10.5	NS
Mean retention time (h)	88.9	78.2	82.2	2.3	Quadratic*
Time of first appearance of the marker (h)	14.17	14.54	13.28	1.40	NS
$1/k_1$	56.9	49.1	52.3	2.8	NS
$1/k_2$	17.9	14.6	16.6	1.2	NS

1. See text for the significance of factors (work and weeks) included in the analysis of variance.
NS = not significant; * = P<0.05.

There was no significant effect of work on the digestibility of DM, OM, ADF, NDF, hemicellulose (HEM) and GE. Table 10 shows coefficients of digestibility for different work loads. Increases in the proportion of leaves in the feed offered improved digestibility coefficients as illustrated by the regression of digestibility coefficients on PLS given in the following equations:

$$DMD = 0.03\ (\pm0.08) + 0.69\ (\pm0.08) \times PLS \qquad P<0.01,\ R^2 = 0.68$$

$$ADFD = 0.25\ (\pm0.04) + 0.52\ (\pm0.08) \times PLS \qquad P<0.01,\ R^2 = 0.52$$

$$NDFD = 0.19\ (\pm0.04) + 0.68\ (\pm0.08) \times PLS \qquad P<0.01,\ R^2 = 0.69$$

$$OMD = 0.06\ (\pm0.05) + 0.70\ (\pm0.09) \times PLS \qquad P<0.01,\ R^2 = 0.65$$

$$HEMD = 0.14\ (\pm0.05) + 0.87\ (\pm0.09) \times PLS \qquad P<0.01,\ R^2 = 0.72$$

$$GED = 0.12\ (\pm0.04) + 0.67\ (\pm0.08) \times PLS \qquad P<0.01,\ R^2 = 0.66$$

The estimated values for the two rate constants (k_1, k_2), the calculated time of first appearance of marker in faeces (TT) and the mean retention time (MRT) are shown in Table 10 for Cr fibre. The rate constants k_1 and k_2 refer to the proportion of matter leaving the rumen and the large intestine, respectively. Their reciprocals represent the retention time in each pool (Grovum and Williams 1973). Work did not significantly influence TT, k_1 and k_2. However, the quadratic effect of work on MRT was significant ($P<0.05$). Work did not significantly affect time spent eating and ruminating or eating and rumination rates (Table 10).

Discussion

Physiological responses to work

Since animals respond to heat stress by reducing their thyroid activity (Johnson 1987; Youssef 1987), significant differences in plasma levels of thyroid hormones between working and non-working animals were expected. This is because heat stress may be more pronounced in working animals than in animals at rest due to the extra body heat gains from increased muscle metabolism in the working animal. However, during Experiment 2 there was an absence of significant differences in plasma T_3 and T_4 concentrations between working oxen and oxen at rest. In Experiment 3, the higher the work load was, the greater was the decrease in plasma T_3 and T_4. Decreases in plasma T_3 and T_4 concentrations as a response to heat stress were reported by El-Nouty and Hassan (1983) and Pearson and Archibald (1990). During Experiment 3, unlike Experiment 2, oxen at rest were not exposed to solar radiation and ambient temperatures were lower. Differences in heat stress between working and non-working oxen were great enough to induce significant differences in plasma concentrations of T_3 and T_4 between the groups.

The higher heat load of working oxen during Experiment 3 relative to oxen at rest did not translate into significant changes in feed intake and digestibility. Christopherson and Kennedy (1983) suggested that extremes of heat and cold are needed before marked differences in digestibility are seen. It is also probable that animals used in these experiments, being born in the area, were well adapted to high ambient temperatures.

Water intake

Although little quantitative information is available, it is generally assumed that oxen need to drink more water during working days than during non-working days, particularly under hot conditions, to compensate for water lost through evaporative cooling processes (sweating and panting). During Experiment 2, both working and non-working oxen drank similar amounts of water. Water consumption during working periods included water intake during days animals were not working. This may have masked any short-term effect work would have on water consumption. However, since plasma thyroid hormone concentrations were also similar in working and non-working periods, the implication is that the extent of heat stress in animals at rest and in those working was similar in this experiment, and water requirements may therefore have been similar also. In Experiment 3, the higher heat load of working oxen, as compared with oxen at rest, suggested by differences in thyroid hormone concentrations, would have accounted for the working oxen drinking significantly more water than non-working oxen.

Feed intake

During Experiment 2, DMI of millet stover increased as the experiment progressed. A similar pattern of intake in working oxen was observed by Pearson and Lawrence (1992). They reported increased feed intake over time and suggested that animals were adapting to the feed during the experiment. In this study this adaptation did not enable oxen to eat more than those at rest or those working lightly, since the overall feed intake during the three-week experimental periods was similar for all work treatments during Experiment 2. Similarly, during Experiment 3 work did not have a significant effect on intake of millet stover.

When DMI was looked at more closely, the interaction between experimental `weeks' and work was significant. DMI was depressed during the first week for oxen working 4 h/day. These animals were, however, able to increase DMI during the following weeks. They were eating as much as oxen either at rest or working 2 h/day by the third week. This suggests that when oxen are subjected to a high work load (more than 4 h/day), feed intake is depressed during the first few days of work and improves progressively thereafter as oxen adapt to the work. Nevertheless this increase of feed intake over time for oxen working 4 h/day did not allow them to eat more than oxen at rest or oxen working lightly.

Most results show little difference in intake between working animals and animals at rest (reviewed by Pearson and Dijkman 1994). The absence of an effect of work on feed intake when time of access to feed was standardised, as in this study, was reported by Pearson and Lawrence (1992) and Pearson and Smith (1994) in cattle, and Bamualim and Ffoulkes (1988) and Bakrie et al (1989) in buffaloes.

The effect of work on feed intake may result from the work stress and/or from the feed restriction during the hours animals work (Pearson and Smith 1994). In this study oxen at rest and working oxen had equal time available to eat. It was assumed that oxen at rest had more opportunities to ruminate than working oxen because oxen rarely ruminate when they work. Since feed intake was not significantly different between working and non-working oxen during both experiments, the limited time available to ruminate may not have been a significant inhibitor of feed intake in working oxen in these experiments. Results in Experiment 3 showed the time spent eating and ruminating was similar whether animals worked 0, 2.5 or 5 h/day. Clearly a 5 h period of feed deprivation, with or without work, was not long enough to disrupt feed intake or feeding behaviour. Similarly, Pearson and Smith (1994) found no effect of feed restriction for 4 h, with or without work, on intake of straw diets by cattle and buffalo.

In Experiment 3 feed intake was significantly affected by the proportion of leaves in the stover and therefore by the quality of the diet. These observations suggest that a strategy to improve intake of these poor quality diets, such as millet stover, would be to increase the amount offered to the working animal, thus allowing greater selection of the more digestible components to compensate for the extra energy used for work.

The concept of additivity of hunger and satiety signals described by Forbes (1995) could at least partly explain the absence of difference or decrease in intake between working animals and animals at rest. When working animals are fed on high roughage diets, the negative signals generated from stretch receptors in the rumen activated by the distension caused by the high cell wall content of the diet could offset the intake stimulating signals induced in tissues as a result of the depletion of energy substrates due to work. However, Faverdin et al (1995) suggested that the negative feedback loop where post-ingestive signals depress the motivation to eat is acceptable to describe the short-term feeding patterns of ruminants. They also suggested that the long-term regulation of feed intake is of significance in animal production and that this is driven by the energy requirements and the body reserves of the animal. The increase of feed intake over time seen in this study supports the concept of the long-term regulation of feed intake. Increases in feed intake were also reported by Zerbini et al (1995) in draft cows working intermittently over a long period of time (90 days). The long-term increased energy requirements for lactation and work may have caused increases in feed intake in these cows. Draft animals work intensively for about nine weeks during the cropping season in semi-arid areas. It is therefore worthwhile investigating the long-term pattern of change in feed intake by draft oxen fed on roughages.

Digestibility and rate of passage of feeds through the digestive tract

In this study DM apparent digestibility and the digestibility of feed fractions were not significantly affected by work. These results agree with those reported by Ffoulkes (1986), Bamualim and Ffoulkes (1988), Pearson (1990) and Pieterson and Teleni (1991) who found no significant differences in digestibility of feed between working and non-working animals. Pearson and Lawrence (1992) also got the same results in Costa Rica. In contrast to these results, significant increases in digestibility as a result of work were reported by Soller et al (1991) and Zerbini et al (1995) in Ethiopia, and

Pearson and Lawrence (1992) in Nepal. In this study, a significant improvement in feed digestibility was observed as the proportion of leaves in the millet stover increased and therefore the quality of the diet improved. Hence differences in diet quality may well have contributed to the different responses in digestibility of feed seen in working oxen.

Rate constants k_1 and k_2 representing the rate of passage of digesta through the rumen and the lower tract, respectively, were not affected by work. This agrees with results reported by Zerbini et al (1995) who did not find significant differences in passage rate of Cr-mordanted hay between working and non-working cows. However, MRT of solid particles in the digestive tract was lower for oxen working 2.5 h/day than for animals at rest or working 5 h/day. This suggests that light exercise may have caused a more rapid rate of passage of feeds in the digestive tract.

Liveweight change

During Experiment 2, oxen at rest were able to gain weight whereas oxen working 2 h/day maintained their live weight. During Experiment 3, oxen at rest maintained their weight while oxen working 2.5 or 5 h/day lost weight. The energy intake from millet stover and concentrate (21.3 g/kg $M^{0.75}$ during Experiment 2) was sufficient to allow weight gains in oxen at rest. During Experiment 3, the level of concentrate offered was lower (10 g/kg $M^{0.75}$) but the animals had opportunities to select more leaves from the millet stover which was given in excess (0.50) of appetite. During Experiment 2, energy requirements for work could be met by intake when animals worked 2 h/day, ensuring the maintenance of weight in these animals. The weight losses seen in oxen working 4 h/day during Experiment 2 and in animals working 2.5 or 5 h/day during Experiment 3 illustrated that energy requirements could not be met from intake alone. In both experiments there was a linear increase in PUN as the work level increased. This suggested that during working periods oxen were breaking down amino acids to supply energy-yielding substrates for work.

Conclusions

Although the rate of passage of undigested feed residues tended to increase with light work, the general picture which emerged was that oxen fed on low quality crop residues can neither increase their feed intake nor use feed more efficiently to compensate for the extra energy used for work. Therefore they mobilise their body reserves to supply muscles with energy-yielding nutrients. Hence weight losses are a constant feature in working oxen relying on roughages for energy intake. During this study oxen working more than 2 h/day lost live weight and PUN increased as work level increased, suggesting that oxen were breaking down amino acids. Oxen could maintain their live weight during resting periods when they were fed sufficient millet stover so that they could select leaves which were more nutritious. Heat load on oxen did not interfere with their digestive physiology. The implications of these results for the formulation of feeding strategies for draft oxen in semi-arid areas include the following considerations. First, since work and heat stress did not influence intake and digestibility of feeds, it may be relevant to predict feed intake of these animals using models developed for other classes of cattle. Second, ways to increase intake of roughages in semi-arid areas must be sought. Treatments of crop residues and the supplementation of these roughages with highly digestible forages supplying rumen degradable and rumen undegradable nutrients must be considered. Where crop residues are abundant, oxen should be given excess residues to increase their feed intake. Finally, since oxen cannot increase their nutrient intake during work when fed crop residues and therefore use their body reserves to perform work, the effect of body condition on work output should be investigated.

4
Effect of body condition before work and weight losses during work on work output

Introduction

Draft oxen in good condition and of suitable live weight are required to ensure timeliness in soil preparation and planting, crucial for successful cropping in the semi-arid areas of West Africa. This is because work output is a function of body size and working animals use long-chain fatty acids from fat reserves to fuel muscular activity during sustained exercise (Preston and Leng 1987; Pethick 1993). Unfortunately, draft oxen often lose weight during the dry season (Wilson 1987). Therefore they have minimum live weight and body reserves at the start of the cultivation period when farm power demand is highest. This is also a time when feed resources are scarce and do not match the nutrient requirements of draft oxen for maintenance, let alone work.

Although the cropping season is relatively short in the semi-arid zones, many oxen are hired out or loaned to other farmers. Hence those oxen that are available may be used over extended periods for crop production and transport. While body condition and weight losses during work may not constrain performance when animals are only used for short periods (three weeks), they take on greater significance where animals are used for longer periods (more than four weeks).

Supplementary feeding is often recommended as a means to produce draft oxen in good condition and live weight to optimise available power. However, feed supplementation is expensive. Furthermore, investigations of the effect of dry season supplementation on draft oxen have generally failed to show any significant benefit of committing scarce feed resources to work output and consequently to better crop production (Dicko and Sangaré 1984; Abiye Astatke et al 1986; Khibe and Bartholomew 1993). Feeding strategies for draft oxen can be better planned if the minimum working weight for cultivation is known and if the losses in weight and body condition that animals can tolerate before work output is affected are known. Hence in this study (Experiment 4) the relationship between body weight, body condition, weight loss during work and work output of draft oxen were investigated.

Material and methods

Animals and feeding

Experiment 4 was conducted from July to September 1994 at the ICRISAT Sahelian Center in Niger. Eighteen oxen, aged 4–7 years, with an average live weight of 326 kg, were used. They were housed as in Experiment 2. They were given chopped millet stover *ad libitum*, supplemented daily with 10 g DM/kg $M^{0.75}$ of a concentrate mix made up of wheat bran (500 g/kg), groundnut cake (350 g/kg), rock phosphate (50 g/kg), crushed bone (50 g/kg) and common salt (50 g/kg). Animals at rest were allowed to eat when other ox teams were working.

Treatments and experimental design

Treatments consisted of three levels of body condition (Plate 4) before work (IBC). The oxen were fed during the three months before the experiment so that they reached contrasting body condition scores as defined by Nicholson and Butterworth (1986) on a scale from 1 (emaciated) to 9 (obese). Three pairs of oxen were assigned to each of the three treatment groups with average body condition scores of 2.33 (poor), 3.67 (medium) and 5.67 (good) for groups 1, 2 and 3, respectively. Average liveweight masses (M) of teams in groups 1, 2 and 3 were 615, 650 and 692 kg, respectively.

The experiment lasted seven weeks. Teams worked for four days each week. Work consisted of pulling a loaded sledge around a flat circuit. Each day, the teams worked for 4 h to complete 10 laps of the circuit. Work stopped when the set distance or the set time was complete, when oxen were unwilling to continue or when it was judged that the oxen were too tired to continue working. During the preparation phase an ergometer (Lawrence and Pearson 1985) was used to measure work performed, distance travelled and elapsed working time for different known loads. A regression analysis of force on sledge load was performed and used to determine the load required for each team so that the draft force exerted was equivalent to 12.5 kgf/100 kg M. The following equation was used to determine work loads:

$$\text{Load (kg)} = 0.201 \times \text{Force (N)} - 7.44.$$

Animals were allowed to stop for 3–4 min after each lap. Respiration rate and rectal temperature were then recorded. Respiration rate was assessed by counting the number of flank movements for 30 s. Rectal temperature was measured with a clinical thermometer. Live weight was measured three days in a row at the beginning of each week. Body condition was assessed each week as defined by Nicholson and Butterworth (1986). Each day, individual feed allowances and refusals were weighed and a food sample taken, dried and ground for laboratory analysis (Chapter 3).

At the end of the 7 weeks of work, 10 animals were monitored for 2 months to investigate the rate of weight gain after work. The animals grazed rainy season natural pastures from 0830 to 1700 hours without supplementation. They were kept in stables after grazing and had access to water *ad libitum*. Live weight was measured for a two-month period every second day in the morning before grazing.

Data analysis

During the course of the experiment two oxen, one in team 3 (poor IBC) and one in team 6 (medium IBC), were impaired by joint disorders. They were consequently allowed to rest from the fifth week of the experiment. The sound oxen in these pairs were teamed up so that they could continue work for the rest of the experiment. Therefore, different sets of data were used to analyse parameters of interest in this

A

B

C

Plate 4. *Examples of oxen in good (A), medium (B) and poor (C) initial body condition used to investigate the effect of body condition before work on work output.*

study. The data set used to analyse daily intake of millet stover and daily weight changes included all weeks and all oxen except oxen 17 and 25. Teams 3 and 6 were excluded from the analyses of speed, power and work output.

Statistical models used to analyse feed intake, weight change, body condition, speed, power and work output using SAS (1985) are given below:

1. Intake of millet stover (g DM/d/kg M and g DM/d/kg $M^{0.75}$)

$$Y_{ijkl} = u + C_i + T_{(i)j} + A_k + W_l + C * A_{ik} + C * W_{il} + W * T_{(i)jl} + e_{ijkl}$$

2. Change in live weight (g/d) and body condition (point/week)

$$Y_{ijl} = u + C_i + T_{(i)j} + W_l + C * W_{il} + W * T_{(i)jl} + e_{ijl}$$

3. Speed (m/s) and power (W and W/100 kg M)

$$Y_{ijkm} = u + C_i + T_{(i)j} + W_k + R_m + C * W_{ik} + C * R_{im} + W * T_{(i)jk} + e_{ijkm}$$

where:

Y = one observation of daily food intake, daily weight change, weekly body condition score, force, distance, speed, power or work

u = mean

C_i = i^{th} IBC score, I =1, 2 and 3 (1 = poor, 2 = medium, 3 = good IBC)

$T_{(i)j}$ = j^{th} oxen team nested within the i^{th} IBC group, j=1,2 and 3

A_k = k^{th} activity, k=1: rest, k=2: work

W_l = l^{th} experimental week, l=1, 2....7

$C * A_{ik}$ = interaction between the i^{th} IBC and the k^{th} activity

$C * W_{il}$ = interaction between the i^{th} IBC and l^{th} week

$W * T_{(i)jl}$ = interaction between the i^{th} week and the j^{th} team in the i^{th} IBC group

R_m = m^{th} lap of the circuit travelled

$C * R_{im}$ = interaction between the i^{th} initial body condition and the m^{th} lap travelled

e = random error

The effect of IBC on daily intake, weight change, speed, power and work was tested using team within condition ($T_{(i)j}$) as the error term. The interaction between week and team within condition ($W.T_{(i)jl}$) served as the error term to test the effects of week and the interaction between week and other factors included in the model. Orthogonal polynomial regressions were fitted for variables such as week, lap, and their interaction with IBC to investigate the trend in food intake, weight change, speed, power and work over time. Mean values are reported ± SE.

Results

Intake of millet stover

Linear effect of IBC (P<0.05) and the linear and quadratic effects of week (P<0.05) on daily intake of millet stover (g/d/kg M; g/d/kg $M^{0.75}$) were observed (Table 11). The poorer the IBC the higher was the intake of millet stover. Intake of millet stover increased steadily over time and reached a plateau by the fourth week. Food intake on working and non-working days were similar.

Table 11. *Daily intake (g/kg M and g/kg $M^{0.75}$) of millet stover over seven weeks by oxen in poor, medium and good initial body condition (IBC) on working and non-working days.*

Sources of variation	Daily feed intake (g/kg M) Mean	(g/kg M) SE	(g/kg $M^{0.75}$) Mean	(g/kg $M^{0.75}$) SE	Significance
Initial body condition					Linear*
Poor	18.1	0.26	75.1	1.08	
Medium	17.2	0.26	72.9	1.07	
Good	15.2	0.22	64.8	0.93	
Activity					NS
Rest	17.2	0.20	72.2	0.86	
Work	16.6	0.19	69.7	0.79	
Week					Linear***
1	13.8	0.22	58.1	0.94	Quadratic***
2	15.4	0.24	64.8	1.00	
3	16.3	0.23	68.4	0.95	
4	17.4	0.23	72.9	0.95	
5	17.0	0.22	71.2	0.93	
6	17.7	0.22	73.6	0.94	
7	17.2	0.24	71.6	1.03	

* = P<0.05; ** = P<0.01; *** = P<0.001; NS = not significant.

Change in live weight and body condition

Differences (P<0.01) in daily weight gain due to IBC were observed. All oxen lost weight during the experiment, but weight losses were highest in oxen in good IBC. Daily weight losses were 456 (SE 103.3), 308 (SE 103.3) and 719 (SE 89.5) g/day for oxen in poor, medium and good IBC, respectively. Weight losses averaged 21.9 kg for oxen in the poor IBC group, 14.8 kg for oxen in the medium IBC group and 34.5 kg for oxen in the good IBC group over the 7 weeks. These weight losses were equivalent to 7.4, 4.7 and 9.9% of the initial M for oxen in poor, medium and good IBC, respectively.

Weight losses estimated from polynomial regressions are illustrated in Table 11 and Figure 1. The pattern of liveweight changes was the same irrespective of IBC. Daily weight losses were highest during the first week of the experiment and decreased from week 1 to week 4. There was a steady increase in weight losses from week 5 to week 7. The regression of daily weight losses on intake of millet stover showed no association between these two parameters.

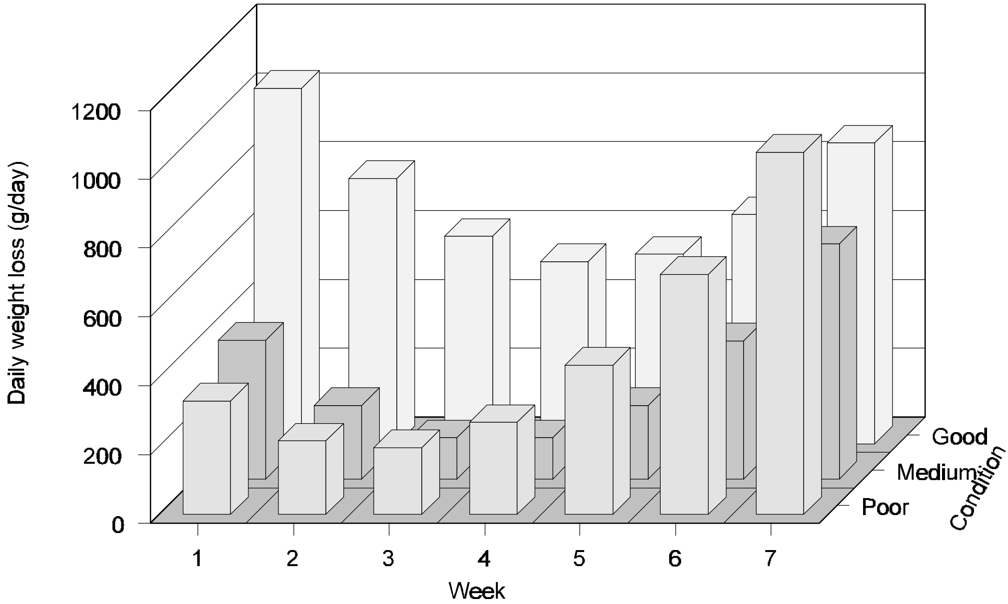

Figure 1. *Liveweight losses over seven weeks of work for oxen in poor, medium and good initial body condition (IBC).*

Body condition scores of all oxen declined over time. The regression of body condition on time showed that the better the IBC the more severe its deterioration was. Body condition score declined at a rate of 0.006, 0.107 and 0.235 points per week, for oxen in poor, medium and good IBC, respectively.

In the 10 oxen monitored on good quality natural pastures after work, rapid weight gains were observed as illustrated by the following regression equations of M (kg) on time (60 days [D] after work):

$M = 257(\pm12) + 0.825(\pm0.054) \times D$ for oxen in poor IBC (at the start of the experiment)

$M = 302(\pm12) + 0.967(\pm0.041) \times D$ for oxen in medium IBC (at the start of the experiment)

$M = 303(\pm11) + 0.870(\pm0.037) \times D$ for oxen in good IBC (at the start of the experiment)

The overall rate of change of M was similar irrespective of the IBC score. However, oxen in poor and medium IBC had higher M gains (3.20 g/d/kg M) than oxen in good IBC (2.87 g/d/kg M). Oxen in poor and medium IBC were able to reach their initial live weight four weeks, on average, after work stopped. It took six weeks after work stopped for oxen in good IBC to reach their pre-work M.

Speed and power

IBC did not affect speed of work of the teams. Power output (W) developed by teams in poor and medium IBC was similar, but significantly lower than that of oxen in good

IBC (P<0.01). However, when power was expressed relative to live weight (W/100 kg M) the effect of IBC was no longer significant. Three ox teams with approximately similar live weight and in different body condition (team 1: poor IBC, 719 kg; team 2: medium IBC, 721 kg; team 3: good IBC, 739 kg) developed similar power output (team 1: 775 W; team 2: 697 W; team 3: 741 W).

Differences in speed and power output due to week were significant (P<0.01, Table 12). Speed and power output increased steadily over weeks for all teams irrespective of their IBC. Even though oxen lost body weight throughout the experiment, there was a significant weekly increase of 0.035 m/s and 25.1 W in speed and power, respectively.

Lap number had a significant (P<0.01) effect on speed and power output. Two contrasting phases are seen in the pattern of power output each day. During the first three laps of work (first hour), there was an increase of 0.01 m/s and 9 W in speed and power, respectively, for each lap. In the second phase starting from the fourth lap, a steady decline in speed and power output of 0.014 m/s and 10.3 W, respectively, were observed for each lap completed.

Table 12. *Speed (m/s) and power (W and W/100 kg M) for oxen in different initial body condition (IBC) over seven weeks and during each lap around the circuit.*

Source of variation	Speed (m/s)	Power (W)	+ (W/100 kg M)
Initial body condition			
Poor	0.94	637	117
Medium	0.86	637	107
Good	0.96	780	118
SE	0.005	4	0.6
Lap			
1	0.95	706	117
2	0.97	722	120
3	0.97	724	120
4	0.95	706	117
5	0.92	690	115
6	0.92	685	114
7	0.89	666	111
8	0.88	654	109
9	0.87	651	108
10	0.87	646	107
SE	0.08	6	1
Week			
1	0.78	590	95
2	0.84	631	103
3	0.88	653	107
4	0.98	725	120
5	1.00	744	124
6	0.96	713	120
7	0.99	739	126
SE	0.07	5	1

Energy balance

Oxen in all body condition groups exhibited a negative energy balance (Table 13). The calculated and the observed liveweight change agreed well.

Table 13. *Intake of metabolisable energy (ME), energy used for maintenance, energy used for work by oxen in poor, medium and good initial body condition (IBC) pulling 12.5 kgf/100 kg M during seven weeks, four days per week.*

	Initial body condition		
	Poor	Medium	Good
Live weight (kg)	308	325	346
Metabolisable energy intake[1] (MJ, ME)	41.98	42.33	40.29
Energy used for maintenance[2] (MJ, ME)	34.77	36.10	37.65
Energy used for work[3] (MJ, ME)	14.06	13.98	16.75
Energy balance (MJ, NE)	–4.86	–5.50	–10.02
Liveweight change[4] (kg/day)			
Calculated	–0.320	–0.370	–0.670
Observed	–0.456	–0.308	–0.719

1. 8.05 MJ ME/kg DM.

2. Energy used for maintenance = (a × b × (0.53 × (M/1.08)0.67) × c (AFRC 1993), where a = 1.15 for bulls, b = 1.10 for the increased metabolic rate during working days, c = 1.05 to account for the unrecorded work done by the oxen during the experiment, for instance walking to the site where work takes place. It is also assumed that the efficiency of utilisation of ME for maintenance is the same as that for work.

3. Energy cost of walking = 1 J/m/kg as found in Chapter 2; efficiency of doing work = 0.32.

4. 1 kg weight change ≡ 15 MJ NE.

Discussion

Feed intake and adaptation to work

As in the previous experiments in this study (Chapter 3) work did not affect intake of millet stover. These results are consistent with most other studies that indicated no differences in intake between working animals and animals at rest (Bamualim et al 1987; Barton and Saadullah 1987; Bakrie et al 1988; Bakrie and Teleni 1991; Soller et al 1991; Pearson and Lawrence 1992; Matthewman et al 1993; Van Thu 1994). Poor body condition before work was more conducive to higher intake of millet stover than good body condition before work over the seven weeks. Early in lactation higher dry matter intakes were seen in cows with low body condition than in those with better body condition (Jones and Garnsworthy 1989). As suggested by Faverdin et al (1995), undernutrition induces an increase in feed intake when availability of food is no longer a limiting factor.

The steady increase in feed intake and power output over seven weeks observed in this study suggests that oxen underwent a period of adaptation to work during the first few days. They became more adapted as work went on and they were therefore able to increase their intake. Bartholomew et al (1994) also attributed increases in speed of working teams over time to an adaptation to work. Therefore, working the animals during the dry season would have the advantage that oxen are fit when cultivation starts and do not have to undergo this adaptation period in the cropping season.

Live weight, body condition and work performance

During the preparation phase of the experiment oxen were fed to reach the targeted body condition and live weight. This was, however, difficult to achieve because liveweight changes were associated with changes in body condition. At the start of the experiment heavier animals tended to have better body condition than lighter animals. To minimise the confounding effect of M and IBC on the rate of work (W) in different treatment groups, power output was expressed relative to M (W/100 kg M). The use of power relative to M to investigate the effect of IBC on work performance was based on the assumption that oxen in good IBC had a higher fat content per kg M than oxen in poor or medium IBC.

Power output is a function of speed and draft force. In this experiment draft force was set to be proportional to M. Therefore any advantage of oxen in good condition over those in poor condition would have been expressed as a higher average walking speed. Relative to oxen in poor condition, oxen in good condition would perform work at a higher rate or for a longer period of time because they would have more body reserves to draw on to fuel muscle activity. However, walking speed was not significantly affected by body condition in this experiment. Furthermore, the effect of IBC on power output was no longer significant when power output was expressed in relation to M. The similarity of power output relative to M for all oxen suggested that animals with same body mass, irrespective of fat content, generated the same power output. This suggests that power output is more dependent on body mass than on body condition. Oxen in good condition did not out-perform oxen with equal M but in poor body condition. These results are consistent with those reported by Bartholomew et al (1994). These authors evaluated the relative importance of body weight and body condition on work performance by applying the same load of 367 N to groups of oxen weighing 310 and 360 kg and in good and poor condition. Light oxen in good condition could not sustain the work level applied. They concluded that live weight rather than body condition is the single most important determinant of work output. Therefore, it seems that farmers should be encouraged to select large-framed animals for draft purposes. This may be constrained by the fact that more young animals are being used for draft purposes with a rapid on-farm turnover rate of these animals, apparently driven by an attractive meat market. There is therefore a genuine need to investigate feeding and management practices that will optimise power and meat output in these farming systems.

Good IBC may allow work for longer periods of time in the cropping season. In this study, oxen in poor IBC sustained average draft forces of 682 N. These animals might not be able to perform ploughing or ridging for extended periods because these two activities require draft forces of about 820 N (Khibe and Bartholomew 1993). They could, however, pull heavily loaded carts without undue stress.

It was expected that weight losses would adversely affect work output. In this experiment power output improved over the weeks while oxen were losing weight. The same trends in liveweight change and power output were reported by Bartholomew et al (1993). Therefore the weight losses oxen can tolerate before work output is affected are difficult to estimate. Continuous and severe weight losses can compromise the health of the animal, or even its life. However, in this experiment oxen were able to regain live weight at a rapid rate when they had access to good quality pasture during the rainy season. It took the animals four to six weeks to reach their pre-work live weight.

An ox weighing 400 kg, ploughing for 5 hours a day, has an extra energy need for work equivalent on average to 0.60 of its energy requirement for maintenance (Chapter 2). These energy requirements for work amount to 22.28 MJ NE. Assuming a value of 8.05 MJ ME/kg DM for millet stover, the animal would need to eat an extra 3.90 kg DM of millet stover if its live weight was to be maintained during the working period. This is unlikely as oxen will not increase their feed intake as a result of work when they are fed roughages. Furthermore, the required amount of millet stover may not be available. Therefore, part of this energy requirement has to be supplied by body reserves or by feeding a concentrate which may be expensive. If the animal is fed on crop residues without feed supplementation and ploughs for 3 weeks during the cropping season, 5 days a week, it will lose about 22 kg M. Assuming a fat content of 0.60 of body weight, this animal would need to have fat reserves of about 13 kg to perform work without losing body weight.

Conclusions

At the start of the cropping season, various body conditions are found in oxen because of differences in feed resources, management practices and the disease situation in farming systems in the semi-arid zone. Observations from this study suggest that a body condition score of between 2 and 3 as defined by Nicholson and Butterworth (1986) would be a low critical score below which work may irreversibly damage the oxen’s health. The ideal body condition score would range between 4 and 6. These animals are neither too fat nor too lean and can perform well if they are in good health. Oxen with a body condition score of over 6 may be too fat to move comfortably and are more susceptible to heat stress than leaner oxen. Moreover, the feeding level required to reach a body condition score over 6 is unlikely to be profitable as far as feeding for work performance is concerned.

Oxen should be supplemented during the cropping season when work is performed for more than six weeks. If the working period is short, weight losses could be tolerated as animals will regain their live weight rapidly.

5
Implications of heat stress on draft oxen

Introduction

In a mature animal at rest most of the energy is used to support basal metabolism, but an ox working at a steady rate, e.g. ploughing, uses nutrients to generate energy in the form of ATP at 6 to 10 times the rate at rest. Only part of this energy is used by muscles while the rest is released as heat. Because of the high ambient temperatures prevailing in the semi-arid tropics, non-evaporative cooling mechanisms are unlikely to be effective because they require a temperature gradient between the animal and the environment. Evaporative cooling mechanisms (panting and sweating) are therefore the main route of heat dissipation in draft oxen working in these areas. Panting and sweating are unlikely to be sufficient to enable the ox to dissipate its excess heat load during work. As a result, body temperatures of working oxen rise when ambient temperatures are high. This can result in hyperthermia during long periods of work. During prolonged work (3–4 h) in hot dry or hot humid conditions, the rectal temperature of work animals may reach 42–43°C associated with muscle temperatures of 44–45°C (Upadhyay 1989).

Under conditions of heat stress, the animal attempts to reduce its body temperature by adjusting many organ systems. The compensations or attempted compensations by the animal subjected to heat stress take approximately the following order (McDowell 1972): 1) change in muscular blood flow, 2) initiation of sweating, 3) increased respiration rate, 4) changes in hormone secretions or endocrine activity, 5) change in behavioural patterns, 6) increased water intake, 7) elevation in body temperature, 8) change in the use of body water and 9) changes in the state of hydration. These changes may occur more rapidly and more intensely in a working animal than in an animal at rest under the same environmental conditions. In addition, the rise in body temperature in the working ox may speed up the onset of fatigue (Nielsen 1992). Fatigue occurs at muscle temperatures above 40ºC due to nervous or neuromuscular interference (South 1961). This may have adverse effects on work rate since the animal will attempt to reduce its metabolic heat production by slowing down.

There are two approaches to analyse the effects of environmental stress on animal performance and physiology (Webster 1983). The first approach involves correlation, whereas the second involves causation between variables. Although the correlation approach may not distinguish between direct and indirect effects, its advantage lies in its potential for strength in numbers. The causation approach is based on classic experimental designs with controlled variables, for instance ambient temperature or relative humidity in climate rooms. It can yield firm conclusions. However, physiological experiments conducted in laboratory settings will not usually simulate the changing environmental circumstances in the field. For instance, the effects of important environmental factors such as wind speed and solar radiation that affect thermoregulatory mechanisms are not taken into account in these types of laboratory experiments. Finch (1986) pointed out that the effect of heat stress on body temperature of cattle in a climate room may differ markedly from that measured in a natural radiant environment. This is because radiation increases sweat gland activity due to local heating effects at the neuroglandular junction (Finch 1986). The correlation approach is used in this chapter to investigate the physiological implications of heat stress on draft oxen and the effects of working under hot conditions on work performance of these oxen. Some aspects of the physiological responses to heat stress such as changes in plasma thyroid hormone concentrations and alterations in water consumption were dealt with in previous chapters. This chapter therefore examines physiological changes related to body temperature and respiration rate of draft oxen working under hot conditions.

Material and methods

Data on physiological parameters reported here were obtained during experiments 2, 3 and 4 detailed in previous chapters. This section reports the measurements of rectal temperature and respiration rate of draft oxen that were carried out during these experiments. A brief summary of the experimental settings is, however, necessary.

Experimental layout

In Experiment 2, 18 oxen were used. They were fed millet stover and a concentrate mix (21.3 g/kg $M^{0.75}$). Oxen were allotted to three treatment groups: rest, work for 2 h/day and work for 4 h/day (2 h in the morning and 2 h in the afternoon). Oxen at rest were exposed to solar radiation when other teams were working. This experiment lasted nine weeks divided into three-week periods, from July to August 1993. Oxen worked pulling a loaded sledge or weeding cereal crops.

In Experiment 3, 12 oxen were allotted to 3 treatment groups: rest, work for 2.5 h/day and work for 5 h/day (2.5 h in the morning and 2.5 h in the afternoon). Animals were fed millet stover and a concentrate mix at a rate of 10 g/$M^{0.75}$ per day. This experiment was carried out between December 1993 and February 1994 for 10 weeks divided into 2-week periods. In both experiments 2 and 3 treatments were applied in sequence during 2- or 3-week experimental periods.

In Experiment 4, 18 oxen were allotted to 3 treatment groups according to their body condition and weight before work: poor, medium and good initial body condition. Animals were given millet stover *ad libitum* and supplemented daily with 10 g DM/kg $M^{0.75}$ of a concentrate mix. They worked 4 h/day (in the morning or in the afternoon), four days a week for seven weeks. This experiment was conducted from July to September 1994. In both experiments 3 and 4, oxen worked pulling a draft force proportional to their body weight (10% in Experiment 3 and 12.5% in Experiment 4).

Measurement of rectal temperature

During Experiment 2 rectal temperature was continuously monitored using a rectal probe. This device was made up of a stainless steel rod about 10 cm long in which a

5000Ω thermistor was inserted. The thermistor was connected to a 21X Campbell data logger which was programmed to measure temperature each second and to average and store temperatures each minute.

The data logger was carried in a backpack harnessed to the oxen (Plate 3). This data logging system allowed the continuous measurement of rectal temperature for any activity performed by the animals. However, since two sets of equipment were available, they were alternated between the four teams of oxen that were working each day. Clinical thermometers were used to monitor changes in rectal temperatures of oxen at rest. After each work session data stored in the data logger were downloaded to a computer using the Campbell 21X data transfer program.

During experiments 3 and 4 rectal temperature was measured using a clinical thermometer. Oxen worked around a circuit and rectal temperature was taken after teams completed each lap.

Measurement of respiration rate

Respiration rate was measured during experiments 3 and 4. Flank movement of each ox in the team was counted after each lap for 1 min using a stop watch.

Climatic data

Information on ambient temperatures and relative humidity was provided by the weather station of the ICRISAT Sahelian Center. Ambient temperature and relative humidity (RH) were continuously monitored in a Stevenson screen and stored every 15 min in a data logger.

Data analysis

Experiment 2

Work rate was expressed in W/100 kg M to standardise power output because oxen performed work of different types, for instance pulling a sledge or weeding. The thermal conditions under which oxen worked were evaluated by a temperature humidity index (THI) combining ambient temperatures and relative humidity. THI were calculated as follows (Du Preez et al 1990):

$$THI = T_{db} + 0.36 \times T_{dp} + 41.2$$

where Tdb and Tdp are dry-bulb and dew-point temperatures, respectively. Tdp was estimated as the difference between dry-bulb and wet-bulb temperatures (Twb). A psychrometric chart with metric units (Curtis 1983) was used to derive an equation estimating Twb given observed values for ambient temperatures and relative humidity (RH):

$$T_{wb} = T_{db} \times (0.6144 + 0.00503 \times RH) + 3.789 \times LOG(RH / T_{db}) - 5.0659$$

The extent and rate of heat stress were assessed in this experiment by fitting second degree polynomial curves of rectal temperature on time in minutes. The polynomial coefficients were then subjected to analysis of variance. Main sources of variation were team, treatment, period, week, time of day, and 30 min working periods. The maximum change in rectal temperature (MIRT) was expressed as the difference between the maximum rectal temperature at a given time during work and the initial values before work started. THI and MIRT were used as covariates. In further analyses THIs during work were grouped into five classes (class 1: THI≤70; 2: 71≤THI≤73; 3: 74≤THI≤76; 4: 77≤THI≤78; 5: THI≥79) and used as a main factor of variation in the analysis of variance.

Experiment 3

Respiration rate (RR) and rectal temperatures (RT) were regressed on number of rounds completed (1 to 6). The slopes of the linear curves obtained were subjected to an analysis of variance including team, oxen within team, period, week and time of day as main sources of variation and the intercept of the curve as a covariate.

Experiment 4

Differences in RR, MIRT and RR between individual oxen was tested using the Duncan test (SAS 1985). The transformation loge (RT–37) (Turner 1984) was used to control homogeneity of variance of RT. The repeatability of RT and MIRT were estimated as:

$$[(\sigma_a/(\sigma_a+\sigma_e))] \quad \text{(Harvey 1990)}$$

where σ_a was the variance component of the individual ox and σ_e was the residual component of variance. The statistical model used included body condition, ox nested within body condition and time of day as main sources of variation. Lap number (1–10) was included as a covariate.

Results

Experiment 2

Minimum, maximum and mean ambient temperatures were 23.0, 35.0 and 29.3°C, respectively, when animals worked in the morning and 24.0, 36.0 and 31.7°C, respectively, when work took place in the afternoon. Minimum and maximum relative humidity were 40.0, 93.0 and 67.4%, respectively, during the morning working sessions and 44.0, 96.0 and 60.0%, respectively, during the afternoon working sessions.

Patterns of change in rectal temperature across time are described in equations 1, 2, 3 and 4 for oxen working 2 h in the morning (WAM), oxen at rest in the morning (RAM), oxen working 2 h in the afternoon (WPM) and oxen at rest in the afternoon (RPM), respectively.

$$\text{WAM: } Y = 37.75 + 0.033025 \times T - 1.3878 \times 10^{-4} \times T^2 \quad \text{(Equation 1)}$$
$$\text{RAM: } Y = 37.90 + 0.007763 \times T - 1.153 \times 10^{-5} \times T^2 \quad \text{(Equation 2)}$$
$$\text{WPM: } Y = 38.53 + 0.0360018 \times T - 1.7604 \times 10^{-4} \times T^2 \quad \text{(Equation 3)}$$
$$\text{RPM: } Y = 38.77 + 0.012605 \times T - 6.627 \times 10^{-5} \times T^2 \quad \text{(Equation 4)}$$

where Y is rectal temperature and T is time in minutes.

Initial rectal temperatures were significantly higher in the afternoon than in the morning both for working oxen and for oxen at rest. Body temperature increased gradually during work. The rate of increase of rectal temperature expressed by the linear component of the polynomial equation and the curvatures of the equation were, however, the same in the morning and in the afternoon when oxen were subjected to the same activity (work or rest). Significant differences in the slope and the curvature of rectal temperature emerged when oxen doing work and oxen at rest were compared either in the morning or in the afternoon. During the 2-h working periods oxen raised their body temperature from 37.75 to 39.71°C in the morning and from 38.53 to 40.32°C in the afternoon. When oxen were at rest and exposed to solar radiation their body temperature increased from 37.90 to 38.67°C in the morning and from 38.77 to 39.26°C in the afternoon. MIRTs were 0.76 (±0.08), 1.27 (±0.082), 1.66 (±0.081) and 1.86 (±0.084)°C for the first, second, third and fourth 30-min working periods in the morning, respectively. Corresponding values in the afternoon were 0.86 (±0.14), 1.49 (±0.14), 1.82 (±0.14) and 2.05 (±0.14)°C, respectively.

Mean THIs increased from 71.9 to 73.2 during morning working sessions and from 74.4 to 75.8 when work took place in the afternoon. There was a negative correlation between THIs and work output. The inclusion of THI as a covariate in the analysis of variance of work rate showed that each increase of one point in THI was associated with a decrease of 10 W/100 kg M in power output. THI as a main source of variation and its interaction with time of day had significant effects ($P<0.01$) on work rate.

The relationship between work rate, rectal temperature and THI is shown in Table 14. Work rate was significantly affected by time of day ($P<0.05$) and 0.5 h intervals of time during work ($P<0.01$), rectal temperatures ($P<0.01$) and THIs ($P<0.01$). Work rate was higher in the morning (108±3.2 W/100 kg M) than in the afternoon (88±3.8 W/100 kg M).

Table 14. *Work rate, maximum increase in rectal temperature (MIRT) and temperature humidity index (THI) for each 0.5-h time interval during work in the morning and in the afternoon (Experiment 2).*

Time of day	0.5-h time intervals during work	Work rate (W/100 kg M)	MIRT (°C)	THI
Morning				
	First	107	0.71	71.9
	Second	118	1.27	72.0
	Third	107	1.66	72.6
	Fourth	100	1.86	73.2
	SE	4.6	0.08	
Afternoon				
	First	97	0.86	74.4
	Second	86	1.49	75.2
	Third	85	1.82	75.7
	Fourth	87	2.05	75.8
	SE	6.5	0.15	

Experiment 3

This experiment was conducted during the coolest period in the year in Niger, from December to February. Minimum, maximum and mean ambient temperatures when animals were working were 17, 30 and 24 C, respectively, in the morning and 26, 34 and 30°C, respectively, in the afternoon. There was a gradual increase in RT and RR during work either in the morning or in the afternoon, but RT and RR were highest during the afternoon working sessions (Table 15). When oxen worked in the morning, their speed increased during the first hour of work and then declined until the last lap when they walked faster because they were heading towards the stables. During the afternoon working sessions, the working speed declined continuously from the start of work.

Table 15. *Rectal temperature (RT), respiration rate (RR) and working speed of oxen working 2.5 h in the morning or in the afternoon (Experiment 3).*

Distance travelled (km)	RT (°C)	RR (count/min)	Speed (m/s)
Morning			
1	37.8	36	0.92
2	38.1	37	0.91
3	38.5	47	0.99
4	38.6	51	0.97
5	38.9	56	0.85
6	39.3	61	0.93
SE	0.13	3	0.03
Afternoon			
1	38.9	59	0.93
2	39.3	66	0.89
3	39.6	78	0.83
4	39.8	82	0.85
5	39.9	86	0.87
6	40.1	78	0.90
SE	0.13	3	0.03

Experiment 4

Maximum, minimum and average ambient temperatures were 30, 17 and 24°C, respectively, and corresponding relative humidity values were 102, 54 and 82%, respectively, when oxen worked in the morning from about 0900 to 1300 hours. Maximum, minimum and average ambient temperatures were 34, 26 and 30 C, respectively, when work took place in the afternoon from 1400 to 1800 hours. Corresponding values for relative humidity were 100, 50 and 73%, respectively.

The animals' physiological responses to THI and work are illustrated in Figure 2 for RR and in Figure 3 for RT. Patterns of changes of THI and power output of oxen working for 4 h in the morning or in the afternoon are shown in Figure 4. THI increased gradually during work either in the morning or in the afternoon. Average THIs were higher in the afternoon (80) than in the morning (77). THI increased from 74 when work started in the morning at about 0900 hours to 79 at the end of work at about 1300 hours. In the afternoon, THI increased during the first part of work from 79 to reach a maximum of 80 on average at about 1545 hours. THI remained constant afterwards for 2 h until about 1730 hours before it started to decrease slowly until work stopped at about 1800 hours.

Mean RR in the morning (74±4 counts/min) was lower ($P<0.01$) than in the afternoon (89±4 counts/min) but the pattern of change was different. RR increased gradually in the morning with a parallel increase in THI. The highest RR in the morning was recorded at the ninth lap after about 3.75 h of work. In the afternoon RR increased during the first hour of work to reach a maximum at the fourth lap at about 1.7 h after work started. The following decrease in RR occurred when THI became constant or declined. This period coincided with a marked decrease in the work rate.

The pattern of changes in RT was similar to that of THI either in the morning or in the afternoon. Mean RT was higher in the afternoon (39.9±0.02°C) than in the morning (39.4±0.02°C) ($P<0.01$). Also the highest RT was reached earlier in the afternoon (fourth lap) than in the morning (ninth lap). RT before work was higher and MIRT lower in the afternoon (38.4±0.09 and 2.5±0.16°C) than in the morning (37.8±0.09 and 2.8±0.16°C). Body condition had a significant effect on the MIRT ($P<0.05$). The extent of increase in RT was larger for oxen in good condition (MIRT = 3.01±0.13) than for oxen in medium (2.39±0.11) or oxen in poor condition (2.11± 0.11).

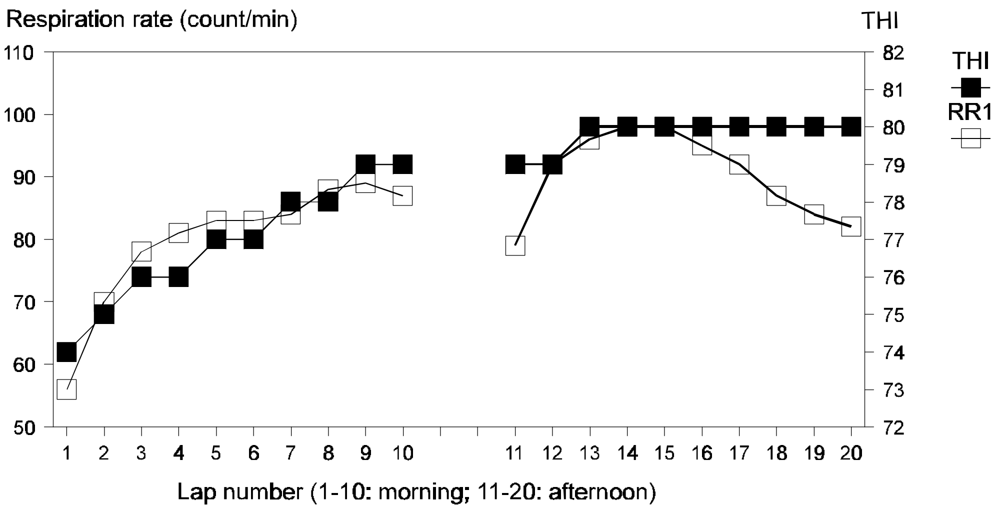

Figure 2. *Change in temperature humidity index (THI) during work and respiration rate of oxen working for 4 hours (10 laps around a circuit) either in the morning (lap 1–10) or in the afternoon (lap 11–20).*

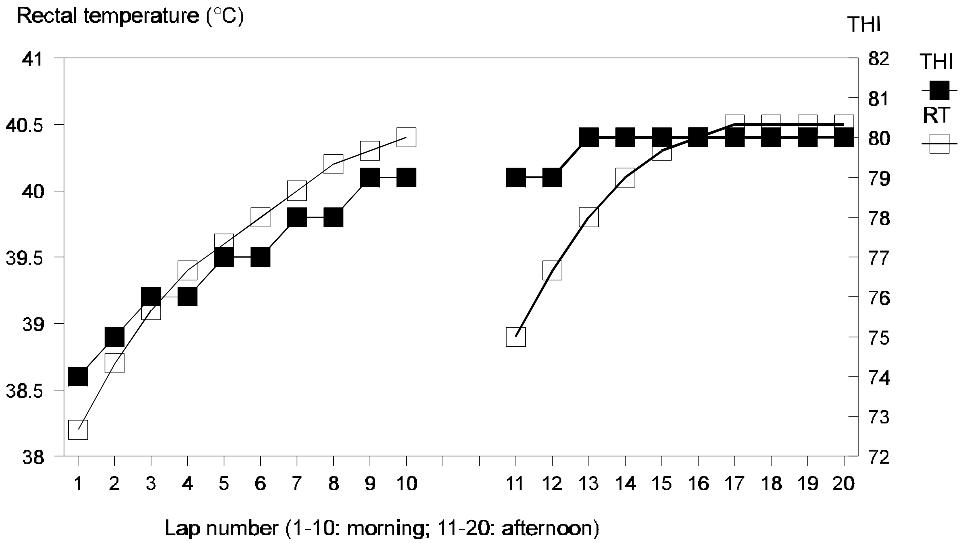

Figure 3. *Change in temperature humidity index (THI) during work and rectal temperature (RT) of oxen working for 4 h (10 laps around a circuit) either in the morning (lap 1–10) or in the afternoon (lap 11–20).*

Table 16 shows the mean RT before work and during work, MIRT and RR for oxen pulling a loaded sledge around a circuit. The oxen used in this experiment fitted into three groups according to the above parameters. The first group included oxen 6, 16 and 17 with high RT, MIRT and RR. The second group was composed of oxen with the lowest values for these parameters (oxen 10, 12, 14 and 1). The third group was made up of oxen with inconsistent or intermediate values of RT, MIRT and RR. The first group seemed to show more pronounced signs of heat stress

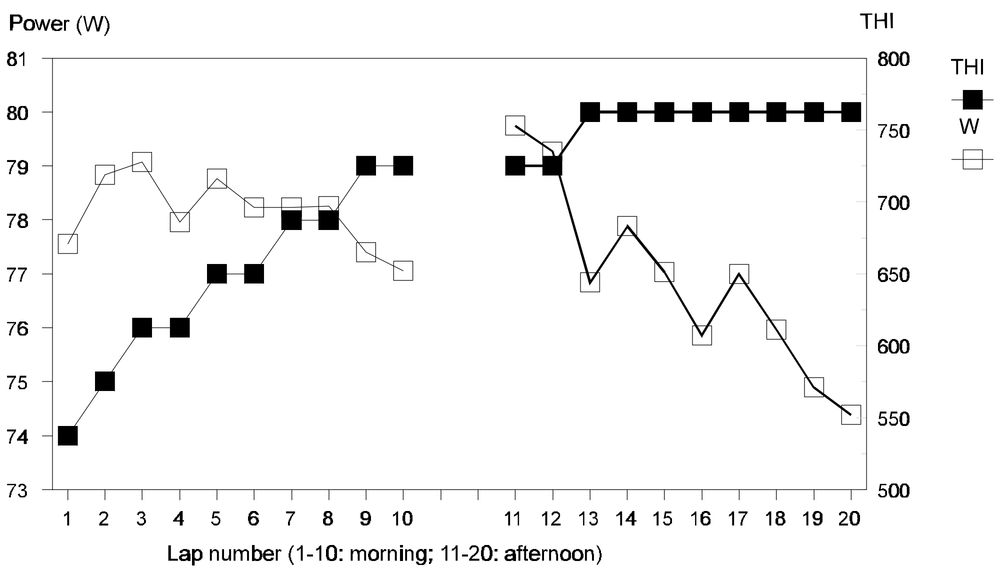

Figure 4. *Change in temperature humidity index (THI) during work and power output (W) by oxen working for 4 h (10 laps around a circuit) either in the morning (lap 1–10) or in the afternoon (lap 11–20)*

than the second group. A marked difference between the first and the second group was their body condition. The animals in the first group had a better body condition on average than animals in the second group.

Repeatability estimates were 0.19 for RT before work, 0.29 for MIRT and 0.16 for RT during work.

When work took place in the morning, two phases of power output were observed. During the first hour of work, there was a steady increase in work rate of teams followed by a gradual decrease of work rate until the cessation of work (Figure 4). During the afternoon working sessions, there was a steep fall in power output right from the start until the end of work. The reduction in the power output was negatively correlated to increases in RT. The increase in RT of 1°C was associated with a reduction in 52 W in power output. The fall in power output due to heat stress was more pronounced during the afternoon when THI and RT were highest.

Table 16. *Mean (±SE) rectal temperature (RT) before work, maximum increase in RT (MIRT), and RT and respiration rate (RR) during work of oxen working 4 h in the morning or in the afternoon to complete 10 laps of a circuit (Experiment 4).*

Ox no.	Average RT before work (°C)	Average MIRT (°C)	Average RT during work (°C)[1]	Average RR during work (count/min)
1	38.1±0.11^{bc}	2.3±0.21^{bc}	38.9^{h}	82±2^{d}
4	37.9±0.12^{abc}	2.9±0.23^{b}	39.3^{de}	78±2^{cd}
5	38.1±0.12^{c}	2.8±0.24^{b}	39.0^{fgh}	91±2^{c}
6	38.5±0.11^{a}	3.5±0.21^{a}	40.1^{a}	106±2^{a}
9	38.1±0.13^{abc}	2.8±0.25^{bc}	39.5cd	82±2^{cd}
10	38.4±0.12^{ab}	2.3±0.22^{b}	39.4^{cd}	61±2^{f}
11	38.1±0.14^{ab}	2.5±0.27^{bc}	39.1^{efg}	66±2^{ef}
12	37.9±0.10^{c}	2.3±0.19^{bc}	38.9^{h}	70±2^{e}
13	38.1±0.10^{abc}	2.8±0.19^{b}	39.5^{cd}	83±2^{cd}
14	38.2±0.12^{abc}	2.1±0.23^{bc}	38.9^{fgh}	55±2^{g}
15	38.1±0.13^{abc}	2.2±0.26^{c}	39.0^{efg}	73±3^{e}
16	37.8±0.15^{d}	3.3±0.28^{a}	39.2^{ef}	102±3 ^{b}
17	38.1±0.13^{abc}	2.9±0.24^{b}	39.5^{c}	101±3^{ab}
21	38.2±0.12^{abc}	2.7±0.23^{bc}	39.4^{cd}	97±2^{ab}
22	38.1±0.12^{abc}	2.9±0.23^{b}	39.3^{de}	99±2^{a}
24	38.1±0.14^{abc}	2.4±0.26^{bc}	39.2^{ef}	68±3^{ef}
25	38.4±0.14^{ab}	2.6±0.26^{bc}	39.8^{b}	62±3^{fg}

1. Reconverted after transformation.

Within columns means with different superscripts are significantly different, $P<0.05$.

Discussion

Oxen working under hot conditions gain body heat both from increased muscle activity and from radiant solar energy. This caused a continuous increase in RR in all experiments reported here. This increase in RR was meant to accelerate heat loss by cattle through respiratory evaporation and to keep RT down. This was difficult for them to achieve as evidenced by RTs that were rising steadily during work. The higher the ambient temperatures, the higher was the increase in RT.

There was a marked variation in the capacity of individual oxen to cope with heat stress. It was also observed that the body condition of an animal significantly influences its tolerance of heat stress. Fatter animals had more difficulty maintaining homeostasis than leaner animals. It is likely that the subcutaneous fat layer of an animal increases the resistance of heat flow from the body to the environment. Therefore part of the individual variations in the capacity of oxen to deal with excess heat load may be related to the state of body reserves. These differences may also be related to other factors which could not be elucidated in this experiment. For instance, one ox in a pair will usually perform more work and therefore will be more stressed than its counterpart. This variation between oxen may also be associated with differences in their intrinsic potential to tolerate heat stress, their better adaptation to work, size, or their temperament.

Repeatability, as estimated by intra-class correlation, measures the fraction of the total variation in a trait attributable to permanent differences between individuals. Estimates of repeatability of RT before work (0.19), RT during work (0.16) and MIRT (0.29) were generally low in this study. Most of the values of the repeatability and heritability of rectal temperature of cattle in the tropics have been estimated from cattle at rest. For instance, Buvanendran et al (1991) reported repeatabilities of 0.18 for RT, similar to that found in this study, and 0.57 for RR of zebu and Friesian-zebu crosses in Nigeria. They concluded that RR seems to be a more reliable physiological index of heat tolerance than other parameters. However, results from this study indicate that, for working oxen, the maximum increment in rectal temperature during work may be a more appropriate index. The expression of a stable body temperature (one that does not depart greatly from the preferred or thermoneutral body temperature) is a correlate to productivity, i.e. milk production, reproduction growth (Turner 1984; Finch 1986; Johnson 1987). This has not yet been established for power output. Turner (1984) reported a heritability of RT of 0.25. Although this may form the basis for the selection of more heat tolerant animals based on RT, the potential usefulness of selecting for low RT may lead to the selection of animals with lower metabolic rate and feed intake (Turner 1984). However, indirect selection of animals of lower RT and higher evaporative losses has been the result of selecting cattle originally for growth in Australia (Frisch 1981). Further studies are needed to investigate the potential application of selection of draft animals for heat tolerance in semi-arid areas using RT.

The pattern of change in power output in the morning and in the afternoon was consistent during all three experiments. Power output was negatively correlated with RT and THI and it was higher in the morning than in the afternoon. Results from this study suggest that heat stress is an important determinant of power output. In the morning, oxen worked fast during the first hour; this was followed by a decrease in work rate. As ambient temperature and metabolic rate increased steadily during work there was a gradual increase in the body heat content despite the increase in respiration rate designed to cool the animal down. The reduction in power output due to heat stress was more obvious during the afternoon working sessions when ambient temperatures were highest. This may at least partly be the result of the accumulation of fatigue for animals that worked both in the morning and in the afternoon. However, during Experiment 4 animals worked for 4 h/day either in the morning or in the afternoon. The same pattern of constant reduction of power output was seen when animals worked in the afternoon. The heat distress caused animals to reduce their speed in order to lower their metabolic heat load. Heat stress speeds up the onset of fatigue. Nielsen (1992) pointed out that high core temperature is the ultimate cause of fatigue due to heat stress. He explained the onset of fatigue by the reduction of the function of motor centres and by the reduction of the ability of the animal to recruit motor units for the required work.

During Experiment 2 the rectal temperatures of both working and non-working animals were measured. The equations developed for the change in rectal temperature could be used to quantify the extra water requirements for working and non-working oxen. The difference between the two rates of rectal temperature change between working and non-working oxen in the afternoon was equal to 0.20°C/min. It was the rate of temperature rise due to work. For the average 300 kg animal this represents a rate of accumulation of heat of 420 W ($300 \times 0.020 \times 4.2 \times 1000/60$) assuming oxen have a specific heat of 4.2 J/g M/°C, the same as water. The energy expenditure for working can be calculated as about 920 W which implies that initially the oxen were able to dissipate nearly 500 W of the heat produced by working. Ultimately all the heat must be dissipated otherwise the animal dies. This means that the 420 W which initially caused a rise in temperature must be removed by evaporation of extra water. The extra water can be estimated as $420 \times 60/2197 = 11.47$ g water per min or 0.668 litres/h assuming heat of evaporation of 2197 J/g water. This can explain why water intake is higher during working than non-working periods (Chapter 3). The estimated extra requirement for water of 0.668 litres/h was derived using a 300 kg animal. This value must therefore be adjusted according to the live weight of the animal, and to the intensity of work and ambient temperature which influence the rise in rectal temperature.

These results have many implications regarding the formulation of strategies to alleviate the heat load that draft animals are subjected to when they work under hot conditions. Unfortunately, strategies developed for other classes of cattle such as dairy or beef cattle in hot areas are unlikely to apply to draft oxen. This is because draft oxen work outdoors, in the field where shade is not always available. Moreover, the feeding of less thermogenic feeds implies the use of concentrates which may be scarce. Providing water to working animals during certain periods of the day, allowing animals to rest between bouts of work and to recover fully after periods of work are possible management strategies that can be contemplated for draft oxen in semi-arid areas.

In this study, oxen were allowed to drink water after work. Provision of water during work should be considered, although in practice water is often not readily available and draft oxen often will not drink immediately water is offered during work. Water is an essential nutrient for these animals, since evaporative cooling (panting and sweating) is the main route for heat dissipation in oxen working under hot conditions. Draft oxen also lose water through abundant salivation. Water consumption during work may have a direct beneficial effect since it allows reduced temperature in the reticulorumen and may therefore improve the comfort of the heat-stressed oxen. Higher water intake during work may increase the heat capacity of the animal's body and may therefore facilitate the maintenance of heat balance (Curtis 1983). Hence, if possible, water should be offered to animals frequently during any working session, not just at the end of the day.

Work should take place during the coolest periods of the day. Working between 1200 to 1600 hours should be avoided in semi-arid areas. Also, oxen should be allowed to rest sufficiently after bouts of work, preferably under tree shades if available. One or two days of rest may also be worthwhile after periods of four or five days of work so that oxen can recover fully to avoid the accumulation of fatigue (Upadhyay 1989).

6
Conclusions and recommendations

Energy requirements of draft oxen working on sandy soils

The average standing metabolic rate of oxen in this study was 5.63 (±0.12) W/kg $M^{0.75}$. Oxen spent less time lying down on working days. This and the fact that underlying metabolic rate may be higher during work mean that the requirements for maintenance of working oxen are higher than those of penned oxen. Therefore the type of management of oxen in a farming system has a considerable effect on the maintenance energy requirements of draft oxen.

The consistency of the soil on which oxen work has a marked effect on their energy cost of walking (E_W). The net energy cost of walking was 1.59 (±0.069), 2.15 (±0.084) and 1.00 (±0.10) J/m/kg M on unploughed soils, ploughed fields and laterite tracks, respectively. One implication of these differences in the E_W is that the lead animal walking on the already ploughed part of the field has an energy requirement for walking that is proportionately 0.37 higher than that of the ox walking on the unploughed soil. The efficiency of ploughing sandy soils was 0.32 and was not different from the efficiency of carting with different loads. Working efficiencies were not influenced by the type of work performed, draft force exerted or walking speed. The energy requirements of draft cattle can therefore be accurately predicted through the application of the factorial method using values for energy budget parameters found in this study.

Average draft forces required to pull a cart with light (300 kg), medium (600 kg) and heavy (900 kg) loads were 360, 480 and 550 N, respectively. Average draft force required to plough sandy soils at an average depth of 15 cm was 978 N. A similar value can be assumed for direct ridging of unploughed sandy soils using a mouldboard plough. Oxen can readily sustain a draft force equivalent to 11 kgf/100 kg of their live weight while working, hence oxen weighing at least 150 to 250 kg, depending on the load, are needed to pull carts in pairs. Farmers are already using young animals for carting in a progressive training process in many farming systems. However, heavier teams are needed for ploughing and ridging. Pairs of oxen weighing about 400 kg each are required if sandy soils are to be ploughed and ridged without undue stress on the oxen.

Nutrient supply for work in draft oxen fed on crop residues

The effect of work on intake was investigated in three experiments in this study. The absence of an effect of work on feed intake was consistent during all three experiments. Neither was the efficiency of utilisation of eaten roughages improved because of work. These results suggest that intake of roughage by working oxen is unlikely to increase as a result of work to compensate for the extra energy expended during work.

Feed intake was significantly influenced by the quality of the millet stover given. Intake of millet stover improved as the proportion of leaves in the stover increased allowing greater selection of the more digestible parts of the plant. When oxen at rest had access to excess millet stover (50% of refusals), they could maintain their body weight. Feed intake was also influenced by the body condition of the animal in this study. Animals in poor body condition had higher feed intakes than animals in good body condition. Feed intake also increased as work progressed in two of the experiments. This was explained by the fact that animals went through an adaptation process as work went on. As a result they could progressively improve their feed intake.

Because working oxen cannot increase feed intake when they are fed on roughages, they mobilise their body reserves to fuel muscle activity. Hence body weight losses are common in working oxen fed on a poor quality diet.

The absence of a significant effect of work on intake and digestibility of feeds by working oxen suggests that feed intake in these animals can be predicted by adjusting models predicting feed intake developed for other categories of cattle. Information from the literature on the intake of working cattle could be combined in a synthetic way to derive equations that predict feed intake. This could lead to the formulation of optimum feed rations for these animals.

Since oxen could not increase feed intake or use feeds more efficiently, they were using their body reserves to supply energy-yielding nutrients to the working muscles. The investigation of the effect of body condition before work and weight losses during work on work output showed that work performance was more dependent on body weight than on body condition. Liveweight losses did not negatively influence work performance. Power output improved over the weeks in which oxen were undergoing liveweight losses.

Heat stress in working oxen

Results from this study showed that heat stress did not interfere with the digestive physiology (intake, digestibility and rate of passage of feeds) of the animals used. Work output was, however, negatively influenced by heat stress. Power output was negatively correlated with temperature humidity index (THI) and rectal temperature (RT). Oxen working under hot conditions lose a great deal of water through panting, sweating, salivation and urine in order to maintain homeostasis. This caused working animals to drink more water than on days when they were at rest in the shade.

Guidelines for feeding strategies for draft oxen in semi-arid areas

The determinants of feeding strategies for draft oxen in semi-arid areas include the availability and feeding value of feed resources, the type and duration of work animals perform, the climatic environment and farmers' objectives.

Scarcity and low quality of feeds available during the long dry season are the main constraints facing farmers keeping draft oxen in semi-arid areas. A high level of supplementation with a good quality food is required to maintain an animal's live weight and to support a certain level of production. This is not realistic in most farming systems in semi-arid areas because farmers have limited cash income earmarked for purchased inputs, and feed competition may direct available resources to other classes of cattle or other species of livestock. Moreover, using expensive feed concentrates during the dry season for improved power output may not be profitable, since it does not lead to significant increases in work and crop outputs. Therefore the reduction of liveweight losses during the dry season using low opportunity cost feed resources is a reasonable objective that is most likely to be accepted by farmers. Strategies to maintain live weight include improved availability of feeds during the dry season and increased intake and digestibility of these feeds.

The first action to be taken in this process is to improve the conservation of feed resources that are abundant during the rainy season and early dry season. Many farmers already collect and store legume hays (groundnut and cowpea). Storing conditions can be enhanced to reduce nutrient losses. The comparative advantages of removal and storage of cereal crop residues for animal feeding versus their grazing by animals in the fields and/or their use for the conservation of soils need to be further assessed. Many farmers have already opted for the collection and storage of millet stover in drier parts of the semi-arid zone. Conservation of harvested roughages from natural pastures should also be encouraged and animal traction can contribute a great deal to this end by facilitating the harvest and transport of forages. Where crop residues are abundant and conserved, oxen could be given as much stover as possible enabling them to be more selective of fine plant parts. Refusals could be re-fed to other types of animals or returned to the field, if labour is not a major constraint.

The second action to be taken is to improve the rumen environment so that oxen can better digest the roughage eaten. Urea treatment of straw has been successfully used by smallholder farmers in Asia, but is used only to a limited extent in sub-Saharan Africa and should be tested on-farm. Fertiliser-grade urea is readily available and is not expensive. Block licks containing non-protein nitrogen (NPN) and other nutrients may have the advantage of being consumed at a lower rate and therefore secure a constant supply of nitrogen to rumen micro-organisms throughout the day. Legume hays and tree fodders may play a crucial role in improving the feeding of draft oxen as these feeds supply rumen-degradable nitrogen and rumen-escape nutrients. They can therefore improve roughage intake. Mineral supplementation using home-made mixtures should be encouraged on-farm. The mixture of crushed bones, common salt and rock phosphate or ammonium phosphate in appropriate proportions could provide oxen with minerals they cannot get from roughages. In semi-arid areas, oxen are used for transport and lifting water during the dry season. Under such circumstances these animals could be supplemented with legume hays, tree fodder and/or domestic cereal brans.

During the cropping season options for feeding draft oxen should take into account the state of body reserves, the duration and intensity of work and the timing of offtake of the animal.

At the start of the cropping season, various body conditions are found in oxen because of differences in feed resources endowment, work performed during the dry season and the diseases that prevail in farming systems in the semi-arid zone. Observations from this study suggest that a body condition score of between 2 and 3 would be the low critical score below which work may irreversibly damage the health of the ox. The ideal body condition score would range between 4 and 6. These animals are neither too fat nor too lean and can perform well if they are in good health. Oxen with a body condition score over 6 may be too fat to move comfortably and are more susceptible to heat stress than leaner oxen. Moreover, the feeding level required to reach a body condition score of over 6 is unlikely to be profitable as far as feeding for work performance is concerned.

Oxen should be supplemented during the cropping season when work is performed for more than six weeks. If the working period is short, supplementary feeding is recommended for animals scheduled to be sold for meat after work so that work does not adversely affect their market value. Oxen with dramatic weight losses during the dry season also need feed supplementation during work. Feed supplementation under the circumstances described above may be based on whole cotton seed, groundnut, sesame or cotton cakes if they are available. These feeds are rich in protein and energy and provide substrates directly used by the working muscles (long chain fatty acids and glycogenic compounds).

If oxen are only worked during a short cropping season and if ox offtake for meat does not occur during the following two months, the animals can be worked on their body reserves. Liveweight losses during work could be regained at a rapid rate after work. In many farming systems, by the time weeding operations are completed, natural pastures are of good quality and quantity and therefore can support compensatory growth after work.

Guidelines for working strategies

This study showed that power output increased as work season progressed despite liveweight losses incurred by oxen. The lower power output observed during the first few days of work is attributed to oxen undergoing an adaptation to work after periods of rest. The increase in power output during the following weeks is the result of the improvement of the fitness of oxen. Timeliness in cropping operations is crucial for successful cropping in semi-arid areas because of the short growing season. Oxen can become fitter by carting during the dry season. Therefore farmers owning and using carts in semi-arid areas can benefit from having oxen that are fit at the onset of the cropping season because cropping tasks are not delayed by lack of fitness of oxen when they resume work.

The energy cost of walking was higher for the animal in the team working on already ploughed soil. In farming systems where cows are used for cropping, they could be teamed up with males so that the female would walk on the unploughed soil. This could minimise the energy requirements for work in draft cows.

Heat stress inhibits work performance. Options to reduce heat stress include working animals in the coolest periods of the day, allowing them to rest and providing water between bouts of work. Providing shade during resting periods is also worthwhile. The number of hours worked per day should be split between morning and afternoon sessions. Oxen should be worked for a total of 6 hours per day, 3 to 4 h in the morning between 0600 or 0700 to 0900 or 1000 hours and for 2 to 3 h in the afternoon from 1600 or 1700 to 1800 or 1900 hours. Oxen should be rested after each hour of work for about 10 min and given water to help them cool down.

Future research

Our understanding of the nutrition of draft animals has progressed a great deal over the last 10 years. The relationships between work and the digestive physiology of draft cattle are better understood. However, there are still areas that need further research. Some of these areas are common to all categories of cattle in semi-arid areas, whereas other research needs are specific to draft animals.

The need to increase the availability of feeds is shared by all domestic livestock in semi-arid areas. This is especially true for ruminants because they now have fewer opportunities to graze large areas because of the increasing pressure on land found in these areas as a result of rapid human population growth. Crop residues will continue to play a central role in the supply of feed for ruminants in these areas. The development through breeding of cereal crop varieties of higher feeding value warrants further research. There is also a need for research on the economics of alternative uses of these resources as animal feed and sources of soil nutrients and as means of limiting soil erosion.

The problem of dry season feed restriction in semi-arid areas is well recognised. Where the supply of forage is not a major problem, the nutrient deficiencies of the available roughages may limit intake. The beneficial effect of nitrogen supplementation in the form of rumen-degradable nitrogen or rumen-escape protein on intake of poor quality roughage is known. There is a need to have more information on the nutritive values of different feed resources (cereal crop residues, crop residues, browses and tree leaves) found in semi-arid areas. This would allow sound feeding strategies to be developed during the dry season.

In the short term, farmers will continue to exploit the annual cycles of nutrient deposition in the form of body reserves during periods of plentiful feed and the mobilisation of body reserves to produce power, milk or a calf during periods of feed shortages. The physiological basis of the capacity of animals to deposit body reserves when good quality feeds are available in sufficient quantity and also their capacity to limit nutrient losses when feed available is limited warrant further research.

The use of the Oxylog and the ergometer allowed significant progress to be made in understanding the nutrition of working animals. Their energy requirements are known more precisely. However, there is still a need to accumulate more information on the energy expenditure and work performance of animals working in varying circumstances dictated by variations in the demand of draft animal power due to differences in soil types, crops grown, implements used and draft animals present in a number of farming systems in semi-arid areas. For instance, the uptake of soil and water conservation techniques by farmers in the semi-arid areas will require more research on the draft forces and therefore animal live weight required and on their nutrient requirements to perform tasks such as ridging and tied-ridging on soils of different types.

A more precise prediction of the nutrient requirements of draft animals requires also that more information be gained on the energy cost of walking on different surfaces and gradients, the effect of exercise and undernutrition on the fasting metabolic rate, and whether the heat increment associated with the use of absorbed nutrients for work differ from that for maintenance (Lawrence and Becker 1994). The implications of heat stress on nutrient requirements of draft animals working under hot conditions is also worth investigating.

There is a significant trend of more young animals and cows being used as draft animals in semi-arid areas. The obvious implication is the competition for the use of available nutrients for growth and work in the growing animal and between work, milk production and reproduction in the working female ruminant. The nutritional implications of using growing animals for work have not yet been investigated. Lawrence and Becker (1994) pointed out that there is a need to improve our understanding of the underlying physiological mechanisms which determine the partition of nutrients between the various functions of the working animals.

The type of management of oxen in a farming system has important implications on the maintenance energy requirements of draft oxen. The daily energy budget of oxen can be estimated in a farming system if time spent for functional activities is known. This information can be obtained by monitoring the daily activities of oxen in a farming system.

There was a steady improvement of power output as work progressed despite liveweight losses incurred by oxen. Further research is therefore needed to determine the optimum work load required during the dry season to ensure oxen are fit for work at the onset of the cropping season.

During this study water was supplied to animals after work. It is important to investigate how providing water during work could help the animal accommodate the excess heat load due to heat gains from increased muscle activity and from solar radiation. Using rectal temperature as the indicator of heat stress, this study showed that animals had different capacities to cope with stress. The implications of this finding regarding the selection of draft animals in semi-arid areas needs further investigation.

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