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Nutrition of draught oxen in semi-arid west Africa. 2. Effect of work on intake, apparent digestibility and rate of passage of food through the gastro-intestinal tract in draught oxen given crop residues

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Abstract

Two experiments were conducted to investigate the relationships between work and intake and digestion of food by draught oxen given millet stover. In the first experiment, intake of millet stover, water intake, live weight, plasma concentrations of triiodothyronine, thyroxine and urea-nitrogen were measured in 18 animals that worked 0, 2 or 4 h/day in sequence during three 3-week experimental periods. Digestibility and rate of passage of food residues through the digestive tract were measured in a second experiment on 12 animals working either 0, 2·5 or 5 h/day in sequence during three 2-week experimental periods. Feeding behaviour was monitored on six animals working either 0, 2·5 or 5 h/day. Work did not affect intake of millet stover, apparent digestibilities and the rate of passage of digesta through the gastro-intestinal tract. This suggests that the nutrient supply from intake of roughages by working oxen is unlikely to be sufficient to compensate for the extra energy expended during work. Food intake was affected by the quality of the millet stover offered. The level of intake of millet stover was proportional to the amount of leaves in the stover. Food intake increased also as work progressed. However, animals mobilized their body reserves to perform work. Animals consumed more water on working days than on days they were at-rest in shade. The heat stress that working animals were subjected to did not appear to interfere with their digestive function.

Keywords: *digestibility, draught animals, food intake, millet stover, work.*

Introduction

Ideally, draught oxen must consume sufficient food before and during the cropping season so they can start work with a reasonable live weight and perform work. However the scarcity and poor quality of foods available before and during the early part of the cropping season in semi-arid areas often limit their nutrient intake. Food intake can be influenced positively or negatively by work through direct or indirect mechanisms. Direct effects of work on food intake occur through physiological changes resulting from exercise. Muscular activity induces a higher metabolic rate in working animals as compared with 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). The occurrence of 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 food intake in working animals (Collier and Beede, 1985).

One indirect effect of work on intake stems from the reduced time animals have access to food. Limited time available to eat and ruminate is a major constraint to increased food intake in working

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ruminants (Pearson and Lawrence, 1992). Time of feeding also affects food intake. Bakrie and Teleni (1991) reported reduced food intake by animals given roughages before work as compared with animals given food after work.

Work also has the potential to affect digestibility of foods by oxen directly and indirectly through changes in a range of factors including increases in body temperature, food particle residence time in the gastro-intestinal tract and effectiveness of mastication on particle breakdown (Weston, 1985). Positive effects of work on food digestibility may stem from the enhancement of microbial fermentation though 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 food 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 food because of limited time to ruminate (Pearson and Smith, 1994). There is need for a clear understanding of the relation between work and digestive physiology for the feeding management of draught oxen to be improved. This study investigated the relationships between food intake and the efficiency of utilization of foods and work performance.

Material and methods

Experiment 1

Animals and feeding. This experiment was conducted from July to September 1993 at the International Livestock Research Institute (ILRI), International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) Sahelian Centre, Sadore, Niger. Eighteen local zebu oxen, aged 4 to 8 years, average live weight 302 (s.e. 18) kg, were used. Oxen were housed in individual concrete-floored pens roofed with zinc sheets. Each pen was fitted with a halved empty oil drum as a food trough and a graduated metal bucket for water. Individual pens were separated with wooden planks to prevent mixing of food and food spillages.

Oxen were trained to pull common farm implements and 55-kg metal sledges. They were given chopped millet stover *ad libitum* except during the working periods. Millet stover was supplemented with a concentrate mix made up (g/kg) of wheat bran (600), groundnut cake (300) and bone meal (100) at a rate of 21·3 g/kg $M^{0.75}$ per day (Table 1). The concentrate was offered when animals returned from work in the morning at about 11.00 h. Millet stover was given when oxen finished eating the concentrate, and at

Table 1 *Chemical composition of millet stover and concentrate food given during experiments 1 and 2 (except for dry matter and gross energy, values are expressed as g/kg DM)*

	Millet stover		Concentrate	
Experiment				
Dry matter (DM) (g/kg)	902	940	905	935
Crude protein (CP)	33	36	293	177
Gross energy (GE) (MJ/kg DM)	17·	18·0	18·	
Organic matter (OM)	964	973	898	
Neutral-detergent fibre (NDF)	789	781	293	197
Acid-detergent fibre (ADF)	539	519	131	72
Hemicellulose (HEM)	274	261	162	125

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 allotted according to their initial body weight in 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 was formed with animals of similar live weight. Rows of each square were formed by ox teams whereas columns represented experimental periods. The experiment lasted 9 weeks, which was divided into three 3-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 for the determination of plasma urea-N (PUN), thyroxine (T_4) and triiodothyronine (T_3). Body weight was measured every week. Food offered and refusals

were weighed every day. Refusals on the floor and food left in troughs were collected separately because of contamination of floor spillage by urine and water.

Laboratory analysis. Daily food 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 a 1-mm screen. The following determinations were made on the weekly pooled samples of foods: acid-detergent fibre (ADF), neutral-detergent fibre (NDF), nitrogen (N) gross energy (GE), ash and organic matter (OM) according to the Association of Official Analytical Chemists (1990).

Plasma T_4 was analysed using the fluorescence polarization 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). PUN was assayed by an enzymatic method using a Bayer Diagnostic RA-2000 random access chemistry analyser (Bayer Diagnostics, Basingstoke, UK).

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

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

where: Y = dependent variable (food intake, water intake, M change, plasma thyroid hormones concentration, urea-nitrogen concentration); μ = overall mean; S_i = effect of ith square, i = 1, 2, 3; $T(S)_{(i)j}$ = effect of the jth team nested within ith square, j = 1, 2, 3; $P(S)_{(i)k}$ = effect of the kth experimental period nested within ith square, k = 1, 2, 3; $A_{(l)}$ = effect of the lth work level, l = 1: 0 h/day, l = 2: 2 h/day and l = 3: 4 h/day; W_m = effect of the mth week, m = 1, 2, 3; $W \times P_{mk}$ = interaction between the mth week and the kth period; $W \times A_{ml}$ = interaction between the mth week and the lth work level; $W \times T(S)_{(i)jm}$ = interaction between the mth week and the jth team in the ith square; E_{ijklm} = effect peculiar to the jth team in the ith square subjected to the lth level of work in mth week of the kth 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 live-weight changes were estimated by regression analysis and were further subjected to analysis of variance using generalized linear models (Statistical Analysis Systems Institute (SAS), 1985).

Experiment 2

Animals and feeding. This experiment was conducted from December 1994 to February 1995 at the ICRISAT Sahelian Centre in Niger. Twelve oxen, aged 4 to 7 years, average weight 288 (s.e. 11) kg, at the start of the experiment, were used. They were housed as in experiment 1. All oxen were given chopped millet stover *ad libitum* except during the working hours. The stover was chopped by hand to lengths of about 12 to 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 1). The concentrate was given at a daily rate of 10 g dry matter per $M^{0.75}$ at 12.00 h after the morning working session. Daily food allowance was adjusted so that refusals were at least equal to a proportion of 0·50 of food 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 draught force exerted was equivalent to proportionately 0·10 of the team live weight. Work was performed continuously, 7 days/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 crossover 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 2-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 1 with the following amendments and additions.

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 draught force exerted was

equivalent to proportionately 0·10 of the team live weight The time taken to travel around the circuit was measured with a stop watch.

Intake and apparent digestibility of food: 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 2-week period. Total faecal collection was carried out for 7-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, 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 7-day collection period, daily samples were thawed, mixed and a subsample (1 kg) was taken and oven dried at 55°C.

Rate of passage of food: sixty grams of chromium-mordanted fibre were given on day 7 of the first and the second periods (Mathers *et al.*, 1989). On that day food was withdrawn from 14.00 until 23.00 h when the markers were given. 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 dry matter 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 4th day, the combination of the 3-h observation periods yielded a 24-h composite behaviour pattern of the animals. This scheme was applied three times consecutively. During each 5-min observation period each of the six animals was observed. The time spent doing a particular activity (eating, ruminating, standing, 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, M 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 apparent 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 1

Minimum, maximum and mean ambient temperatures were 23·0, 35·0 and 29·3°C when animals worked in the morning and 24·0, 36·0 and 31·7°C when work took place in the afternoon. Minimum, maximum and mean relative humidities were 0·400, 0·930 and 0·674 during the morning working sessions and 0·440, 0·960 and 0·600 during the afternoon working sessions.

Plasma T_4 and T_3 concentrations were not affected by level of work (Table 2). There was a significant linear increase in PUN as level of work increased ($P < 0·01$; Table 2).

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 per kg $M^{0·75}$ ($P < 0·01$) and in g DM per kg M ($P < 0·05$). The interaction between treatment and week was significant for DMI-g/kg M and close to significance at the 5% probability level ($P = 0·07$) for DMI-g/kg $M^{0·75}$. Table 2 shows daily work characteristics, food and water intake and weekly live-weight changes. Food intakes of animals working 2 and 4 h/day include food 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 able to increase their intake 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 l/day, l/kg M, l/kg

Table 2 *Experiment 1: daily work output, load and power and intake of millet stover, water intake, live-weight changes, plasma thyroid hormones (T_4, T_3) and urea nitrogen (PUN) concentrations for oxen working, 0, 2 and 4 h/day*

Variables	Work level						Significance
	0 h/day		2 h/day		4 h/day		
Work characteristics							
Daily work output (kJ)	0		3233	(0·22)†	6763	(0·33)	
Load (N/kg M)	0		0·89	(0·26)	0·88	(0·23)	
Power (W)	0		583	(0·11)	616	(0·10)	
Power (W/100 kg)	0		90	(0·28)	92	(0·18)	
Daily intake of millet stover							
kg DM	4·72	0·045	4·78	0·049	4·60	0·049	
g DM/kg M	15·46	0·17	15·94	0·19	15·50	0·19	
g DM/kg $M^{0·75}$	64·40	0·65	66·06	0·72	64·04	0·72	
Daily water intake							
litre (l)	30·5	0·47	30·2	0·51	30·3	0·51	
l/kg M	0·099	0·001	0·099	0·002	0·101	0·002	
l/kg $M^{0·75}$	0·41	0·007	0·42	0·008	0·42	0·008	
l/kg DMI	6·45	0·09	6·32	0·09	6·58	0·09	
T_4 (nmol/l)	56·3	1·2	52·7	1·2	52·3	1·2	
T_3 (nmol/l)	0·95	0·03	0·94	0·03	0·98	0·03	
PUN (mmol/l)	4·0	1·14	4·5	0·14	4·83	0·14	Linear**
Live-weight change (kg/week)	3·72	0·76	1·58	0·84	−2·19	0·82	*

† Values in parentheses are CV

$M^{0·75}$ or l/kg DMI (Table 2). In this experiment, oxen at-rest were tethered in the sun while other teams were working. Body-weight change was significantly affected by work ($P < 0·05$; Table 2).

Experiment 2

There was a significant linear increase in PUN concentration as work level increased ($P < 0·05$; Table 3). 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.

Plasma T_4 concentration decreased as work level increased (Table 4). There was a significant linear decrease ($P < 0·01$) in plasma T_3 concentrations as work load increased and over weeks ($P < 0·001$).

Intake of millet stover was not significantly influenced by work. Table 3 shows mean DMI, water intake and live weight over 2-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 food intake as the proportion of leaves increased:

$$\text{DMI (g/kg M)} = 12·8 \text{ (s.e. } 1·09) + 5·4 \text{ (s.e. } 1.18) \times \text{PLS}$$
$$(P < 0·01;\ R^2 = 0.30)$$

$$\text{DMI (g/kg } M^{0·75}) = 52·5 \text{ (s.e. } 4·44) + 20·8 \text{ (s.e. } 7·65) \times \text{PLS}$$
$$(P < 0·01;\ R^2 = 0·28).$$

Table 3 *Experiment 2: least-square means for intake of millet stover, water intake, live weight and plasma concentration of urea nitrogen (PUN) of oxen working 0, 2·5 and 5 h/day*

	Work level			
	0 h/day	2·5 h/day	5 h/day	s.e.
Intake of millet stover				
g/kg M	15·13	16·22	16·15	0·20
g/kg $M^{0·75}$	61·36	65·82	65·51	0·83
Water intake				
l/day	21·35[a]	25·20[b]	28·51[c]	0·380
l/kg M	0·08[a]	0·09[b]	0·11[c]	0·014
l/kg $M^{0·75}$	0·32[a]	0·38[b]	0·43[c]	0·050
l/kg DMI	5·37[a]	5·83[b]	6·44[c]	0·120
PUN (mmol/l)†				
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)†				
Week 1	597	610	615	3
Week 2	599	602	597	3

† See text for the significance of factors (work and week) included in the analysis of variance.

[a,b,c] Values in the same row with different superscripts are significantly different $P < 0·05$.

Table 4 *Experiment 2: effect of work on food apparent digestibility, gastro-intestinal rate of passage of solid particles, thyroxine (T4), triiodothyronine (T_3) plasma concentrations, and feeding behaviour parameters in oxen*

	Work level				
	0 h/day	2·5 h/day	5 h/day	s.e.	Significance
Apparent digestibility†					
DM	0·42	0·43	0·43	0·011	
OM	0·45	0·46	0·45	0·012	
ADF	0·54	0·54	0·55	0·010	
NDF	0·57	0·57	0·58	0·009	
HEM	0·63	0·63	0·65	0·009	
GE	0·49	0·49	0·51	0·009	
T_4 (nmol/l)‡					
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	
T_3 (nmol/l)‡					
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	
Time spent ruminating (min/day)	339	400	344	42	
Time spent eating and ruminating (min/day)	715	785	799	49	
Eating rate (g DMI per min)	14·1	10·9	15·3	2·6	
Rumination rate (min/g DMI)	88·3	108·1	78·7	10·5	
MRT (h)	88·9	78·2	82·2	2·3	Quadratic
TT (h)	14·17	14·54	13·28	1·40	
$1/k_1$	56·9	49·1	52·3	2·8	
$1/k_2$	17·9	14·6	16·6	1·2	

† For abbreviations see Table 1.
‡ See text for the significance of factors (work and weeks) included in the analysis of variance.

There was a significant increase in water intake as work level increased (Table 3). Work caused live-weight losses whereas oxen at-rest were able to maintain their body weight (Table 3).

There was no significant effect of work on the apparent digestibility of DM, OM, ADF, NDF, hemicellulose (HEM) and GE. Table 4 shows coefficients of apparent digestibility for different work loads. Increases in the proportion of leaves in the food offered improved apparent digestibility coeffficients as illustrated by the regression of apparent digestibility coefficients on PLS given in the following equations:

$$DMD = 0{\cdot}03 \text{ (s.e. } 0{\cdot}08) + 0{\cdot}69 \text{ (s.e. } 0{\cdot}08) \times PLS \quad (P < 0{\cdot}01, R^2 = 0{\cdot}68)$$

$$ADFD = 0{\cdot}25 \text{ (s.e. } 0{\cdot}04) + 0{\cdot}52 \text{ (s.e. } 0{\cdot}08) \times PLS \quad (P < 0{\cdot}01, R^2 = 0{\cdot}52)$$

$$NDFD = 0{\cdot}19 \text{ (s.e. } 0{\cdot}04) + 0{\cdot}68 \text{ (s.e. } 0{\cdot}08) \times PLS \quad (P < 0{\cdot}01, R^2 = 0{\cdot}69)$$

$$OMD = 0{\cdot}06 \text{ (s.e. } 0{\cdot}05) + 0{\cdot}70 \text{ (s.e. } 0{\cdot}09) \times PLS \quad (P < 0{\cdot}01, R^2 = 0{\cdot}65)$$

$$HEMD = 0{\cdot}14 \text{ (s.e. } 0{\cdot}05) + 0{\cdot}87 \text{ (s.e. } 0{\cdot}09) \times PLS \quad (P < 0{\cdot}01, R^2 = 0{\cdot}72)$$

$$GED = 0{\cdot}12 \text{ (s.e. } 0.04) + 0{\cdot}67 \text{ (s.e. } 0{\cdot}08) \times PLS \quad (P < 0{\cdot}01, R^2 = 0{\cdot}66).$$

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 4 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 ($P < 0{\cdot}05$). Work did not significantly affect time spent eating and ruminating or eating and rumination rates (Table 4).

Discussion

In experiment 1 there was an absence of significant differences in plasma T_3 and T_4 concentrations between working oxen and oxen at-rest. However in experiment 2, the higher the work load, 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 Pearson and Archibald (1990) and El-Nouty and Hassan (1983). During experiment 2, unlike experiment 1, 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 2 relative to oxen at rest did not translate into significant changes in food intake and digestibility. Christopherson and Kennedy (1983) suggest that extremes of heat or 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.

Although little quantitative information is available, it is generally assumed that oxen need to consume more water during working days as compared with non-working days, particularly under hot conditions to compensate for water lost through evaporative cooling processes (sweating and panting). During experiment 1, both working and non-working oxen consumed 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 were similar in this experiment and water requirements may therefore have been similar also. In experiment 2, 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 consuming significantly more water than non-working oxen.

During experiment 1, 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 food intake over time and suggested that animals were adapting to the food during the experiment. In the present study this adaptation did not enable oxen to eat more than those at-rest or those working lightly, since the overall food intake during the 3-week experimental periods were similar for all work treatments during experiment 1. Similarly, during experiment 2, work did not have a significant effect on intake of millet stover.

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

The effect of work on food intake may result from the work stress and/or from the food restriction during hours animals work (Pearson and Smith, 1994). In the present 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 food intake was not significantly different between working and non-working oxen during both experiments, then the limited time available to ruminate may not have been a significant inhibitor of food intake in working oxen in these experiments. Results in experiment 2 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 food deprivation, with or without work, was not long enough to disrupt food intake or feeding behaviour. Similarly, Pearson and Smith (1994) found no effect of food restriction for 4 h, with or without work on intake of straw diets by cattle and buffalo.

In experiment 2 food 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 in working animals as compared with animals at-rest. When working animals are given 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) suggest 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 suggested that the long-term regulation of food 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 food intake over time seen in this study supports the concept of the long-term regulation of food intake. Increases in food intake were also reported by Zerbini *et al.* (1995) in draught 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 food intake in these cows.

In this study, DM apparent digestibility and the apparent digestibility of food fractions were not significantly affected by work. These results agree with those reported by several others (see Pearson and Dijkman, 1994). In the present study, a significant improvement in food apparent digestibility was observed as the proportion of leaves in the millet stover increased and therefore as the quality of the diet improved. Hence differences in diet quality may well have contributed to the different responses in apparent digestibility of food 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 less 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 more rapid rate of passage of foods in the digestive tract.

During experiment 1, oxen at-rest were able to gain weight whereas oxen working 2 h/day maintained their M. During experiment 2, 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 DM per kg $M^{0.75}$ during experiment 2) was sufficient to allow weight gains in oxen at-rest. During experiment 2, the level of concentrate offered was lower (10 g DM per 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 1, 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 1 and in animals working 2·5 or 5 h/day during experiment 2 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 catabolizing amino acids to supply energy-yielding substrates for work.

Conclusions

Although the rate of passage of undigested food residues tended to increase with light work, oxen given low quality crop residues could neither increase their food intake nor use food more efficiently to compensate for the extra energy used for work. Therefore they mobilized their body reserves to supply energy to working muscles. Hence weight loss is a constant feature in working oxen relying on roughages for energy intake. Oxen could maintain their weight during resting periods when they were given sufficient millet stover so that they could select leaves which were more nutritious. Heat stress on oxen did not interfere with their digestive physiology. The implications of these results for the formulation of feeding strategies for draught oxen in semi-arid areas include the following considerations. First, since work and heat stress did not influence intake and digestibility of foods, it may be relevant to predict food intake of these animals using models developed for other classes of cattle. Secondly, 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 food intake. Finally, since oxen cannot increase their nutrient intake during work when given crop residues and therefore use their body reserves to perform work, the effect of body condition on work output should be investigated.

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